



Agenzia Nazionale per le Nuove Tecnologie,  
l'Energia e lo Sviluppo Economico Sostenibile



*Ministero dello Sviluppo Economico*

## RICERCA DI SISTEMA ELETTRICO

# SPES-IRIS Facilità RELAP5 sensitivity analyses on the containment system for design review

*F. Bianchi, R. Ferri*



SPES-IRIS FACILITY RELAP5 SENSITIVITY ANALYSES ON THE CONTAINMENT SYSTEM FOR  
DESIGN REVIEW

F. Bianchi, R. Ferri

Settembre 2010

Report Ricerca di Sistema Elettrico

Accordo di Programma Ministero dello Sviluppo Economico – ENEA

Area: Produzione e fonti energetiche

Tema: Nuovo Nucleare da Fissione

Responsabile Tema: Stefano Monti, ENEA

|                                       |                                                |               |              |
|---------------------------------------|------------------------------------------------|---------------|--------------|
| <b>ENEA</b> Ricerca Sistema Elettrico | Sigla di identificazione<br>NNFISS – LP2 – 017 | Distrib.<br>R | Pag. di<br>1 |
|---------------------------------------|------------------------------------------------|---------------|--------------|

**Titolo**

**SPES3-IRIS facility RELAP5 sensitivity analyses on the containment system for design review**

**Ente emittente: SIET**

## PAGINA DI GUARDIA

**Descrittori**

Tipologia del documento: Rapporto tecnico/Technical Report  
 Collocazione contrattuale: Accordo di programma ENEA-MSE: tema di ricerca "Nuovo nucleare da fissione"  
 Argomenti trattati: Reattori ad acqua leggera/Light Water Reactors

**Sommario**

This report has been issued in the frame of the second research programme of ENEA-MSE agreement and it is one of the deliverables of the Task B "IRIS integral testing –Design review of SPES3 facility and IRIS design follow-up" of the work programme 2 "Evolutionary INTD (International Near Term Deployment) Reactors" of the research theme on "Nuovo Nucleare da Fissione".

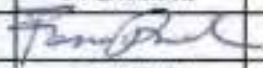
The document summarizes the results of sensitivity calculations on the SPES3 facility containment system for reviewing the facility design to match the IRIS plant calculation results.

**Note**

**Confidential information property of ENEA – not to be used for any purposes other than that for which is supplied**

Copia n.

In carico a:

|      |             |           |       |                                                                                      |       |                                                                                       |
|------|-------------|-----------|-------|--------------------------------------------------------------------------------------|-------|---------------------------------------------------------------------------------------|
| 2    |             |           | NOME  |                                                                                      |       |                                                                                       |
|      |             |           | FIRMA |                                                                                      |       |                                                                                       |
| 1    |             |           | NOME  |                                                                                      |       |                                                                                       |
|      |             |           | FIRMA |                                                                                      |       |                                                                                       |
| 0    | EMISSIONE   | 15.9.2010 | NOME  | F. Bianchi                                                                           |       | S. Monti                                                                              |
|      |             |           | FIRMA |  |       |  |
| REV. | DESCRIZIONE | DATA      |       | CONVALIDA                                                                            | VISTO | APPROVAZIONE                                                                          |



Società Informazioni Esperienze Termoidrauliche  
Via Nino Bixio, 27c - 29121 Piacenza (I)

## EMITTENTE

issued by

## Unità di Produzione

Production Unit

**CLIENTE: ENEA**

client:

**COMMESSA: 1PN000BA90245**

job:

**DISCO:**

disk:

**PAGINA: 1 DI: 369**

page:

of:

**IDENTIFICATIVO:**

SIET 01 526 RT 09 Rev.0

document:

**Classe Ris.:**

confidential

**ALLEGATI: CD-**

enclosures: ROM

**TITOLO: SPES3-IRIS facility RELAP5 sensitivity analyses on the containment system for design review**  
title:

**REDATTORI: R. Ferri**

prepared by:

### LISTA DI DISTRIBUZIONE

distribution list

ENEA  
ENEA  
ENEA

Fosco  
Paride  
Renato

Bianchi  
Meloni  
Tinti

SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET  
SIET

Andrea  
Stefano  
Gustavo  
Cinzia  
Roberta  
Stefano  
Matteo  
Alfredo  
Stefano  
Massimo  
Marco  
Gaetano

Achilli  
Botti  
Cattadori  
Congiu  
Ferri  
Gandolfi  
Greco  
Luce  
Monti  
Orsi  
Rigamonti  
Tortora

**0**

2010-08-31

**EMISSIONE**

*Roberto Ferri*  
R. Ferri

*Gustavo Cattadori*  
G. Cattadori

**Draft A**

2010-07-10

**DRAFT A**

R. Ferri

G. Cattadori

REV.  
rev.

DATA  
date

DESCRIZIONE  
description

REDAZIONE  
prepared by

APPROVAZIONE  
approved by

Informazioni strettamente riservate di proprietà SIET SpA - Da non utilizzare per scopi diversi da quelli per cui sono state fornite.  
Confidential information property of SIET SpA - Not to be used for any purpose other than those for which it is supplied.



## CONTENTS

|                                                                            |           |
|----------------------------------------------------------------------------|-----------|
| <i>I. LIST OF TABLES .....</i>                                             | <i>4</i>  |
| <i>II. LIST OF FIGURES .....</i>                                           | <i>5</i>  |
| <i>III. NOMENCLATURE.....</i>                                              | <i>17</i> |
| <i>1. SCOPE .....</i>                                                      | <i>19</i> |
| <i>2. INTRODUCTION .....</i>                                               | <i>20</i> |
| <i>3. SPES3 AND IRIS MODELS .....</i>                                      | <i>21</i> |
| 3.1 SPES3 schemes and RELAP5 nodalization evolution .....                  | 21        |
| 3.2 IRIS RELAP5 and GOTHIC nodalization evolution .....                    | 21        |
| <i>4. DVI DEG BREAK: BASE CASE SPES3-97 AND IRIS30H_LB_HT1.....</i>        | <i>42</i> |
| 4.1 SPES3-97 and IRIS30h_LB_HT1.....                                       | 42        |
| 4.1.1 Transient phases and description.....                                | 42        |
| 4.1.2 Dry-Well metal structures .....                                      | 49        |
| 4.1.3 Case conclusions .....                                               | 49        |
| <i>5. DVI DEG BREAK: SENSITIVITY CASES ON THE CONTAINMENT SYSTEM .....</i> | <i>96</i> |
| 5.1 Sensitivity case: SPES3-94.....                                        | 107       |
| 5.2 Sensitivity case: SPES3-99.....                                        | 107       |
| 5.3 Sensitivity cases: SPES3-100 and SPES3-103 .....                       | 107       |
| 5.4 Sensitivity case: SPES3-104.....                                       | 107       |
| 5.5 Sensitivity case: SPES3-105.....                                       | 108       |
| 5.6 Sensitivity case: SPES3-106.....                                       | 108       |
| 5.7 Sensitivity case: SPES3-107.....                                       | 109       |
| 5.8 Sensitivity case: SPES3-108.....                                       | 109       |
| 5.9 Sensitivity case: SPES3-109.....                                       | 110       |
| 5.10 Sensitivity case: SPES3-110.....                                      | 110       |
| 5.11 Sensitivity case: SPES3-111.....                                      | 111       |
| 5.12 Sensitivity case: SPES3-112.....                                      | 111       |
| 5.13 Sensitivity case: SPES3-115.....                                      | 112       |
| 5.14 Sensitivity case: SPES3-118.....                                      | 112       |
| 5.15 Sensitivity case: SPES3-119.....                                      | 113       |
| 5.16 Sensitivity case: SPES3-120.....                                      | 113       |
| 5.17 Sensitivity case: SPES3-122.....                                      | 114       |

|                                                                                     |     |
|-------------------------------------------------------------------------------------|-----|
| 5.18 Sensitivity case: SPES3-124.....                                               | 114 |
| 6. DVI DEG BREAK: SPES3-127 AND IRIS-HT5G (INTERMEDIATE STEP COMPARISON).....       | 159 |
| 6.1 SPES3-127 and IRIS HT5g.....                                                    | 160 |
| 6.1.1 Transient phases and description.....                                         | 160 |
| 6.1.2 Primary to secondary to RWST heat transfer.....                               | 167 |
| 6.1.3 Case conclusions.....                                                         | 168 |
| 7. DVI DEG BREAK: SENSITIVITY ON RWST AND EHRS.....                                 | 221 |
| 7.1 Sensitivity case: SPES3-130.....                                                | 221 |
| 7.1.1 SG-EHRS loop filling ratio.....                                               | 222 |
| 7.2 RWST-EHRS stand alone model sensitivity analyses.....                           | 222 |
| 7.2.1 Influence of EHRS tube material on exchanged power.....                       | 222 |
| 7.2.2 Influence of RWST slice model and tube Fouling Factor on exchanged power..... | 223 |
| 7.3 Sensitivity case: SPES3-132.....                                                | 223 |
| 7.4 SPES3 and PERSEO RWST-EHRS stand alone model sensitivity analyses.....          | 224 |
| 7.5 SPES3 and IRIS EHRS-RWST stand alone model parametric cases.....                | 225 |
| 7.6 Sensitivity case: SPES3-135.....                                                | 225 |
| 8. DVI DEG BREAK: DESIGN REVIEW SPES3-146 CASE AND IRIS HT6_RWSTC.....              | 247 |
| 8.1 SPES3-146 and IRIS HT6_rwstc.....                                               | 248 |
| 8.1.1 Transient phases and description.....                                         | 248 |
| 8.1.2 Primary to secondary to RWST heat transfer.....                               | 255 |
| 8.1.3 Case conclusions.....                                                         | 256 |
| 9. DVI DEG BREAK: DESIGN REVIEW SPES3-147 CASE AND IRIS HT6_RWSTC.....              | 307 |
| 9.1 SPES3-147 and IRIS HT6_rwstc.....                                               | 308 |
| 9.1.1 Transient phases and description.....                                         | 308 |
| 9.1.2 Primary to secondary to RWST heat transfer.....                               | 315 |
| 9.1.3 Case conclusions.....                                                         | 316 |
| 10. CONCLUSIONS.....                                                                | 367 |
| 11. REFERENCES.....                                                                 | 368 |
| 12. ATTACHMENTS.....                                                                | 369 |

## I. LIST OF TABLES

|                                                                                                  |     |
|--------------------------------------------------------------------------------------------------|-----|
| Tab.3. 1 - Summary of SPES3 and IRIS nodalizations evolution .....                               | 22  |
| Tab.4. 1 – SPES3-97 and IRIS30h_LB_HT1 steady state conditions .....                             | 50  |
| Tab.4. 2 – SPES3-97 and IRIS-HT1 list of the main events.....                                    | 51  |
| Tab.5. 1 – Summary of SPES3 sensitivity cases on the containment system .....                    | 116 |
| Tab.5. 2 – IRIS and SPES3 containment gas and liquid volumes .....                               | 120 |
| Tab.6. 1 – SPES3-127 and IRIS HT5g steady state conditions.....                                  | 169 |
| Tab.6. 2 – SPES3-127 and IRIS HT5g list of the main events.....                                  | 170 |
| Tab.6. 3 – SPES3-127 and IRIS HT5g SG RELAP5 model geometrical and heat transfer parameters .... | 172 |
| Tab.6. 4 – SPES3-127 and IRIS HT5g EHRS RELAP5 model geometrical and heat transfer parameters    | 173 |
| Tab.7. 1 – Summary of SPES3 sensitivity cases on the RWST and EHRS systems .....                 | 228 |
| Tab.7. 2 – SPES3-130 SG-EHRS loop mass distribution .....                                        | 230 |
| Tab.7. 3 – EHRS power with Inconel-600 and AISI 304 .....                                        | 231 |
| Tab.7. 4 – RWST-EHRS sensitivity on FF and “Hot column” area .....                               | 231 |
| Tab.7. 5 – SPES3 and IRIS RWST-EHRS stand alone model sensitivities.....                         | 232 |
| Tab.7. 6 – SPES3 and IRIS EHRS-RWST parametric cases: power versus pressure.....                 | 233 |
| Tab.8. 1 – SPES3-146 and IRIS- HT6_rwstc steady state conditions .....                           | 257 |
| Tab.8. 2 – SPES3-146 and IRIS HT6_rwstc list of the main events .....                            | 258 |
| Tab.9. 1 – SPES3-147 and IRIS-HT6_rwstc steady state conditions .....                            | 317 |
| Tab.9. 2 – SPES3-147 and IRIS HT6_rwstc list of the main events (fatta).....                     | 318 |

## II. LIST OF FIGURES

|                                                                                                                                     |    |
|-------------------------------------------------------------------------------------------------------------------------------------|----|
| Fig.3. 1 – SPES3 general view.....                                                                                                  | 23 |
| Fig.3. 2 – SPES3 primary, secondary loop B, and containment system layout .....                                                     | 24 |
| Fig.3. 3 – SPES3 secondary system A and C layout .....                                                                              | 25 |
| Fig.3. 4 – SPES3 Primary System RELAP5 nodalization for case SPES3-97.....                                                          | 26 |
| Fig.3. 5 – SPES3 Secondary System-A and B and related EHRS RELAP5 nodalization for case SPES3-97<br>.....                           | 27 |
| Fig.3. 6 – SPES3 Secondary System-C and related EHRS RELAP5 nodalization for case SPES3-97 .....                                    | 28 |
| Fig.3. 7 – SPES3 Containment System RELAP5 nodalization for case SPES3-97.....                                                      | 29 |
| Fig.3. 8 – SPES3 Containment System RELAP5 nodalization for case SPES3-124 (PSS to DW vent pipes<br>and PSS bottom) .....           | 30 |
| Fig.3. 9 – SPES3 Containment System RELAP5 nodalization for case SPES3-127 (PSS bottom).....                                        | 31 |
| Fig.3. 10 – SPES3 RWST RELAP5 nodalization for case SPES3-130 (top steam discharge pipe).....                                       | 32 |
| Fig.3. 11 – SPES3 Secondary System and EHRS System RELAP5 nodalization for case SPES3-146 and<br>SPES3-147 (EHRS loop piping) ..... | 33 |
| Fig.3. 12 – IRIS Reactor Vessel general view .....                                                                                  | 34 |
| Fig.3. 13 – IRIS Containment System general view .....                                                                              | 35 |
| Fig.3. 14 – IRIS Engineered Safety Feature scheme .....                                                                             | 36 |
| Fig.3. 15 – IRIS Primary, Secondary and EHRS system RELAP5 nodalization for case HT1 .....                                          | 37 |
| Fig.3. 16 – IRIS Containment system GOTHIC nodalization for case HT1.....                                                           | 38 |
| Fig.3. 17 – IRIS containment system GOTHIC model for case HT5 (PSS to DW vent pipe connection) .....                                | 39 |
| Fig.3. 18 – IRIS EHRS and RWST RELAP5 nodalization for case HT5g (RWST) .....                                                       | 40 |
| Fig.3. 19 – IRIS EHRS and RWST RELAP5 nodalization for case HT6_rwstc (EHRS and RWST) .....                                         | 41 |
| Fig.4.1 – SPES3-97 and IRIS HT1 DVI break flow (window) .....                                                                       | 53 |
| Fig.4.2 – SPES3-97 and IRIS HT1 DVI break flow (window) .....                                                                       | 53 |
| Fig.4.3 – SPES3-97 and IRIS HT1 DVI break flow .....                                                                                | 54 |
| Fig.4.4 – SPES3-97 and IRIS HT1 DW pressure (window) .....                                                                          | 54 |
| Fig.4.5 – SPES3-97 and IRIS HT1 DW pressure .....                                                                                   | 55 |
| Fig.4.6 – SPES3-97 and IRIS HT1 PRZ pressure (window) .....                                                                         | 55 |
| Fig.4.7 – SPES3-97 and IRIS HT1 PRZ pressure (window) .....                                                                         | 56 |
| Fig.4.8 – SPES3-97 and IRIS HT1 PRZ pressure.....                                                                                   | 56 |
| Fig.4.9 – SPES3-97 and IRIS HT1 PRZ and DW pressures (window) .....                                                                 | 57 |
| Fig.4.10 – SPES3-97 and IRIS HT1 PRZ and DW pressures.....                                                                          | 57 |
| Fig.4.11 – SPES3-97 and IRIS HT1 PRZ and DW pressures (detail).....                                                                 | 58 |
| Fig.4.12 – SPES3-97 and IRIS HT1 ADS Stage-I mass flow (window) .....                                                               | 58 |
| Fig.4.13 – SPES3-97 and IRIS HT1 ADS Stage-I mass flow.....                                                                         | 59 |
| Fig.4.14 – SPES3-97 and IRIS HT1 DW to PSS mass flow (window) .....                                                                 | 59 |
| Fig.4.15 – SPES3-97 and IRIS HT1 PSS to DW integral flow (window).....                                                              | 60 |
| Fig.4.16 – SPES3-97 and IRIS HT1 PSS level (window).....                                                                            | 60 |

|                                                                                           |    |
|-------------------------------------------------------------------------------------------|----|
| Fig.4.17 – SPES3-97 and IRIS HT1 DW non-condensable gas quality (window) .....            | 61 |
| Fig.4.18 – SPES3-97 and IRIS HT1 DW non-condensable gas quality .....                     | 61 |
| Fig.4.19 – SPES3-97 and IRIS HT1 PSS pressure (window) .....                              | 62 |
| Fig.4.20 – SPES3-97 and IRIS HT1 PSS pressure .....                                       | 62 |
| Fig.4.21 – SPES3-97 and IRIS HT1 LGMS pressure (window) .....                             | 63 |
| Fig.4.22 – SPES3-97 and IRIS HT1 LGMS pressure .....                                      | 63 |
| Fig.4.23 – SPES3-97 and IRIS HT1 DW and PSS pressure (window) .....                       | 64 |
| Fig.4.24 – SPES3-97 and IRIS HT1 DW and PSS pressure .....                                | 64 |
| Fig.4.25 – SPES3-97 and IRIS HT1 PSS to DW pipe level .....                               | 65 |
| Fig.4.26 – SPES3-97 and IRIS HT1 RC level (window) .....                                  | 65 |
| Fig.4.27 – SPES3-97 and IRIS HT1 DW level .....                                           | 66 |
| Fig.4.28 – SPES3-97 and IRIS HT1 PSS liquid and gas temperature (window) .....            | 66 |
| Fig.4.29 – SPES3-97 and IRIS HT1 PSS liquid and gas temperature .....                     | 67 |
| Fig.4.30 – SPES3-97 and IRIS HT1 DW to PSS integral flow (first phase of injection) ..... | 67 |
| Fig.4.31 – SPES3-97 and IRIS HT1 core power (window) .....                                | 68 |
| Fig.4.32 – SPES3-97 and IRIS HT1 core power .....                                         | 68 |
| Fig.4.33 – SPES3-97 and IRIS HT1 SG power (window) .....                                  | 69 |
| Fig.4.34 – SPES3-97 and IRIS HT1 SG power .....                                           | 69 |
| Fig.4.35 – SPES3-97 and IRIS HT1 SG ss mass flow (window) .....                           | 70 |
| Fig.4.36 – SPES3-97 and IRIS HT1 SG ss mass flow .....                                    | 70 |
| Fig.4.37 – SPES3-97 and IRIS HT1 EHRS cold leg mass flow (window) .....                   | 71 |
| Fig.4.38 – SPES3-97 and IRIS HT1 EHRS cold leg mass flow .....                            | 71 |
| Fig.4.39 – SPES3-97 and IRIS HT1 EHRS power (window) .....                                | 72 |
| Fig.4.40 – SPES3-97 and IRIS HT1 EHRS power .....                                         | 72 |
| Fig.4.41 – SPES3-97 and IRIS HT1 SG ss outlet pressure (window) .....                     | 73 |
| Fig.4.42 – SPES3-97 and IRIS HT1 SG ss outlet pressure .....                              | 73 |
| Fig.4.43 – SPES3-97 and IRIS HT1 SG-1 ss level (window) .....                             | 74 |
| Fig.4.44 – SPES3-97 and IRIS HT1 SG-1 ss level .....                                      | 74 |
| Fig.4.45 – SPES3-97 and IRIS HT1 PRZ level .....                                          | 75 |
| Fig.4.46 – SPES3-97 and IRIS HT1 DVI break SPLIT integral flow .....                      | 75 |
| Fig.4.47 – SPES3-97 and IRIS HT1 pump inlet liquid fraction .....                         | 76 |
| Fig.4.48 – SPES3-97 and IRIS HT1 core inlet flow (window) .....                           | 76 |
| Fig.4.49 – SPES3-97 and IRIS HT1 core inlet flow .....                                    | 77 |
| Fig.4.50 – SPES3-97 and IRIS HT1 RI-DC check valve mass flow (window) .....               | 77 |
| Fig.4.51 – SPES3-97 and IRIS HT1 RI-DC check valve mass flow .....                        | 78 |
| Fig.4.52 – SPES3-97 and IRIS HT1 core liquid void fraction (window) .....                 | 78 |
| Fig.4.53 – SPES3-97 and IRIS HT1 core liquid void fraction .....                          | 79 |
| Fig.4.54 – SPES3-97 and IRIS HT1 ADS Stage-I integral flow (window) .....                 | 79 |
| Fig.4.55 – SPES3-97 and IRIS HT1 ADS Stage-I integral flow .....                          | 80 |
| Fig.4.56 – SPES3-97 and IRIS HT1 RV mass .....                                            | 80 |
| Fig.4.57 – SPES3-97 and IRIS HT1 EBT injection mass flow (window) .....                   | 81 |
| Fig.4.58 – SPES3-97 and IRIS HT1 EBT injection mass flow .....                            | 81 |

|                                                                                           |     |
|-------------------------------------------------------------------------------------------|-----|
| Fig.4.59 – SPES3-97 and IRIS HT1 EBT balance line to RV mass flow (window) .....          | 82  |
| Fig.4.60 – SPES3-97 and IRIS HT1 EBT level (window) .....                                 | 82  |
| Fig.4.61 – SPES3-97 and IRIS HT1 EBT level.....                                           | 83  |
| Fig.4.62 – SPES3-97 and IRIS HT1 DVI mass flow (window) .....                             | 83  |
| Fig.4.63 – SPES3-97 and IRIS HT1 DVI mass flow .....                                      | 84  |
| Fig.4.64 – SPES3-97 and IRIS HT1 Core inlet and outlet temperatures (window).....         | 84  |
| Fig.4.65 – SPES3-97 and IRIS HT1 Core inlet and outlet temperatures .....                 | 85  |
| Fig.4.66 – SPES3-97 and IRIS HT1 core heater rod outer surface temperature (window) ..... | 85  |
| Fig.4.67 – SPES3-97 and IRIS HT1 core heater rod outer surface temperature.....           | 86  |
| Fig.4.68 – SPES3-97 and IRIS HT1 LGMS injection mass flow (window) .....                  | 86  |
| Fig.4.69 – SPES3-97 and IRIS HT1 LGMS mass (window).....                                  | 87  |
| Fig.4.70 – SPES3-97 and IRIS HT1 LGMS and DVI pressure (window) .....                     | 87  |
| Fig.4.71 – SPES3-97 and IRIS HT1 LGMS and DVI pressure.....                               | 88  |
| Fig.4.72 – SPES3-97 and IRIS HT1 RC to DVI mass flow (window) .....                       | 88  |
| Fig.4.73 – SPES3-97 and IRIS HT1 RC to DVI mass flow.....                                 | 89  |
| Fig.4.74 – SPES3-97 and IRIS HT1 RC to DVI integral mass flow.....                        | 89  |
| Fig.4.75 – SPES3-97 and IRIS HT1 QT level.....                                            | 90  |
| Fig.4.76 – SPES3-97 and IRIS HT1 ADS Stage-II mass flow (window) .....                    | 90  |
| Fig.4.77 – SPES3-97 and IRIS HT1 ADS Stage-II mass flow.....                              | 91  |
| Fig.4.78 – SPES3-97 and IRIS HT1 RWST temperature .....                                   | 91  |
| Fig.4.79 – SPES3-97 and IRIS HT1 RWST mass.....                                           | 92  |
| Fig.4.80 – SPES3-97 and IRIS HT1 RWST pressure .....                                      | 92  |
| Fig.4.81 – SPES3-97 and IRIS HT1 RWST power (window) .....                                | 93  |
| Fig.4.82 – SPES3-97 and IRIS HT1 RWST power .....                                         | 93  |
| Fig.4.83 – SPES3-97 and IRIS HT1 DW power (window).....                                   | 94  |
| Fig.4.84 – SPES3-97 and IRIS HT1 DW power .....                                           | 94  |
| Fig.4.85 – SPES3-97 and IRIS HT1 DW inner and outer wall temperature (window) .....       | 95  |
| Fig.4.86 – SPES3-97 and IRIS DW inner and outer wall temperature.....                     | 95  |
| <br>                                                                                      |     |
| Fig.5. 1 – SPES3-94, 89 and IRIS HT1: DW pressure (window) .....                          | 121 |
| Fig.5. 2 – SPES3-94, 89 and IRIS HT1: DW pressure.....                                    | 121 |
| Fig.5. 3 – SPES3-99, 97 and IRIS HT1: DW pressure (window) .....                          | 122 |
| Fig.5. 4 – SPES3-99, 97 and IRIS HT1: DW pressure.....                                    | 122 |
| Fig.5. 5 – SPES3-99, 100, 103 and IRIS HT1: DW pressure (window) .....                    | 123 |
| Fig.5. 6 – SPES3-99, 104 and IRIS HT1: DW pressure (window) .....                         | 123 |
| Fig.5. 7 – SPES3-99, 105 and IRIS HT1: DW pressure (window) .....                         | 124 |
| Fig.5. 8 – SPES3-99, 105 and IRIS HT1: DW heat structure power (window) .....             | 124 |
| Fig.5. 9 – SPES3-99, 105 and IRIS HT1: DW heat structure energy (window) .....            | 125 |
| Fig.5. 10 – SPES3-104, 106 and IRIS HT1: DW pressure (window) .....                       | 125 |
| Fig.5. 11 – SPES3-104, 106 and IRIS HT1: PSS pressure (window) .....                      | 126 |
| Fig.5. 12 – SPES3-107 and 99: Core power (window).....                                    | 126 |
| Fig.5. 13 – SPES3-107 and 99: SG total power (window) .....                               | 127 |

|                                                                                       |     |
|---------------------------------------------------------------------------------------|-----|
| Fig.5. 14 – SPES3-107 and 99: SG tube primary side level .....                        | 127 |
| Fig.5. 15 – SPES3-108, 105, 107 and IRIS HT1: DW pressure (window) .....              | 128 |
| Fig.5. 16 – SPES3-108, 105, 107 and IRIS HT1: DW pressure (window) .....              | 128 |
| Fig.5. 17 – SPES3-108, 105 and IRIS HT1: DW heat structure power (window) .....       | 129 |
| Fig.5. 18 – SPES3-108, 105 and IRIS HT1: DW heat structure power (window) .....       | 129 |
| Fig.5. 19 – SPES3-108 and IRIS HT1: DVI break mass flow (window) .....                | 130 |
| Fig.5. 20 – SPES3-108 and IRIS HT1: ADS Stage-I mass flow (window) .....              | 130 |
| Fig.5. 21 – SPES3-108 and IRIS HT1: ADS Stage-I mass flow (window) .....              | 131 |
| Fig.5. 22 – SPES3-108, 105 and IRIS HT1: DW heat structure energy (window) .....      | 131 |
| Fig.5. 23 – SPES3-108, 105 and IRIS HT1: DW heat structure energy (window) .....      | 132 |
| Fig.5. 24 – SPES3-108 and IRIS HT1: DW air quality (window) .....                     | 132 |
| Fig.5. 25 – SPES3-108 and IRIS HT1: LGMS injection mass flow (window) .....           | 133 |
| Fig.5. 26 – SPES3-108 and IRIS HT1: PSS to DW injection mass flow (window) .....      | 133 |
| Fig.5. 27 – SPES3-109, 107 and IRIS HT1: PSS to DW injection mass flow (window) ..... | 134 |
| Fig.5. 28 – SPES3-109, 107 and IRIS HT1: DW pressure (window) .....                   | 134 |
| Fig.5. 29 – SPES3-110, 109 and IRIS HT1: PSS to DW injection mass flow (window) ..... | 135 |
| Fig.5. 30 – SPES3-110, 109: DW to PSS mass (blowdown phase) .....                     | 135 |
| Fig.5. 31 – SPES3-110, 109 and IRIS HT1: DW pressure (window) .....                   | 136 |
| Fig.5. 32 – SPES3-111, 105, 104 and IRIS HT1: DW pressure (window) .....              | 136 |
| Fig.5. 33 – SPES3-112, 108, and IRIS HT1: DW pressure (window) .....                  | 137 |
| Fig.5. 34 – SPES3-115, 108, 107 and IRIS HT1: DW pressure (window) .....              | 137 |
| Fig.5. 35 – SPES3-115, 107 and IRIS HT1: LGMS injection mass flow (window) .....      | 138 |
| Fig.5. 36 – SPES3-115 and IRIS HT1: ADS ST and DT Stage-I mass flow (window) .....    | 138 |
| Fig.5. 37 – SPES3-115 and IRIS HT1: EHRS-A,B and C cold leg mass flow (window) .....  | 139 |
| Fig.5. 38 – SPES3-118, 115 and IRIS HT1: DW pressure (window) .....                   | 139 |
| Fig.5. 39 – SPES3-118, 115 and IRIS HT1: LGMS injection mass flow (window) .....      | 140 |
| Fig.5. 40 – SPES3-118, 115 and IRIS HT1: PSS to DW injection mass flow (window) ..... | 140 |
| Fig.5. 41 – SPES3-118, 115 and IRIS HT1: EHRS-C cold leg mass flow (window) .....     | 141 |
| Fig.5. 42 – SPES3-119 and IRIS HT1: DW pressure (window) .....                        | 141 |
| Fig.5. 43 – SPES3-119 and IRIS HT1: PSS to DW injection mass flow (window) .....      | 142 |
| Fig.5. 44 – SPES3-119 and IRIS HT1: LGMS injection mass flow (window) .....           | 142 |
| Fig.5. 45 – SPES3-119, 107 and IRIS HT1: RC to DVI injection mass flow (window) ..... | 143 |
| Fig.5. 46 – SPES3-119 and IRIS HT1: RC to DVI injection mass flow (window) .....      | 143 |
| Fig.5. 47 – SPES3-119 and IRIS HT1: EHRS-C cold leg mass flow (window) .....          | 144 |
| Fig.5. 48 – SPES3-120 and IRIS HT1: DW pressure (window) .....                        | 144 |
| Fig.5. 49 – SPES3-120 and IRIS HT1: LGMS injection mass flow (window) .....           | 145 |
| Fig.5. 50 – SPES3-120 and IRIS HT1: PSS to DW injection mass flow (window) .....      | 145 |
| Fig.5. 51 – SPES3-120 and IRIS HT1: LGMS and DVI pressure (window) .....              | 146 |
| Fig.5. 52 – SPES3-120 and IRIS HT1: PSS vent pipe level (window) .....                | 146 |
| Fig.5. 53 – SPES3-120 and IRIS HT1: RC level (window) .....                           | 147 |
| Fig.5. 54 – SPES3-120 and IRIS HT1: DW level (window) .....                           | 147 |
| Fig.5. 55 – SPES3-120 and IRIS HT1: PSS and DW pressure (window) .....                | 148 |



|                                                                                   |     |
|-----------------------------------------------------------------------------------|-----|
| Fig.5. 56 – SPES3-120 and IRIS HT1: PSS level (window).....                       | 148 |
| Fig.5. 57 – SPES3-122, 120 and IRIS HT1: DW pressure (window) .....               | 149 |
| Fig.5. 58 – SPES3-124 and IRIS HT5g: DW pressure (window) .....                   | 149 |
| Fig.5. 59 – SPES3-124 and IRIS HT5g: DW pressure.....                             | 150 |
| Fig.5. 60 – SPES3-124 and IRIS HT5g: DW to PSS mass flow (window) .....           | 150 |
| Fig.5. 61 – SPES3-124 and IRIS HT5g: PSS and DW pressure (window) .....           | 151 |
| Fig.5. 62 – SPES3-124 and IRIS HT5g: PSS level (window).....                      | 151 |
| Fig.5. 63 – SPES3-124 and IRIS HT5g: PSS mass (window).....                       | 152 |
| Fig.5. 64 – SPES3-124 and IRIS HT5g: LGMS injection mass flow (window) .....      | 152 |
| Fig.5. 65 – SPES3-124 and IRIS HT5g: LGMS and DVI pressure (window) .....         | 153 |
| Fig.5. 66 – SPES3-124 and IRIS HT5g: LGMS and DVI pressure (window) .....         | 153 |
| Fig.5. 67 – SPES3-124 and IRIS HT5g: LGMS mass (window) .....                     | 154 |
| Fig.5. 68 – SPES3-124 and IRIS HT5g: DW level (window) .....                      | 154 |
| Fig.5. 69 – SPES3-124 and IRIS HT5g: PSS vent pipe level.....                     | 155 |
| Fig.5. 70 – SPES3-124 and IRIS HT5g RWST temperature.....                         | 155 |
| Fig.5. 71 – SPES3-124 and IRIS HT5g RWST mass.....                                | 156 |
| Fig.5. 72 – SPES3-124 and IRIS HT5g RWST pressure .....                           | 156 |
| Fig.5. 73 – SPES3-124 and IRIS HT5g RWST power .....                              | 157 |
| Fig.5. 74 – SPES3-124 and IRIS HT5g EHRS cold leg mass flow (window) .....        | 157 |
| Fig.5. 75 – SPES3-124 and IRIS HT5g EHRS cold leg mass flow .....                 | 158 |
|                                                                                   |     |
| Fig.6. 1 – SPES3-127 and IRIS HT5g DVI break flow (window).....                   | 174 |
| Fig.6. 2 – SPES3-127 and IRIS HT5g DVI break flow (window) .....                  | 174 |
| Fig.6. 3 – SPES3-127 and IRIS HT5g DVI break flow .....                           | 175 |
| Fig.6. 4 – SPES3-127 and IRIS HT5g DW pressure (window) .....                     | 175 |
| Fig.6. 5 – SPES3-127 and IRIS HT5g DW pressure.....                               | 176 |
| Fig.6. 6 – SPES3-127 and IRIS HT5g PRZ pressure (window) .....                    | 176 |
| Fig.6. 7 – SPES3-127 and IRIS HT5g PRZ pressure (window) .....                    | 177 |
| Fig.6. 8 – SPES3-127 and IRIS HT5g PRZ pressure.....                              | 177 |
| Fig.6. 9 – SPES3-127 and IRIS HT5g PRZ and DW pressures (window) .....            | 178 |
| Fig.6. 10 – SPES3-127 and IRIS HT5g PRZ and DW pressures.....                     | 178 |
| Fig.6. 11 – SPES3-127 and IRIS HT5g PRZ and DW pressures (detail).....            | 179 |
| Fig.6. 12 – SPES3-127 and IRIS HT5g ADS Stage-I mass flow (window) .....          | 179 |
| Fig.6. 13 – SPES3-127 and IRIS HT5g ADS Stage-I mass flow.....                    | 180 |
| Fig.6. 14 – SPES3-127 and IRIS HT5g DW to PSS mass flow (window) .....            | 180 |
| Fig.6. 15 – SPES3-127 and IRIS HT5g PSS to DW integral flow (window) .....        | 181 |
| Fig.6. 16 – SPES3-127 and IRIS HT5g PSS level (window).....                       | 181 |
| Fig.6. 17 – SPES3-127 and IRIS HT5g DW non-condensable gas quality (window) ..... | 182 |
| Fig.6. 18 – SPES3-127 and IRIS HT5g DW non-condensable gas quality.....           | 182 |
| Fig.6. 19 – SPES3-127 and IRIS HT5g PSS pressure (window) .....                   | 183 |
| Fig.6. 20 – SPES3-127 and IRIS HT5g PSS pressure.....                             | 183 |
| Fig.6. 21 – SPES3-127 and IRIS HT5g LGMS pressure (window) .....                  | 184 |



|                                                                                             |     |
|---------------------------------------------------------------------------------------------|-----|
| Fig.6. 22 – SPES3-127 and IRIS HT5g LGMS pressure.....                                      | 184 |
| Fig.6. 23 – SPES3-127 and IRIS HT5g DW and PSS pressure (window) .....                      | 185 |
| Fig.6. 24 – SPES3-127 and IRIS HT5g DW and PSS pressure .....                               | 185 |
| Fig.6. 25 – SPES3-127 and IRIS HT5g PSS to DW pipe level .....                              | 186 |
| Fig.6. 26 – SPES3-127 and IRIS HT5g RC level (window).....                                  | 186 |
| Fig.6. 27 – SPES3-127 and IRIS HT5g DW level .....                                          | 187 |
| Fig.6. 28 – SPES3-127 and IRIS HT5g PSS liquid and gas temperature (window) .....           | 187 |
| Fig.6. 29 – SPES3-127 and IRIS HT5g PSS liquid and gas temperature.....                     | 188 |
| Fig.6. 30 – SPES3-127 and IRIS HT5g DW to PSS integral flow (first phase of injection)..... | 188 |
| Fig.6. 31 – SPES3-127 and IRIS HT5g core power (window).....                                | 189 |
| Fig.6. 32 – SPES3-127 and IRIS HT5g core power .....                                        | 189 |
| Fig.6. 33 – SPES3-127 and IRIS HT5g SG power (window) .....                                 | 190 |
| Fig.6. 34 – SPES3-127 and IRIS HT5g SG power .....                                          | 190 |
| Fig.6. 35 – SPES3-127 and IRIS HT5g SG ss mass flow (window) .....                          | 191 |
| Fig.6. 36 – SPES3-127 and IRIS HT5g SG ss mass flow .....                                   | 191 |
| Fig.6. 37 – SPES3-127 and IRIS HT5g EHRS cold leg mass flow (window) .....                  | 192 |
| Fig.6. 38 – SPES3-127 and IRIS HT5g EHRS cold leg mass flow .....                           | 192 |
| Fig.6. 39 – SPES3-127 and IRIS HT5g EHRS power (window) .....                               | 193 |
| Fig.6. 40 – SPES3-127 and IRIS HT5g EHRS power .....                                        | 193 |
| Fig.6. 41 – SPES3-127 and IRIS HT5g SG ss outlet pressure (window).....                     | 194 |
| Fig.6. 42 – SPES3-127 and IRIS HT5g SG ss outlet pressure .....                             | 194 |
| Fig.6. 43 – SPES3-127 and IRIS HT5g SG-1ss collapsed level (window).....                    | 195 |
| Fig.6. 44 – SPES3-127 and IRIS HT5g SG-1ss collapsed level .....                            | 195 |
| Fig.6. 45 – SPES3-127 and IRIS HT5g PRZ level .....                                         | 196 |
| Fig.6. 46 – SPES3-127 and IRIS HT5g DVI break SPLIT integral flow .....                     | 196 |
| Fig.6. 47 – SPES3-127 and IRIS HT5g pump inlet liquid fraction .....                        | 197 |
| Fig.6. 48 – SPES3-127 and IRIS HT5g core outlet flow (window) .....                         | 197 |
| Fig.6. 49 – SPES3-127 and IRIS HT5g core outlet flow.....                                   | 198 |
| Fig.6. 50 – SPES3-127 and IRIS HT5g RI-DC check valve mass flow (window) .....              | 198 |
| Fig.6. 51 – SPES3-127 and IRIS HT5g RI-DC check valve mass flow.....                        | 199 |
| Fig.6. 52 – SPES3-127 and IRIS HT5g core liquid void fraction (window) .....                | 199 |
| Fig.6. 53 – SPES3-127 and IRIS HT5g core liquid void fraction .....                         | 200 |
| Fig.6. 54 – SPES3-127 and IRIS HT5g ADS Stage-I integral flow (window) .....                | 200 |
| Fig.6. 55 – SPES3-127 and IRIS HT5g ADS Stage-I integral flow .....                         | 201 |
| Fig.6. 56 – SPES3-127 and IRIS HT5g RV mass .....                                           | 201 |
| Fig.6. 57 – SPES3-127 and IRIS HT5g EBT injection mass flow (window) .....                  | 202 |
| Fig.6. 58 – SPES3-127 and IRIS HT5g EBT injection mass flow .....                           | 202 |
| Fig.6. 59 – SPES3-127 and IRIS HT5g EBT balance line to RV mass flow (window) .....         | 203 |
| Fig.6. 60 – SPES3-127 and IRIS HT5g EBT level (window) .....                                | 203 |
| Fig.6. 61 – SPES3-127 and IRIS HT5g EBT level .....                                         | 204 |
| Fig.6. 62 – SPES3-127 and IRIS HT5g DVI mass flow (window) .....                            | 204 |
| Fig.6. 63 – SPES3-127 and IRIS HT5g DVI mass flow.....                                      | 205 |

|                                                                                              |     |
|----------------------------------------------------------------------------------------------|-----|
| Fig.6. 64 – SPES3-127 and IRIS HT5g Core inlet and outlet temperatures (window).....         | 205 |
| Fig.6. 65 – SPES3-127 and IRIS HT5g Core inlet and outlet temperatures .....                 | 206 |
| Fig.6. 66 – SPES3-127 and IRIS HT5g core heater rod outer surface temperature (window) ..... | 206 |
| Fig.6. 67 – SPES3-127 and IRIS HT5g core heater rod outer surface temperature.....           | 207 |
| Fig.6. 68 – SPES3-127 and IRIS HT5g LGMS injection mass flow (window).....                   | 207 |
| Fig.6. 69 – SPES3-127 and IRIS HT5g LGMS mass (window).....                                  | 208 |
| Fig.6. 70 – SPES3-127 and IRIS HT5g LGMS and DVI pressure (window) .....                     | 208 |
| Fig.6. 71 – SPES3-127 and IRIS HT5g LGMS and DVI pressure .....                              | 209 |
| Fig.6. 72 – SPES3-127 and IRIS HT5g RC to DVI mass flow (window) .....                       | 209 |
| Fig.6. 73 – SPES3-127 and IRIS HT5g RC to DVI mass flow.....                                 | 210 |
| Fig.6. 74 – SPES3-127 and IRIS HT5g RC to DVI integral mass flow.....                        | 210 |
| Fig.6. 75 – SPES3-127 and IRIS HT5g QT level .....                                           | 211 |
| Fig.6. 76 – SPES3-127 and IRIS HT5g ADS Stage-II mass flow (window) .....                    | 211 |
| Fig.6. 77 – SPES3-127 and IRIS HT5g ADS Stage-II mass flow.....                              | 212 |
| Fig.6. 78 – SPES3-127 and IRIS HT5g RWST temperature.....                                    | 212 |
| Fig.6. 79 – SPES3-127 and IRIS HT5g RWST mass.....                                           | 213 |
| Fig.6. 80 – SPES3-127 and IRIS HT5g RWST pressure .....                                      | 213 |
| Fig.6. 81 – SPES3-127 and IRIS HT5g RWST top mass flow .....                                 | 214 |
| Fig.6. 82 – SPES3-127 and IRIS HT5g RWST top integral mass flow .....                        | 214 |
| Fig.6. 83 – SPES3-127 and IRIS HT5g RWST power (window).....                                 | 215 |
| Fig.6. 84 – SPES3-127 and IRIS HT5g RWST power .....                                         | 215 |
| Fig.6. 85 – SPES3-127 and IRIS HT5g DW power (window).....                                   | 216 |
| Fig.6. 86 – SPES3-127 and IRIS HT5g DW power .....                                           | 216 |
| Fig.6. 87 – SPES3-127 and IRIS HT5g DW inner and outer wall temperature (window) .....       | 217 |
| Fig.6. 88 – SPES3-127 and IRIS HT5g DW inner and outer wall temperature.....                 | 217 |
| Fig.6. 89 – SPES3-127 and IRIS HT5g T (PRZ) – T (SG) .....                                   | 218 |
| Fig.6. 90 – SPES3-127 and IRIS HT5g SG global heat transfer coefficient .....                | 218 |
| Fig.6. 91 – SPES3-127 and IRIS HT5g T (EHRS) – T (RWST).....                                 | 219 |
| Fig.6. 92 – SPES3-127 and IRIS HT5g EHRS global heat transfer coefficient.....               | 219 |
| Fig.6. 93 – SPES3-127 and IRIS HT5g T (PRZ) – T (RWST).....                                  | 220 |
| Fig.6. 94 – SPES3-127 and IRIS HT5g PRZ-RWST global heat transfer coefficient .....          | 220 |
| Fig.7. 1 - SPES3-130, 127 and IRIS HT5g: RWST temperature.....                               | 234 |
| Fig.7. 2 - SPES3-130, 127 and IRIS HT5g: DW pressure.....                                    | 234 |
| Fig.7. 3 - SPES3-130: SG-EHRS loop mass.....                                                 | 235 |
| Fig.7. 4 - SPES3-130: SG-EHRS loop A partial masses.....                                     | 235 |
| Fig.7. 5 - SPES3-130: SG-EHRS loop B partial masses.....                                     | 236 |
| Fig.7. 6 - SPES3-130: SG-EHRS loop C partial masses .....                                    | 236 |
| Fig.7. 7 - SPES3-130: EHRS heat exchanger collapsed level.....                               | 237 |
| Fig.7. 8 – RWST-EHRS stand alone model (nodalization).....                                   | 238 |
| Fig.7. 9 – Inconel-600 and AISI 304 thermal conductivity .....                               | 239 |
| Fig.7. 10 – SPES3-132, 130 and IRIS HT5g EHRS power .....                                    | 239 |

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Fig.7. 11 – SPES3-132, 130 and IRIS HT5g EHRS power (window) .....                                | 240 |
| Fig.7. 12 – SPES3-132, 130 and IRIS HT5g DW pressure.....                                         | 240 |
| Fig.7. 13 – SPES3-132, 130 and IRIS HT5g: RWST temperature.....                                   | 241 |
| Fig.7. 14 – SPES3-AB and SPES3-C RWST-EHRS stand alone models (nodalization) .....                | 242 |
| Fig.7. 15 – IRIS Original RWST-EHRS stand alone model (nodalization) .....                        | 243 |
| Fig.7. 16 – IRIS Perseo RWST-EHRS stand alone model (nodalization) .....                          | 244 |
| Fig.7. 17 – SPES3 and IRIS EHRS-RWST parametric cases: power versus pressure .....                | 245 |
| Fig.7. 18 – SPES3-135, SPES3-132 and IRIS HT5g DW pressure .....                                  | 245 |
| Fig.7. 19 – SPES3-135 and SPES3-132 SG secondary side mass flow .....                             | 246 |
|                                                                                                   |     |
| Fig.8. 1 – SPES3-146 and IRIS HT6_rwstc DVI break flow (window) .....                             | 260 |
| Fig.8. 2 – SPES3-146 and IRIS HT6_rwstc DVI break flow (window) .....                             | 260 |
| Fig.8. 3 – SPES3-146 and IRIS HT6_rwstc DVI break flow .....                                      | 261 |
| Fig.8. 4 – SPES3-146 and IRIS HT6_rwstc DW pressure (window) .....                                | 261 |
| Fig.8. 5 – SPES3-146 and IRIS HT6_rwstc DW pressure .....                                         | 262 |
| Fig.8. 6 – SPES3-146 and IRIS HT6_rwstc PRZ pressure (window).....                                | 262 |
| Fig.8. 7 – SPES3-146 and IRIS HT6_rwstc PRZ pressure (windows) .....                              | 263 |
| Fig.8. 8 – SPES3-146 and IRIS HT6_rwstc PRZ pressure (windows) .....                              | 263 |
| Fig.8. 9 – SPES3-146 and IRIS HT6_rwstc PRZ and DW pressures (window).....                        | 264 |
| Fig.8. 10 – SPES3-146 and IRIS HT6_rwstc PRZ and DW pressures .....                               | 264 |
| Fig.8. 11 – SPES3-146 and IRIS HT6_rwstc PRZ and DW pressures (detail) .....                      | 265 |
| Fig.8. 12 – SPES3-146 and IRIS HT6_rwstc ADS Stage-I mass flow (window).....                      | 265 |
| Fig.8. 13 – SPES3-146 and IRIS HT6_rwstc ADS Stage-I mass flow .....                              | 266 |
| Fig.8. 14 – SPES3-146 and IRIS HT6_rwstc DW to PSS mass flow (window).....                        | 266 |
| Fig.8. 15 – SPES3-146 and IRIS HT6_rwstc PSS to DW integral flow (window) .....                   | 267 |
| Fig.8. 16 – SPES3-146 and IRIS HT6_rwstc PSS level (window) .....                                 | 267 |
| Fig.8. 17 – SPES3-146 and IRIS HT6_rwstc DW non-condensable gas quality (window).....             | 268 |
| Fig.8. 18 – SPES3-146 and IRIS HT6_rwstc DW non-condensable gas quality .....                     | 268 |
| Fig.8. 19 – SPES3-146 and IRIS HT6_rwstc PSS pressure (window).....                               | 269 |
| Fig.8. 20 – SPES3-146 and IRIS HT6_rwstc PSS pressure .....                                       | 269 |
| Fig.8. 21 – SPES3-146 and IRIS HT6_rwstc LGMS pressure (window).....                              | 270 |
| Fig.8. 22 – SPES3-146 and IRIS HT6_rwstc LGMS pressure .....                                      | 270 |
| Fig.8. 23 – SPES3-146 and IRIS HT6_rwstc DW and PSS pressure (window).....                        | 271 |
| Fig.8. 24 – SPES3-146 and IRIS HT6_rwstc DW and PSS pressure .....                                | 271 |
| Fig.8. 25 – SPES3-146 and IRIS HT6_rwstc PSS to DW pipe level .....                               | 272 |
| Fig.8. 26 – SPES3-146 and IRIS HT6_rwstc RC level (window) .....                                  | 272 |
| Fig.8. 27 – SPES3-146 and IRIS HT6_rwstc DW level .....                                           | 273 |
| Fig.8. 28 – SPES3-146 and IRIS HT6_rwstc PSS liquid and gas temperature (window).....             | 273 |
| Fig.8. 29 – SPES3-146 and IRIS HT6_rwstc PSS liquid and gas temperature .....                     | 274 |
| Fig.8. 30 – SPES3-146 and IRIS HT6_rwstc DW to PSS integral flow (first phase of injection) ..... | 274 |
| Fig.8. 31 – SPES3-146 and IRIS HT6_rwstc core power (window) .....                                | 275 |
| Fig.8. 32 – SPES3-146 and IRIS HT6_rwstc core power.....                                          | 275 |

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Fig.8. 33 – SPES3-146 and IRIS HT6_rwstc SG power (window) .....                                  | 276 |
| Fig.8. 34 – SPES3-146 and IRIS HT6_rwstc SG power .....                                           | 276 |
| Fig.8. 35 – SPES3-146 and IRIS HT6_rwstc SG ss mass flow (window) .....                           | 277 |
| Fig.8. 36 – SPES3-146 and IRIS HT6_rwstc SG ss mass flow .....                                    | 277 |
| Fig.8. 37 – SPES3-146 and IRIS HT6_rwstc EHRS cold leg mass flow (window) .....                   | 278 |
| Fig.8. 38 – SPES3-146 and IRIS HT6_rwstc EHRS cold leg mass flow .....                            | 278 |
| Fig.8. 39 – SPES3-146 and IRIS HT6_rwstc EHRS power (window) .....                                | 279 |
| Fig.8. 40 – SPES3-146 and IRIS HT6_rwstc EHRS power .....                                         | 279 |
| Fig.8. 41 – SPES3-146 and IRIS HT6_rwstc SG ss outlet pressure (window) .....                     | 280 |
| Fig.8. 42 – SPES3-146 and IRIS HT6_rwstc SG ss outlet pressure .....                              | 280 |
| Fig.8. 43 – SPES3-146 and IRIS HT6_rwstc SG-1ss collapsed level (window) .....                    | 281 |
| Fig.8. 44 – SPES3-146 and IRIS HT6_rwstc SG-1ss collapsed level .....                             | 281 |
| Fig.8. 45 – SPES3-146 and IRIS HT6_rwstc PRZ level .....                                          | 282 |
| Fig.8. 46 – SPES3-146 and IRIS HT6_rwstc DVI break SPLIT integral flow .....                      | 282 |
| Fig.8. 47 – SPES3-146 and IRIS HT6_rwstc pump inlet liquid fraction .....                         | 283 |
| Fig.8. 48 – SPES3-146 and IRIS HT6_rwstc core outlet flow (window) .....                          | 283 |
| Fig.8. 49 – SPES3-146 and IRIS HT6_rwstc core outlet flow .....                                   | 284 |
| Fig.8. 50 – SPES3-146 and IRIS HT6_rwstc RI-DC check valve mass flow (window) .....               | 284 |
| Fig.8. 51 – SPES3-146 and IRIS HT6_rwstc RI-DC check valve mass flow .....                        | 285 |
| Fig.8. 52 – SPES3-146 and IRIS HT6_rwstc core liquid void fraction (window) .....                 | 285 |
| Fig.8. 53 – SPES3-146 and IRIS HT6_rwstc core liquid void fraction .....                          | 286 |
| Fig.8. 54 – SPES3-146 and IRIS HT6_rwstc ADS Stage-I integral flow (window) .....                 | 286 |
| Fig.8. 55 – SPES3-146 and IRIS HT6_rwstc ADS Stage-I integral flow .....                          | 287 |
| Fig.8. 56 – SPES3-146 and IRIS HT6_rwstc RV mass .....                                            | 287 |
| Fig.8. 57 – SPES3-146 and IRIS HT6_rwstc EBT injection mass flow (window) .....                   | 288 |
| Fig.8. 58 – SPES3-146 and IRIS HT6_rwstc EBT injection mass flow .....                            | 288 |
| Fig.8. 59 – SPES3-146 and IRIS HT6_rwstc EBT balance line to RV mass flow (window) .....          | 289 |
| Fig.8. 60 – SPES3-146 and IRIS HT6_rwstc EBT level (window) .....                                 | 289 |
| Fig.8. 61 – SPES3-146 and IRIS HT6_rwstc EBT level .....                                          | 290 |
| Fig.8. 62 – SPES3-146 and IRIS HT6_rwstc DVI mass flow (window) .....                             | 290 |
| Fig.8. 63 – SPES3-146 and IRIS HT6_rwstc DVI mass flow .....                                      | 291 |
| Fig.8. 64 – SPES3-146 and IRIS HT6_rwstc Core inlet and outlet temperatures (window) .....        | 291 |
| Fig.8. 65 – SPES3-146 and IRIS HT6_rwstc Core inlet and outlet temperatures .....                 | 292 |
| Fig.8. 66 – SPES3-146 and IRIS HT6_rwstc Core heater rod outer surface temperature (window) ..... | 292 |
| Fig.8. 67 – SPES3-146 and IRIS HT6_rwstc Core heater rod outer surface temperature .....          | 293 |
| Fig.8. 68 – SPES3-146 and IRIS HT6_rwstc LGMS injection mass flow (window) .....                  | 293 |
| Fig.8. 69 – SPES3-146 and IRIS HT6_rwstc LGMS mass (window) .....                                 | 294 |
| Fig.8. 70 – SPES3-146 and IRIS HT6_rwstc LGMS and DVI pressure (window) .....                     | 294 |
| Fig.8. 71 – SPES3-146 and IRIS HT6_rwstc LGMS and DVI pressure .....                              | 295 |
| Fig.8. 72 – SPES3-146 and IRIS HT6_rwstc RC to DVI mass flow (window) .....                       | 295 |
| Fig.8. 73 – SPES3-146 and IRIS HT6_rwstc RC to DVI mass flow .....                                | 296 |
| Fig.8. 74 – SPES3-146 and IRIS HT6_rwstc RC to DVI integral mass flow .....                       | 296 |

|                                                                                            |     |
|--------------------------------------------------------------------------------------------|-----|
| Fig.8. 75 – SPES3-146 and IRIS HT6_rwstc QT level .....                                    | 297 |
| Fig.8. 76 – SPES3-146 and IRIS HT6_rwstc ADS Stage-II mass flow (window).....              | 297 |
| Fig.8. 77 – SPES3-146 and IRIS HT6_rwstc ADS Stage-II mass flow .....                      | 298 |
| Fig.8. 78 – SPES3-146 and IRIS HT6_rwstc RWST temperature .....                            | 298 |
| Fig.8. 79 – SPES3-146 and IRIS HT6_rwstc RWST mass .....                                   | 299 |
| Fig.8. 80 – SPES3-146 and IRIS HT6_rwstc RWST pressure.....                                | 299 |
| Fig.8. 81 – SPES3-146 and IRIS HT6_rwstc RWST top mass flow.....                           | 300 |
| Fig.8. 82 – SPES3-146 and IRIS HT6_rwstc RWST top integral mass flow.....                  | 300 |
| Fig.8. 83 – SPES3-146 and IRIS HT6_rwstc RWST power (window) .....                         | 301 |
| Fig.8. 84 – SPES3-146 and IRIS HT6_rwstc RWST power .....                                  | 301 |
| Fig.8. 85 – SPES3-146 and IRIS HT6_rwstc DW power (window) .....                           | 302 |
| Fig.8. 86 – SPES3-146 and IRIS HT6_rwstc DW power.....                                     | 302 |
| Fig.8. 87 – SPES3-146 and IRIS HT6_rwstc DW inner and outer wall temperature (window)..... | 303 |
| Fig.8. 88 – SPES3-146 and IRIS HT6_rwstc DW inner and outer wall temperature .....         | 303 |
| Fig.8. 89 – SPES3-146 and IRIS HT6_rwstc T (PRZ) – T (SG).....                             | 304 |
| Fig.8. 90 – SPES3-146 and IRIS HT6_rwstc SG global heat transfer coefficient.....          | 304 |
| Fig.8. 91 – SPES3-146 and IRIS HT6_rwstc T (EHRS) – T (RWST) .....                         | 305 |
| Fig.8. 92 – SPES3-146 and IRIS HT6_rwstc EHRS global heat transfer coefficient.....        | 305 |
| Fig.8. 93 – SPES3-146 and IRIS HT6_rwstc T (PRZ) – T (RWST) .....                          | 306 |
| Fig.8. 94 – SPES3-146 and IRIS HT6_rwstc PRZ-RWST global heat transfer coefficient.....    | 306 |
|                                                                                            |     |
| Fig.9. 1 - SPES3-147 and IRIS HT6_rwstc DVI break flow (window) .....                      | 320 |
| Fig.9. 2 - SPES3-147 and IRIS HT6_rwstc DVI break flow (window) .....                      | 320 |
| Fig.9. 3 - SPES3-147 and IRIS HT6_rwstc DVI break flow.....                                | 321 |
| Fig.9. 4 - SPES3-147 and IRIS HT6_rwstc DW pressure (window).....                          | 321 |
| Fig.9. 5 – SPES3-147 and IRIS HT6_rwstc DW pressure .....                                  | 322 |
| Fig.9. 6 – SPES3-147 and IRIS HT6_rwstc PRZ pressure (windows).....                        | 322 |
| Fig.9. 7 – SPES3-147 and IRIS HT6_rwstc PRZ pressure (windows).....                        | 323 |
| Fig.9. 8 – SPES3-147 and IRIS HT6_rwstc PRZ pressure .....                                 | 323 |
| Fig.9. 9 – SPES3-147 and IRIS HT6_rwstc PRZ and DW pressures (window).....                 | 324 |
| Fig.9. 10 – SPES3-147 and IRIS HT6_rwstc PRZ and DW pressures .....                        | 324 |
| Fig.9. 11 – SPES3-147 and IRIS HT6_rwstc PRZ and DW pressures (detail) .....               | 325 |
| Fig.9. 12 – SPES3-147 and IRIS HT6_rwstc ADS Stage-I mass flow (window).....               | 325 |
| Fig.9. 13 – SPES3-147 and IRIS HT6_rwstc ADS Stage-I mass flow .....                       | 326 |
| Fig.9. 14 – SPES3-147 and IRIS HT6_rwstc DW to PSS mass flow (window).....                 | 326 |
| Fig.9. 15 – SPES3-147 and IRIS HT6_rwstc PSS to DW integral flow (window) .....            | 327 |
| Fig.9. 16 – SPES3-147 and IRIS HT6_rwstc PSS level (window) .....                          | 327 |
| Fig.9. 17 – SPES3-147 and IRIS HT6_rwstc DW non-condensable gas quality (window).....      | 328 |
| Fig.9. 18 – SPES3-147 and IRIS HT6_rwstc DW non-condensable gas quality .....              | 328 |
| Fig.9. 19 – SPES3-147 and IRIS HT6_rwstc PSS pressure (window).....                        | 329 |
| Fig.9. 20 – SPES3-147 and IRIS HT6_rwstc PSS pressure .....                                | 329 |
| Fig.9. 21 – SPES3-147 and IRIS HT6_rwstc LGMS pressure (window).....                       | 330 |



|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Fig.9. 22 – SPES3-147 and IRIS HT6_rwstc LGMS pressure .....                                      | 330 |
| Fig.9. 23 – SPES3-147 and IRIS HT6_rwstc DW and PSS pressure (window).....                        | 331 |
| Fig.9. 24 – SPES3-147 and IRIS HT6_rwstc DW and PSS pressure .....                                | 331 |
| Fig.9. 25 – SPES3-147 and IRIS HT6_rwstc PSS to DW pipe level .....                               | 332 |
| Fig.9. 26 – SPES3-147 and IRIS HT6_rwstc RC level (window) .....                                  | 332 |
| Fig.9. 27 – SPES3-147 and IRIS HT6_rwstc DW level .....                                           | 333 |
| Fig.9. 28 – SPES3-147 and IRIS HT6_rwstc PSS liquid and gas temperature (window).....             | 333 |
| Fig.9. 29 – SPES3-147 and IRIS HT6_rwstc PSS liquid and gas temperature .....                     | 334 |
| Fig.9. 30 – SPES3-147 and IRIS HT6_rwstc DW to PSS integral flow (first phase of injection) ..... | 334 |
| Fig.9. 31 – SPES3-147 and IRIS HT6_rwstc core power (window) .....                                | 335 |
| Fig.9. 32 – SPES3-147 and IRIS HT6_rwstc core power.....                                          | 335 |
| Fig.9. 33 – SPES3-147 and IRIS HT6_rwstc SG power (window).....                                   | 336 |
| Fig.9. 34 – SPES3-147 and IRIS HT6_rwstc SG power .....                                           | 336 |
| Fig.9. 35 – SPES3-147 and IRIS HT6_rwstc SG ss mass flow (window) .....                           | 337 |
| Fig.9. 36 – SPES3-147 and IRIS HT6_rwstc SG ss mass flow .....                                    | 337 |
| Fig.9. 37 – SPES3-147 and IRIS HT6_rwstc EHRS cold leg mass flow (window) .....                   | 338 |
| Fig.9. 38 – SPES3-147 and IRIS HT6_rwstc EHRS cold leg mass flow.....                             | 338 |
| Fig.9. 39 – SPES3-147 and IRIS HT6_rwstc EHRS power (window) .....                                | 339 |
| Fig.9. 40 – SPES3-147 and IRIS HT6_rwstc EHRS power.....                                          | 339 |
| Fig.9. 41 – SPES3-147 and IRIS HT6_rwstc SG ss outlet pressure (window) .....                     | 340 |
| Fig.9. 42 – SPES3-147 and IRIS HT6_rwstc SG ss outlet pressure.....                               | 340 |
| Fig.9. 43 – SPES3-147 and IRIS HT6_rwstc SG-1ss collapsed level (window) .....                    | 341 |
| Fig.9. 44 – SPES3-147 and IRIS HT6_rwstc SG-1ss collapsed level.....                              | 341 |
| Fig.9. 45 – SPES3-147 and IRIS HT6_rwstc PRZ level.....                                           | 342 |
| Fig.9. 46 – SPES3-147 and IRIS HT6_rwstc DVI break SPLIT integral flow .....                      | 342 |
| Fig.9. 47 – SPES3-147 and IRIS HT6_rwstc pump inlet liquid fraction .....                         | 343 |
| Fig.9. 48 – SPES3-147 and IRIS HT6_rwstc core outlet flow (window).....                           | 343 |
| Fig.9. 49 – SPES3-147 and IRIS HT6_rwstc core outlet flow .....                                   | 344 |
| Fig.9. 50 – SPES3-147 and IRIS HT6_rwstc RI-DC check valve mass flow (window).....                | 344 |
| Fig.9. 51 – SPES3-147 and IRIS HT6_rwstc RI-DC check valve mass flow .....                        | 345 |
| Fig.9. 52 – SPES3-147 and IRIS HT6_rwstc core liquid void fraction (window).....                  | 345 |
| Fig.9. 53 – SPES3-147 and IRIS HT6_rwstc core liquid void fraction .....                          | 346 |
| Fig.9. 54 – SPES3-147 and IRIS HT6_rwstc ADS Stage-I integral flow (window) .....                 | 346 |
| Fig.9. 55 – SPES3-147 and IRIS HT6_rwstc ADS Stage-I integral flow .....                          | 347 |
| Fig.9. 56 – SPES3-147 and IRIS HT6_rwstc RV mass.....                                             | 347 |
| Fig.9. 57 – SPES3-147 and IRIS HT6_rwstc EBT injection mass flow (window).....                    | 348 |
| Fig.9. 58 – SPES3-147 and IRIS HT6_rwstc EBT injection mass flow etichetta figura .....           | 348 |
| Fig.9. 59 – SPES3-147 and IRIS HT6_rwstc EBT balance line to RV mass flow (window) .....          | 349 |
| Fig.9. 60 – SPES3-147 and IRIS HT6_rwstc EBT level (window) .....                                 | 349 |
| Fig.9. 61 – SPES3-147 and IRIS HT6_rwstc EBT level .....                                          | 350 |
| Fig.9. 62 – SPES3-147 and IRIS HT6_rwstc DVI mass flow (window).....                              | 350 |
| Fig.9. 63 – SPES3-147 and IRIS HT6_rwstc DVI mass flow .....                                      | 351 |

|                                                                                                   |     |
|---------------------------------------------------------------------------------------------------|-----|
| Fig.9. 64 – SPES3-147 and IRIS HT6_rwstc Core inlet and outlet temperatures (window) .....        | 351 |
| Fig.9. 65 – SPES3-147 and IRIS HT6_rwstc Core inlet and outlet temperatures.....                  | 352 |
| Fig.9. 66 – SPES3-147 and IRIS HT6_rwstc Core heater rod outer surface temperature (window) ..... | 352 |
| Fig.9. 67 – SPES3-147 and IRIS HT6_rwstc Core heater rod outer surface temperature .....          | 353 |
| Fig.9. 68 – SPES3-147 and IRIS HT6_rwstc LGMS injection mass flow (window) .....                  | 353 |
| Fig.9. 69 – SPES3-147 and IRIS HT6_rwstc LGMS mass (window) .....                                 | 354 |
| Fig.9. 70 – SPES3-147 and IRIS HT6_rwstc LGMS and DVI pressure (window).....                      | 354 |
| Fig.9. 71 – SPES3-147 and IRIS HT6_rwstc LGMS and DVI pressure .....                              | 355 |
| Fig.9. 72 – SPES3-147 and IRIS HT6_rwstc RC to DVI mass flow (window).....                        | 355 |
| Fig.9. 73 – SPES3-147 and IRIS HT6_rwstc RC to DVI mass flow .....                                | 356 |
| Fig.9. 74 – SPES3-147 and IRIS HT6_rwstc RC to DVI integral mass flow .....                       | 356 |
| Fig.9. 75 – SPES3-147 and IRIS HT6_rwstc QT level .....                                           | 357 |
| Fig.9. 76 – SPES3-147 and IRIS HT6_rwstc ADS Stage-II mass flow (window).....                     | 357 |
| Fig.9. 77 – SPES3-147 and IRIS HT6_rwstc ADS Stage-II mass flow .....                             | 358 |
| Fig.9. 78 – SPES3-147 and IRIS HT6_rwstc RWST temperature .....                                   | 358 |
| Fig.9. 79 – SPES3-147 and IRIS HT6_rwstc RWST mass .....                                          | 359 |
| Fig.9. 80 – SPES3-147 and IRIS HT6_rwstc RWST pressure.....                                       | 359 |
| Fig.9. 81 – SPES3-147 and IRIS HT6_rwstc RWST top mass flow.....                                  | 360 |
| Fig.9. 82 – SPES3-147 and IRIS HT6_rwstc RWST top integral mass flow.....                         | 360 |
| Fig.9. 83 – SPES3-147 and IRIS HT6_rwstc RWST power (window) .....                                | 361 |
| Fig.9. 84 – SPES3-147 and IRIS HT6_rwstc RWST power .....                                         | 361 |
| Fig.9. 85 – SPES3-147 and IRIS HT6_rwstc DW power (window) .....                                  | 362 |
| Fig.9. 86 – SPES3-147 and IRIS HT6_rwstc DW power.....                                            | 362 |
| Fig.9. 87 – SPES3-147 and IRIS HT6_rwstc DW inner and outer wall temperature (window).....        | 363 |
| Fig.9. 88 – SPES3-147 and IRIS HT6_rwstc DW inner and outer wall temperature .....                | 363 |
| Fig.9. 89 – SPES3-147 and IRIS HT6_rwstc T (PRZ) – T (SG).....                                    | 364 |
| Fig.9. 90 – SPES3-147 and IRIS HT6_rwstc SG global heat transfer coefficient.....                 | 364 |
| Fig.9. 91 – SPES3-147 and IRIS HT6_rwstc T (EHRS) – T (RWST) .....                                | 365 |
| Fig.9. 92 – SPES3-147 and IRIS HT6_rwstc EHRS global heat transfer coefficient .....              | 365 |
| Fig.9. 93 – SPES3-147 and IRIS HT6_rwstc T (PRZ) – T (RWST) .....                                 | 366 |
| Fig.9. 94 – SPES3-147 and IRIS HT6_rwstc PRZ-RWST global heat transfer coefficient.....           | 366 |



### III. NOMENCLATURE

|          |                                                                            |
|----------|----------------------------------------------------------------------------|
| ADS      | Automatic Depressurization System                                          |
| ADS-DT   | ADS-Double Train                                                           |
| ADS-ST   | ADS-Single Train                                                           |
| BAF      | Bottom of Active Fuel                                                      |
| Bot, bot | Bottom                                                                     |
| BC       | Base Case                                                                  |
| CIRTEN   | Consorzio Interuniversitario Nazionale per la Ricerca Tecnologica Nucleare |
| CRDM     | Control Rod Drive Mechanism                                                |
| CV       | Containment Volume                                                         |
| D        | Diameter                                                                   |
| Di       | inner diameter                                                             |
| d        | diameter                                                                   |
| DC       | Downcomer                                                                  |
| DEG      | Double Ended Guillotine                                                    |
| DP       | Differential pressure                                                      |
| DT       | Difference of temperature                                                  |
| DTh      | Heat transfer Diameter (RELAP5 parameter)                                  |
| DVI      | Direct Vessel Injection                                                    |
| DW       | Dry Well                                                                   |
| EBT      | Emergency Boration Tank                                                    |
| EHRS     | Emergency Heat Removal System                                              |
| FER      | University of Zagreb                                                       |
| FF       | Fouling Factor (RELAP5 parameter)                                          |
| FL       | Feed Line                                                                  |
| FW       | Feed Water                                                                 |
| GOTHIC   | Generation Of Thermal-Hydraulic Information for Containments               |
| HX       | Heat Exchanger                                                             |
| IRIS     | International Reactor Innovative and Secure                                |
| LGMS     | Long Term Gravity Make-up System                                           |
| LM       | LOCA Mitigation signal                                                     |
| LOCA     | Loss of Coolant Accident                                                   |
| mid      | middle                                                                     |
| MFIV     | Main Feed Isoaltion Valve                                                  |
| MSIV     | Main Steam Isolation Valve                                                 |
| n.a.     | Not available                                                              |
| NPP      | Nuclear Power Plant                                                        |
| NRC      | Nuclear Regulatory Commission                                              |
| P        | Pressure                                                                   |

|       |                                                         |
|-------|---------------------------------------------------------|
| PCC   | Passive Containment Cooling                             |
| PRZ   | Pressurizer                                             |
| PSS   | Pressure Suppression System                             |
| PWR   | Pressurized Water Reactor                               |
| QT    | Quench Tank                                             |
| RC    | Reactor Cavity                                          |
| RC    | Concentric reduction (in the geometrical detail tables) |
| RCCA  | Rod Cluster Control Assembly                            |
| RELAP | REactor Loss of coolant Analysis Program                |
| RI    | Riser                                                   |
| R&D   | Research and Development                                |
| RPV   | Reactor Pressure Vessel                                 |
| RV    | Reactor Vessel                                          |
| RWST  | Refuelling Water Storage Tank                           |
| S     | Safeguard signal                                        |
| SC    | Sensitivity case                                        |
| SG    | Steam Generator                                         |
| SIET  | Società Informazioni Esperienze Termoidrauliche         |
| SL    | Steam Line                                              |
| SPES  | Simulatore Per Esperienze di Sicurezza                  |
| T     | Temperature                                             |
| TAF   | Top of Active Fuel                                      |
| WEC   | Westinghouse Electric Company                           |

## 1. SCOPE

The primary goal of this document is to describe the results of sensitivity calculations on the SPES3-IRIS facility containment system for reviewing the facility design to match the IRIS plant calculation results.

The direct comparison of the IRIS plant and the SPES3 facility main variables (facility model based on the conceptual design with the updates of the final design geometrical data) put in evidence that the largest source of discrepancies derived from the different pressure response of the containment systems during the same LOCA transient.

This led to investigate possible SPES3 containment and EHRS modifications and the RELAP5 Mod. 3.3 code was run for different cases. The DVI DEG break transient was investigated for different containment configurations and the results compared among them and with the IRIS plant case.

The comparisons provided information on the required modifications to the facility design and gave indications on some operating procedures to be adopted to reach an adequate steady-state to start the transient from.

## 2. INTRODUCTION

The SPES3-IRIS facility (1:100 volume scale and 1:1 height scale) is being designed at SIET laboratories to simulate the IRIS, an integral, modular, medium size PWR, belonging to the Innovative Nuclear Power Plants, under development by an international consortium led by Westinghouse, [1] [2].

The RELAP5 thermal-hydraulic code [3] was chosen to simulate the whole SPES3 facility: primary, secondary and containment systems and a complete nodalization of SPES3 was developed, based on the conceptual design of the facility and on the successive design updates as reported in [2] [4].

Qualified steady state conditions were reached, based on the actual IRIS nominal conditions, and five base case transients were studied with large attention to the occurring phenomena and sequence of events [5]. In particular, three SB-LOCAs and two secondary side breaks were simulated, according to what specified in the test matrix [1].

Moreover, WEC and CIRTEN performed a preliminary scaling analysis on the DVI DEG break transient that evidenced important differences on the containment pressure, especially in the early phases of the accident and at the pressure peak value [6] [7]. This led to perform two additional sensitivity cases that investigated the possibility of thermally insulate the Dry-Well on the inner side in order to correctly simulate the heat losses to the environment [8].

Once investigated the phenomena occurring in the five base cases, the attention was focused on the DVI DEG break for a direct comparison of the RELAP5 SPES3 results with the IRIS plant simulation obtained by the RELAP5 and GOTHIC coupled codes. Such comparison led to perform a series of sensitivity cases on the containment to better understand the reason of the differences and take the SPES3 response closer to the IRIS one.

This work, described in detail in this document, is part of the SPES3 facility design review that has lead to modify the facility nodalization and to update and improve the SPES3 final design with respect to what reported in [4] [9] [10] [11].

### 3. SPES3 AND IRIS MODELS

This section reports the schemes of the SPES3 facility and the RELAP5 nodalizations utilized in the cases described in the following chapters. The IRIS schemes and nodalizations for RELAP5 and GOTHIC codes are reported too and they are summarized in

Tab.3. 1.

#### 3.1 SPES3 schemes and RELAP5 nodalization evolution

The general view of SPES3 is reported in Fig.3. 1, while the SPES3 flow diagrams are reported in Fig.3. 2 and Fig.3. 3 for the primary and secondary loops (Loop A equal to Loop B).

The details of the SPES3 base nodalizations are reported in [4] together with the scheme of all components. This chapter reports the modifications to the model consequent to the component and piping updates as described in the following chapters.

Fig.3. 4, Fig.3. 5, Fig.3. 6, Fig.3. 7 report the SPES3 RELAP5 nodalization for case SPES3-97 (based on achievements reported in [5]), starting point of the sensitivity analyses necessary to review the SPES3 design and to reduce the differences between SPES3 and IRIS behavior.

Fig.3. 8 and Fig.3. 9 report the SPES3 RELAP5 nodalization for cases SPES3-124 and SPES3-127 with the modification of the PSS to DW vent pipes, extensions and connections to DW and the PSS bottom re-modeling.

Fig.3. 10 and Fig.3. 11 report the SPES3 RELAP5 nodalization for cases SPES3-130, SPES3-146 and SPES3-147 with the modification of the RWST top discharge system and EHRS loop piping.

#### 3.2 IRIS RELAP5 and GOTHIC nodalization evolution

The general view of IRIS Reactor vessel and Containment System are reported in Fig.3. 12 and Fig.3. 13, while the IRIS Engineered Safety Feature scheme is reported in Fig.3. 14.

The details of the IRIS base nodalizations are reported in [12]. This chapter summarizes the main modifications to the model consequent to the comparison with the SPES3 results. The details of the modifications are reported in [13].

Fig.3. 15 and Fig.3. 16 report the IRIS RELAP5 and GOTHIC nodalization for case HT1, starting point of the comparison with SPES3 results.

Fig.3. 17 and Fig.3. 18 report the IRIS GOTHIC and RELAP5 nodalization for case HT5g, with the modification of the PSS to DW vent pipes connections to DW and RWST remodeling.

Fig.3. 19 reports the IRIS RELAP5 nodalization for cases HT6\_rwstc with the modification of EHRS and RWST remodeling.

**Tab.3. 1 - Summary of SPES3 and IRIS nodalizations evolution**

| <b>SPES3 nodalization</b> | <b>Characteristics</b>                                                                       |
|---------------------------|----------------------------------------------------------------------------------------------|
| SPES3-97                  | Starting point for the sensitivity analyses                                                  |
| SPES3-124                 | Modification to the PSS to DW main vent pipes and vent extensions.<br>PSS bottom re-modeling |
| SPES3-127                 | PSS bottom re-modeling                                                                       |
| SPES3-130                 | Modification to RWST top discharge system                                                    |
| SPES3-146                 | Modification to EHRS loop piping                                                             |
| SPES3-147                 | Modification to EHRS loop piping (as in SPES3-146) but 13 SG tubes per row                   |

| <b>IRIS nodalization</b> | <b>Characteristics</b>                                                               |
|--------------------------|--------------------------------------------------------------------------------------|
| IRIS-HT1                 | Starting point for the comparison with SPES3                                         |
| IRIS-HT5g                | Modificatio to the PSS to DW vent pipe extension connection to DW<br>RWST remodeling |
| IRIS-HT6_rwst            | EHRS and RWST remodeling                                                             |



**Fig.3. 1 – SPES3 general view**

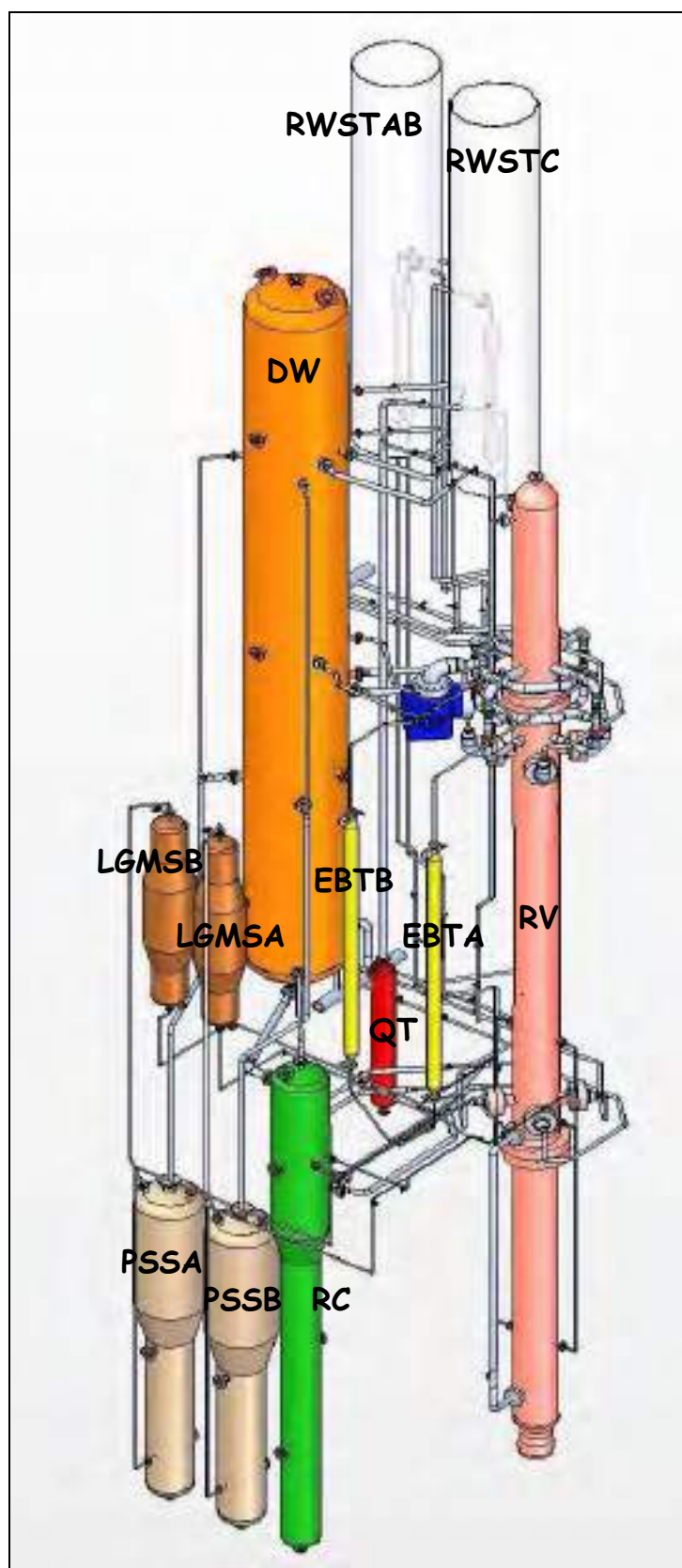
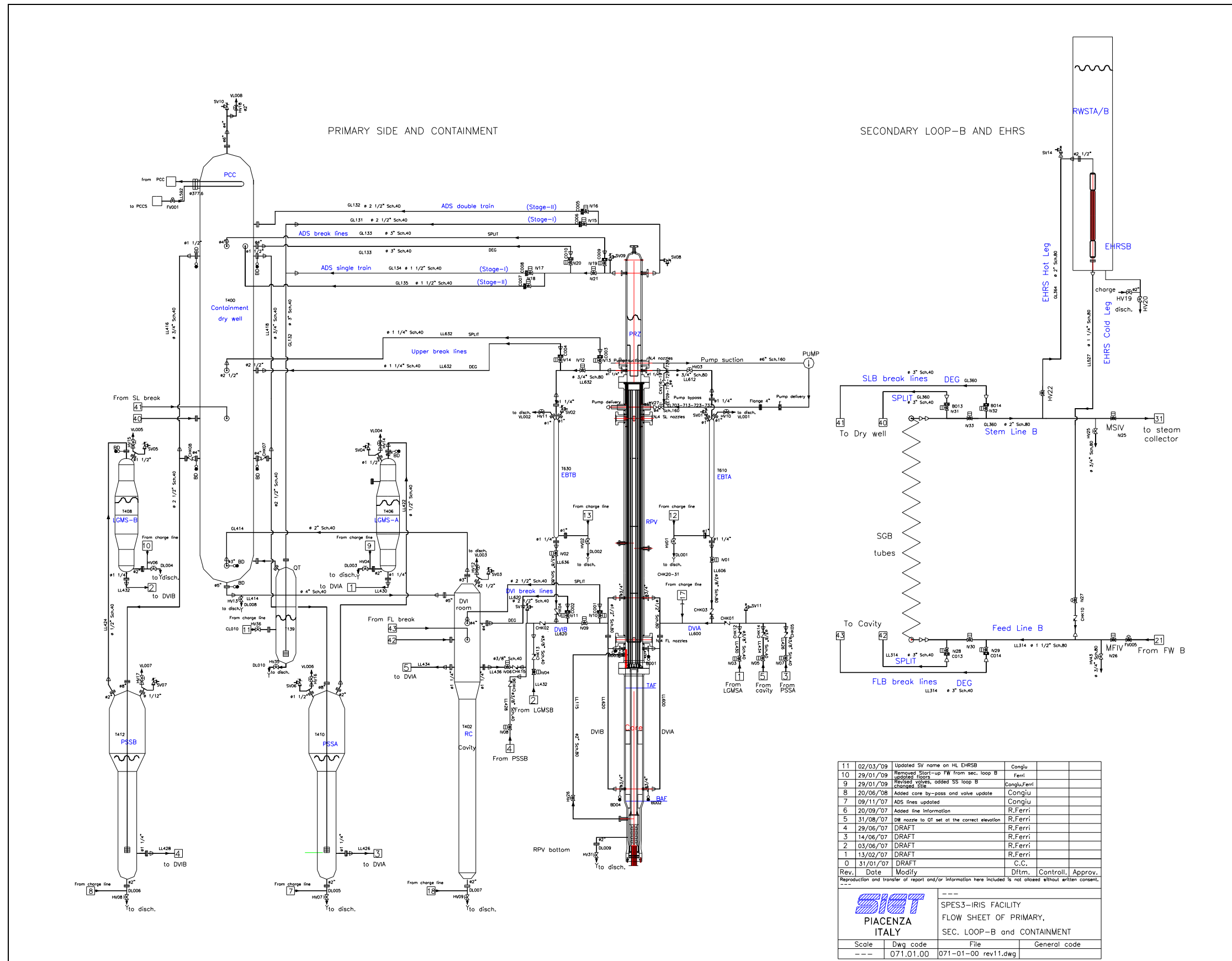


Fig.3. 2 – SPES3 primary, secondary loop B, and containment system layout



**Fig.3. 3 – SPES3 secondary system A and C layout**

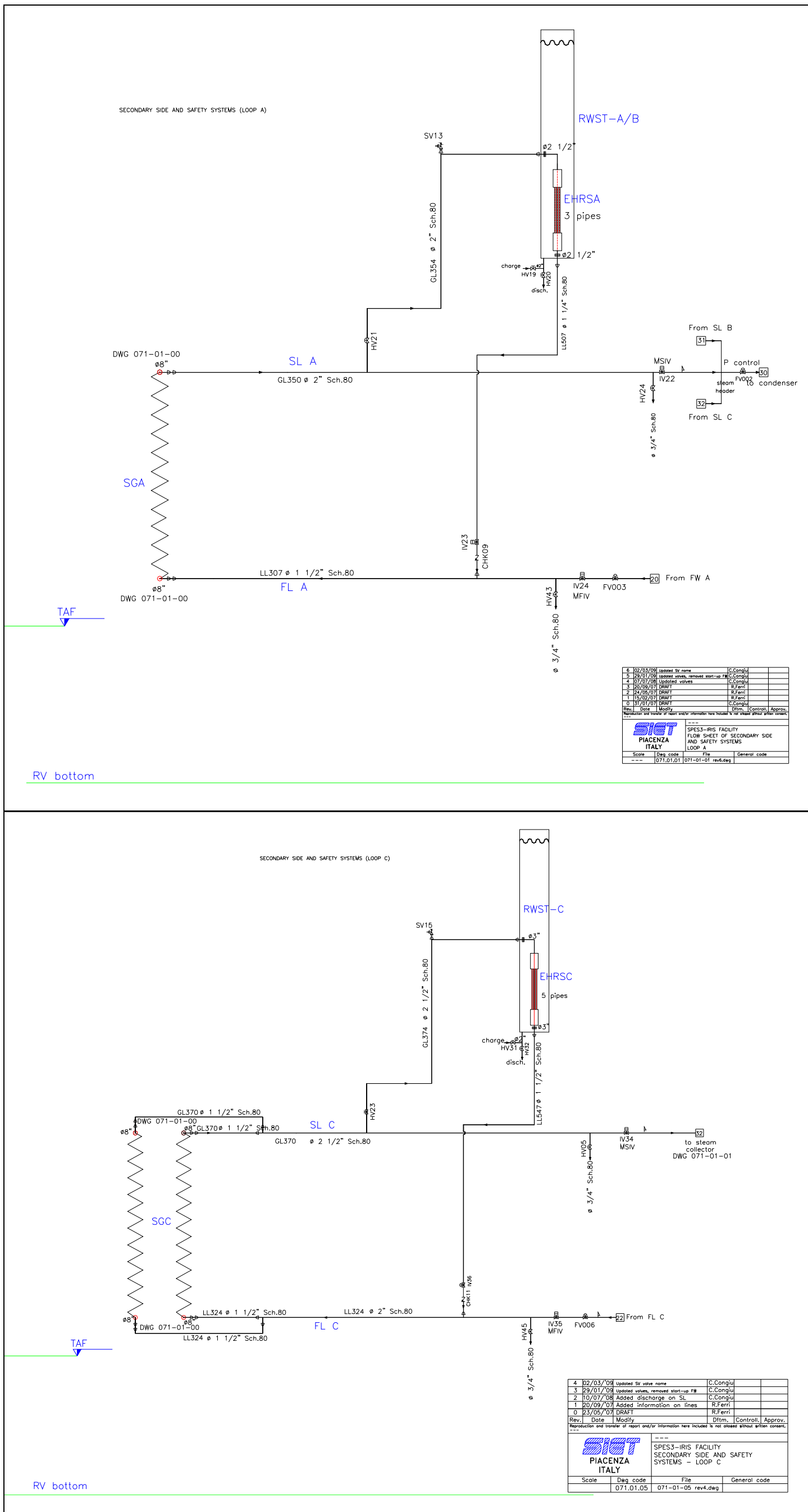


Fig.3. 4 – SPES3 Primary System RELAP5 nodalization for case SPES3-97

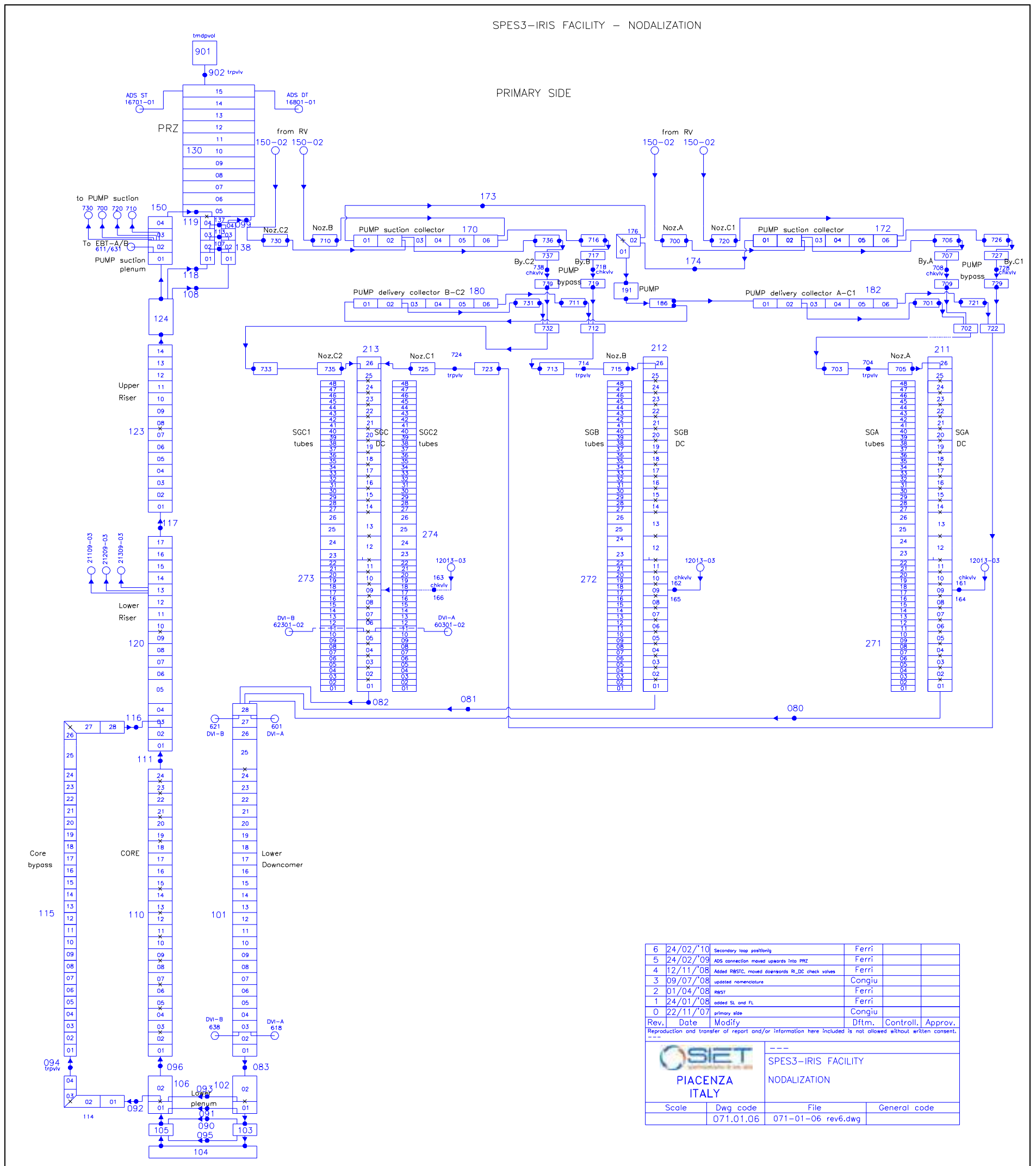


Fig.3. 5 – SPES3 Secondary System-A and B and related EHRS RELAP5 nodalization for case SPES3-97

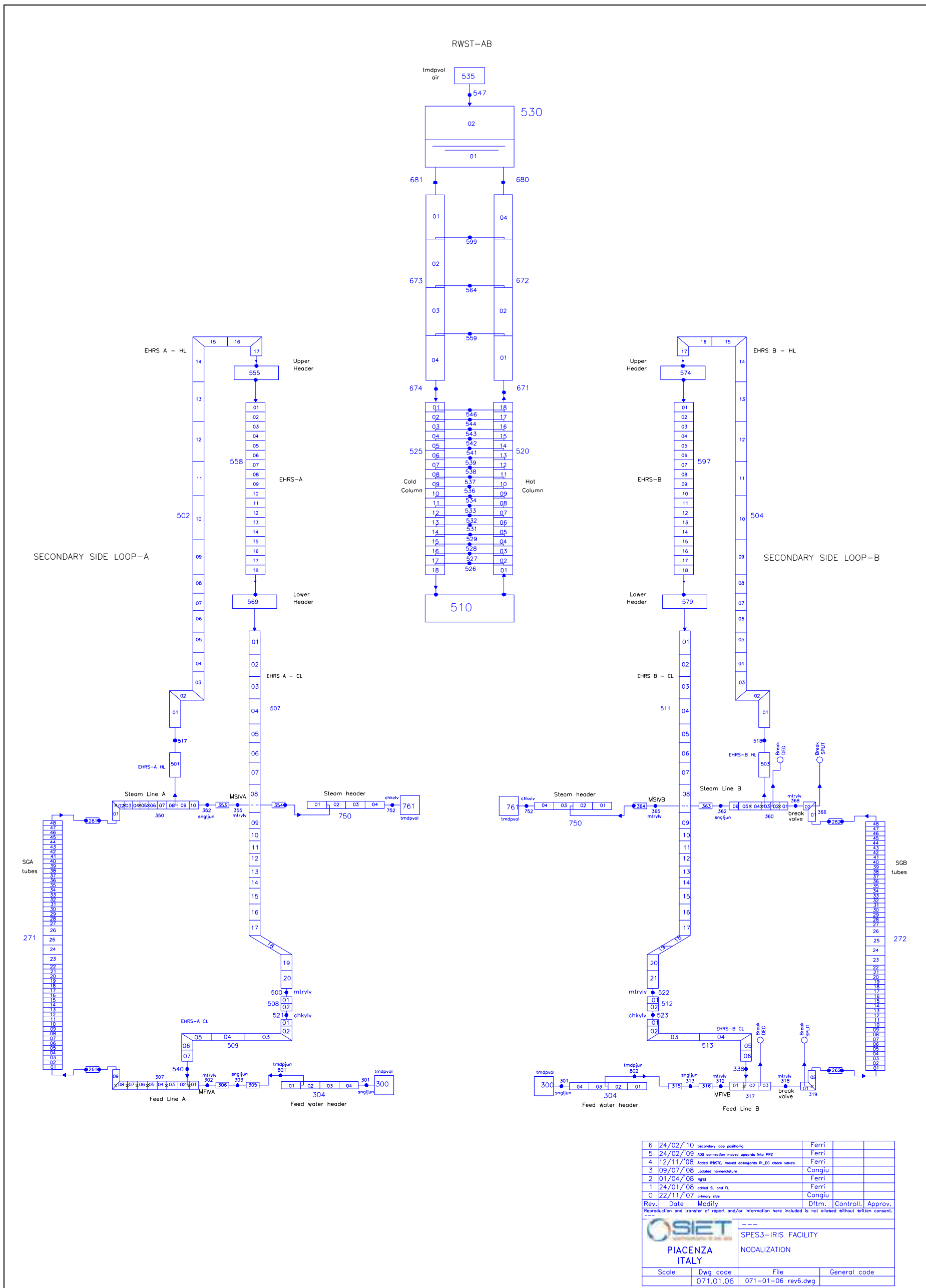
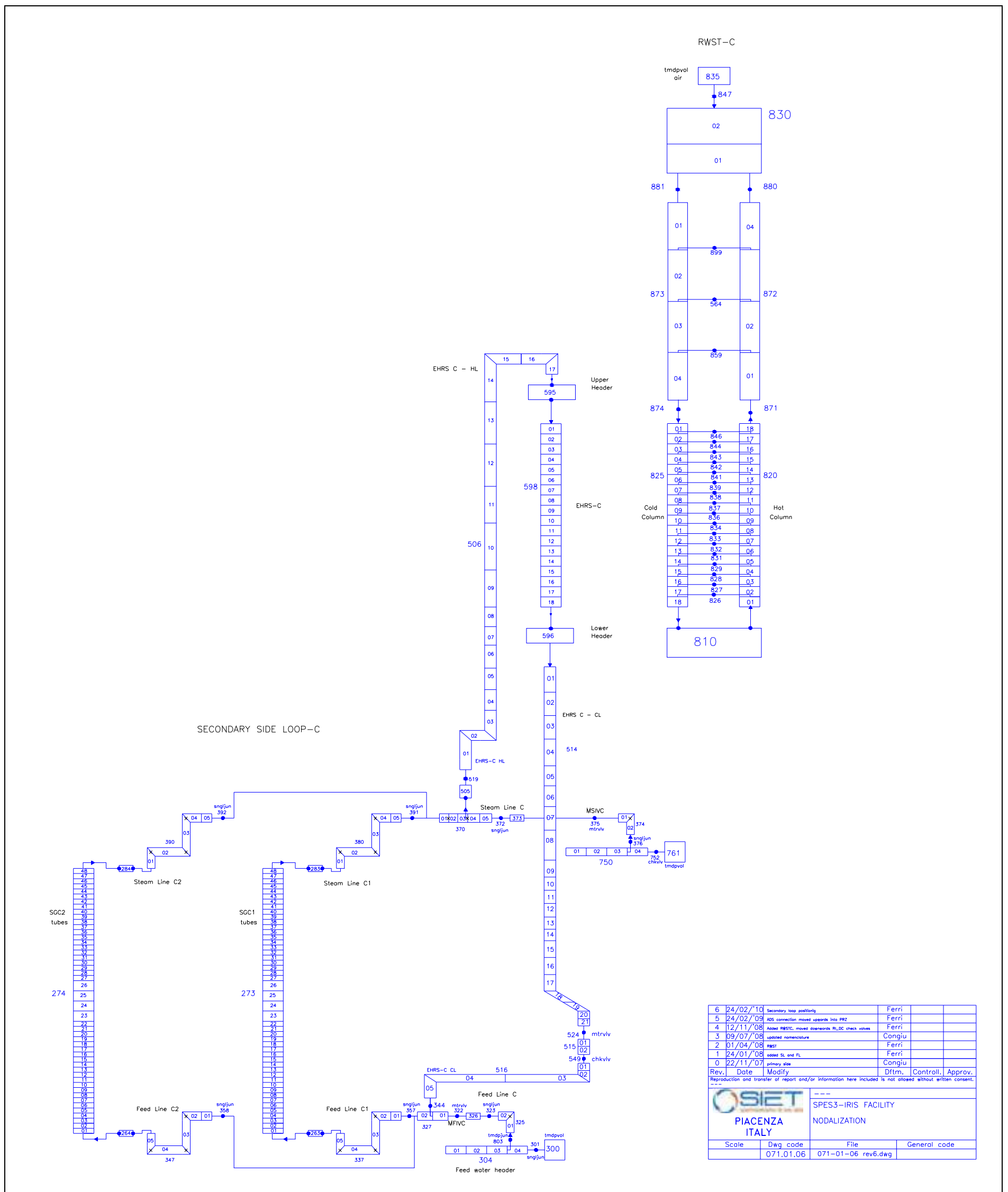


Fig.3. 6 – SPES3 Secondary System-C and related EHRS RELAP5 nodalization for case SPES3-97



|                                                                                                              |           |                                                 |                                            |          |         |
|--------------------------------------------------------------------------------------------------------------|-----------|-------------------------------------------------|--------------------------------------------|----------|---------|
| 6                                                                                                            | 24/02/10  | Secondary loop positioning                      | Ferri                                      |          |         |
| 5                                                                                                            | 24/02/09  | ASIS correction moved upwards into PREZ         | Ferri                                      |          |         |
| 4                                                                                                            | 12/11/08  | Added PREZIC, moved downwards RLDC check valves | Ferri                                      |          |         |
| 3                                                                                                            | 09/07/08  | Updated nomenclature                            | Congiu                                     |          |         |
| 2                                                                                                            | 01/04/08  | PREZ                                            | Ferri                                      |          |         |
| 1                                                                                                            | 24/01/08  | added SL and FL                                 | Ferri                                      |          |         |
| 0                                                                                                            | 22/11/07  | primary side                                    | Congiu                                     |          |         |
| Rev.                                                                                                         | Date      | Modify                                          | Dftm.                                      | Control. | Approv. |
| Reproduction and transfer of report and/or information here included is not allowed without written consent. |           |                                                 |                                            |          |         |
| <br>PIACENZA<br>ITALY   |           |                                                 | ---<br>SPES3-IRIS FACILITY<br>NODALIZATION |          |         |
| Scale                                                                                                        | Dwg code  | File                                            | General code                               |          |         |
|                                                                                                              | 071.01.06 | 071-01-06 rev6.dwg                              |                                            |          |         |



**Fig.3. 7 – SPES3 Containment System RELAP5 nodalization for case SPES3-97**

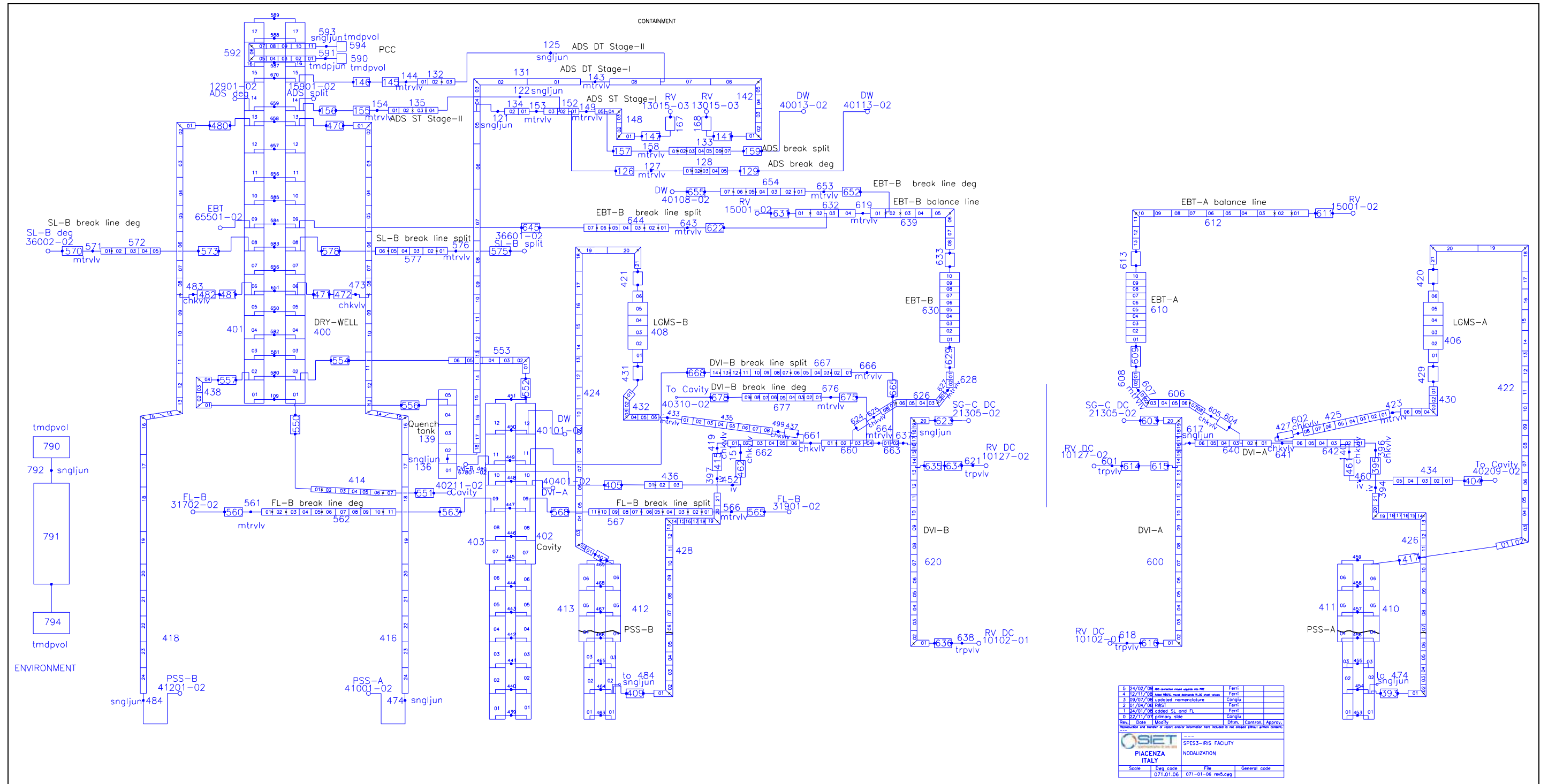




Fig.3. 8 – SPES3 Containment System RELAP5 nodalization for case SPES3-124 (PSS to DW vent pipes and PSS bottom)

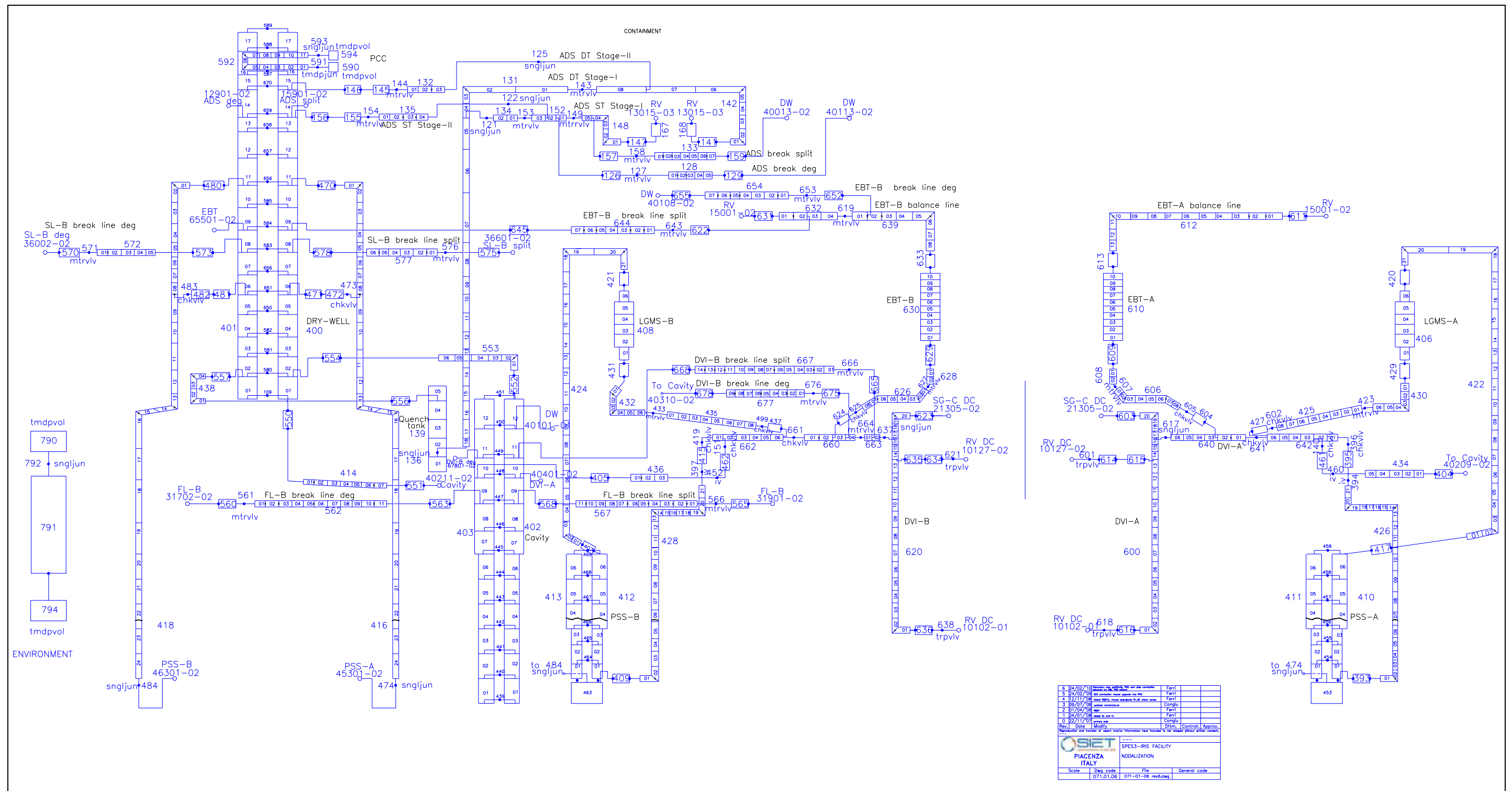


Diagram illustrating the SPES3-IRIS Facility Nodalization, showing the layout of the facility, including the Containment, Environment, and DVI-A/B sections. The diagram details various components, break lines, and flow paths, including ADS DT Stage-I, ADS ST Stage-I, ADS break split, ADS break deg, EBT-B break line deg, EBT-B balance line, EBT-B, EBT-A, LGMS-B, LGMS-A, DVI-B break line split, DVI-B break line deg, DVI-A, DVI-B, PSS-B, PSS-A, and various break lines (SL-B, FL-B).

Legend:

| Rev. | Date     | Modify     | Drawn      | Checked    | Approved   |
|------|----------|------------|------------|------------|------------|
| 1    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 2    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 3    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 4    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 5    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 6    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 7    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 8    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 9    | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |
| 10   | 24/02/10 | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS | SPES3-IRIS |

Scale: 0.71, 0.06 0.71-01-06 rev7.dwg

The image contains two schematic diagrams of a two-stage refrigeration system, labeled RWST-AB and RWST-C. Each diagram shows a condenser, evaporator, and intermediate flash tank with associated piping and pressure points. The left diagram (RWST-AB) has a condenser at 530, evaporator at 510, and intermediate tank at 520. The right diagram (RWST-C) has a condenser at 830, evaporator at 810, and intermediate tank at 820. Both diagrams include a 'Cold Column' and a 'Hot Column' for the intermediate stage. The diagrams are labeled with various pressure points and flow rates.

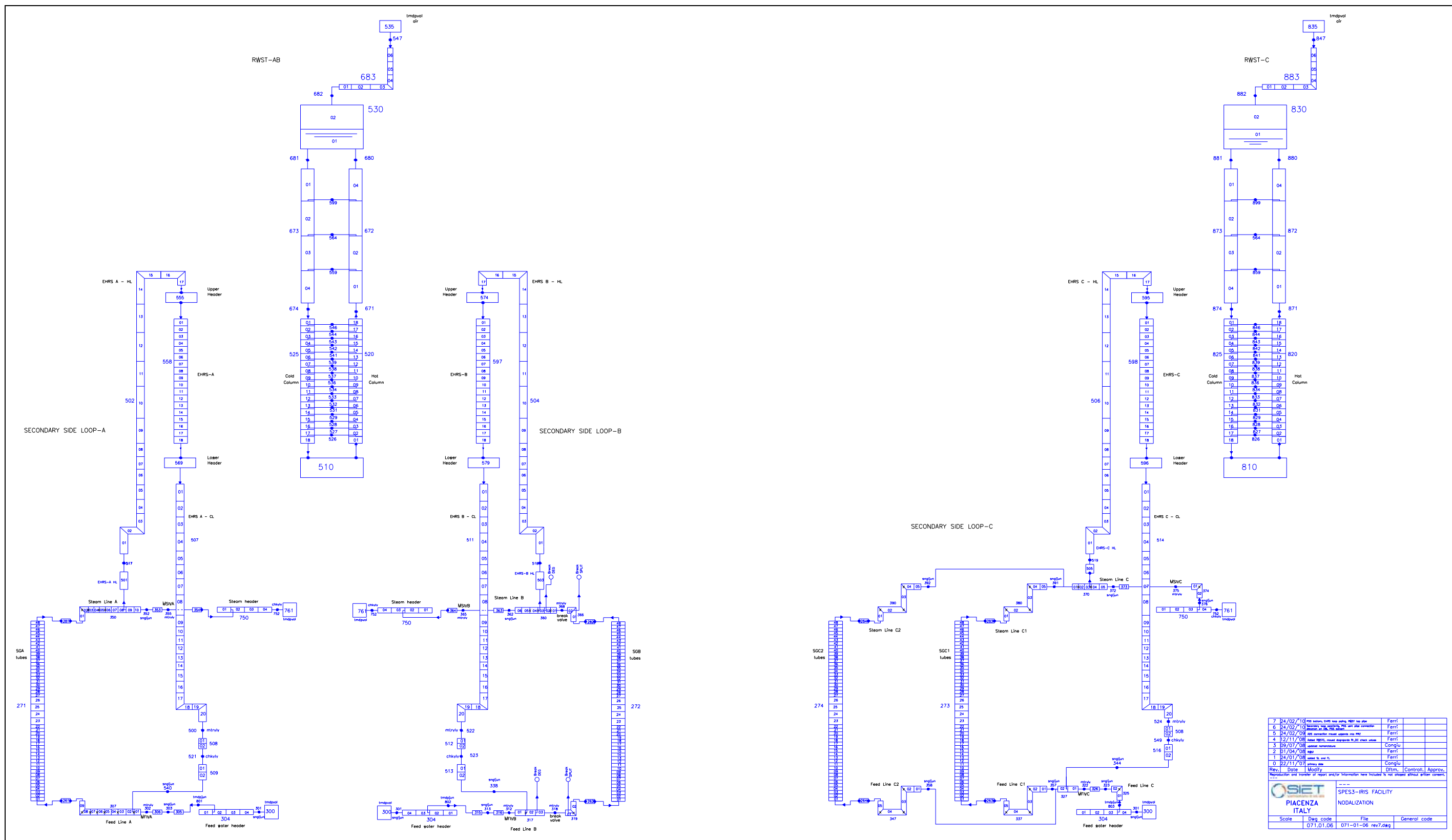
**RWST-AB Diagram:**

- Condenser:** Labeled 530. It has a top inlet at 682 and a bottom outlet at 681. The internal pressure is 02. Below the condenser is a horizontal separator with pressure 01.
- Intermediate Stage:** Consists of a 'Cold Column' and a 'Hot Column' connected by a horizontal pipe at pressure 599.
  - Cold Column:** Labeled 525. It has a top inlet at 673 and a bottom outlet at 674. The internal pressure is 03. It contains 18 horizontal trays with pressure points ranging from 546 to 526.
  - Hot Column:** Labeled 520. It has a top inlet at 672 and a bottom outlet at 671. The internal pressure is 02. It contains 18 horizontal trays with pressure points ranging from 542 to 501.
- Evaporator:** Labeled 510. It has a top inlet at 674 and a bottom outlet at 671. The internal pressure is 01.
- Pressure Points:** 683, 682, 681, 680, 673, 672, 674, 671, 547, 546, 544, 543, 542, 541, 539, 538, 537, 536, 534, 533, 532, 531, 529, 528, 527, 526.

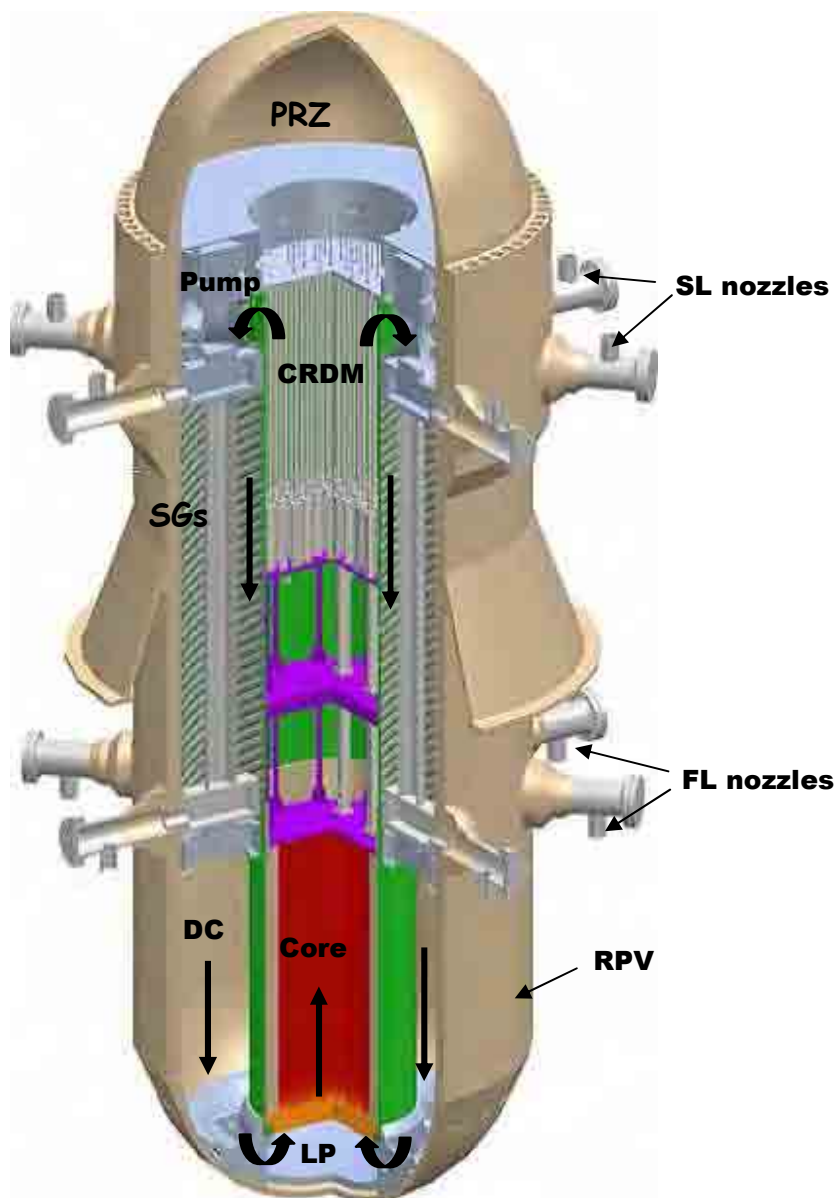
**RWST-C Diagram:**

- Condenser:** Labeled 830. It has a top inlet at 882 and a bottom outlet at 881. The internal pressure is 02. Below the condenser is a horizontal separator with pressure 01.
- Intermediate Stage:** Consists of a 'Cold Column' and a 'Hot Column' connected by a horizontal pipe at pressure 899.
  - Cold Column:** Labeled 825. It has a top inlet at 873 and a bottom outlet at 874. The internal pressure is 03. It contains 18 horizontal trays with pressure points ranging from 846 to 826.
  - Hot Column:** Labeled 820. It has a top inlet at 872 and a bottom outlet at 871. The internal pressure is 02. It contains 18 horizontal trays with pressure points ranging from 842 to 801.
- Evaporator:** Labeled 810. It has a top inlet at 874 and a bottom outlet at 871. The internal pressure is 01.
- Pressure Points:** 883, 882, 881, 880, 873, 872, 874, 871, 847, 846, 844, 843, 842, 841, 839, 838, 837, 836, 834, 833, 832, 831, 829, 828, 827, 826.

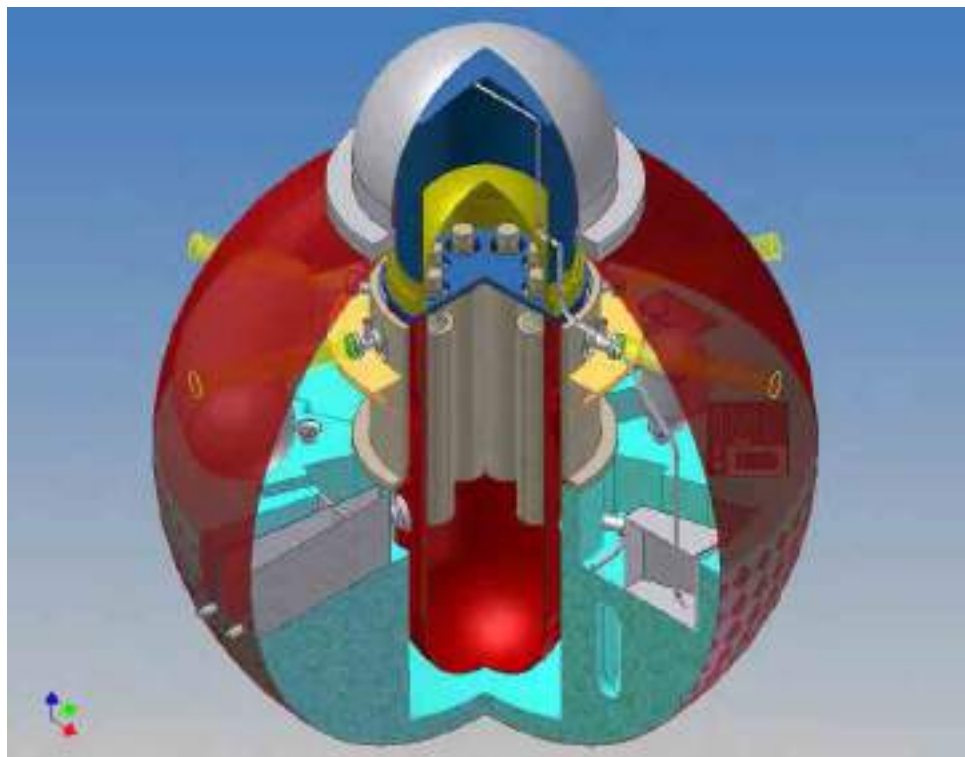
Fig.3. 11 – SPES3 Secondary System and EHRS System RELAP5 nodalization for case SPES3-146 and SPES3-147 (EHRS loop piping)



**Fig.3. 12 – IRIS Reactor Vessel general view**



**Fig.3. 13 – IRIS Containment System general view**



The diagram illustrates the Emergency Heat Removal System (EHRS) for a nuclear reactor, showing the Integral Reactor Vessel and its connections to various components. The system includes:

- Integral Reactor Vessel**: The central component, connected to the RV Cavity.
- ADS (Automatic Depressure System) Stages**: ADS-A, ADS-B, and ADS-C, connected to the vessel and the Main Vent (1 of 6).
- Main Vent (1 of 6)**: Connected to the ADS stages.
- LGMS/PSS pressure balance line (1 of 2)**: Connected to the vessel.
- LGMS Tank (1 of 2)**: Connected to the pressure balance line.
- Suppression Pool (1 of 2)**: Connected to the vessel.
- ADS Quench Tank**: Connected to the vessel.
- EBT (1 of 2)**: Connected to the vessel.
- DVI-1 (1 of 2)**: Connected to the vessel.
- Long Term Core Makeup from RV Cavity (1 of 2)**: Connected to the vessel.
- RV Cavity**: Connected to the vessel.
- RCP (1 of 8)**: Connected to the vessel.
- SG Steam Lines (2 of 8)**: Connected to the vessel.
- Steam Generator (1 of 8)**: Connected to the vessel.
- SG Feed Water Lines (2 of 8)**: Connected to the vessel.
- SG Makeup Tank (1 of 8)**: Connected to the SG Feed Water Lines.
- Main Feed Line (1 of 4) Isolation Valves**: Connected to the SG Makeup Tank.
- Main Steam Line (1 of 4) Isolation Valves**: Connected to the SG Makeup Tank.
- AUX. BLDG.**: Connected to the Main Steam Line.
- Start Up Feed Water**: Connected to the Main Feed Line.



Fig.3. 15 – IRIS Primary, Secondary and EHRS system RELAP5 nodalization for case HT1

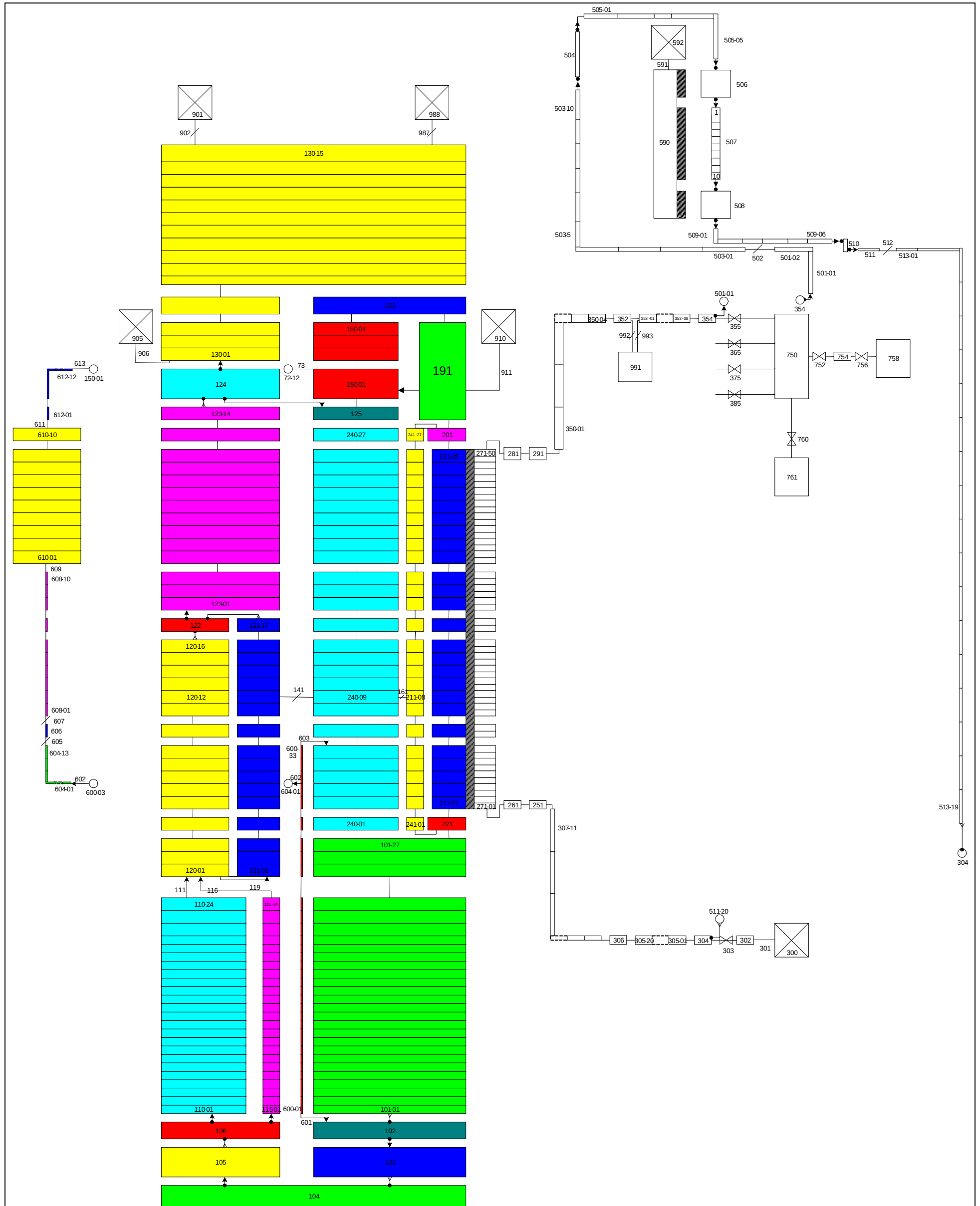


Fig.3. 16 – IRIS Containment system GOTHIC nodalization for case HT1

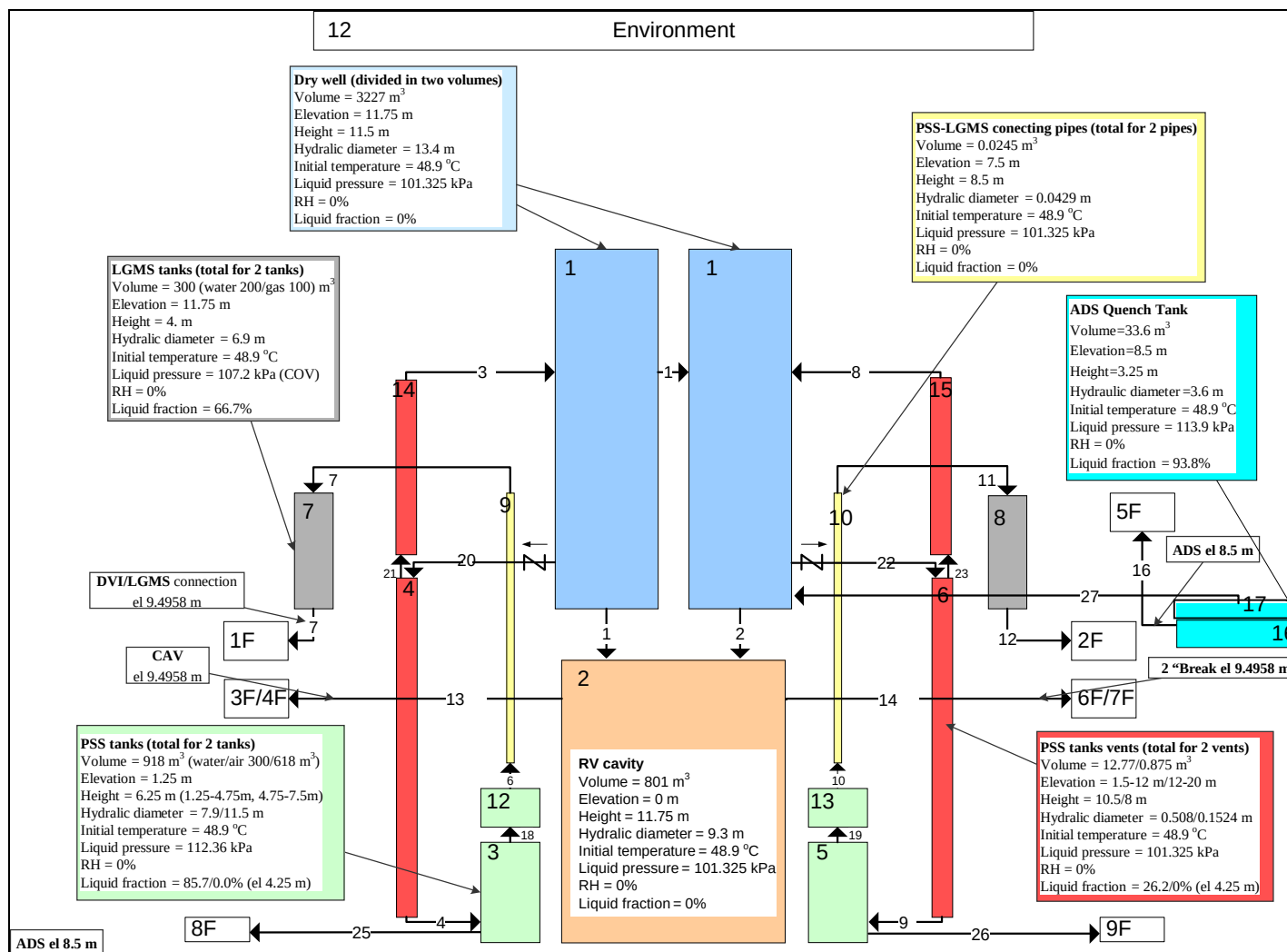
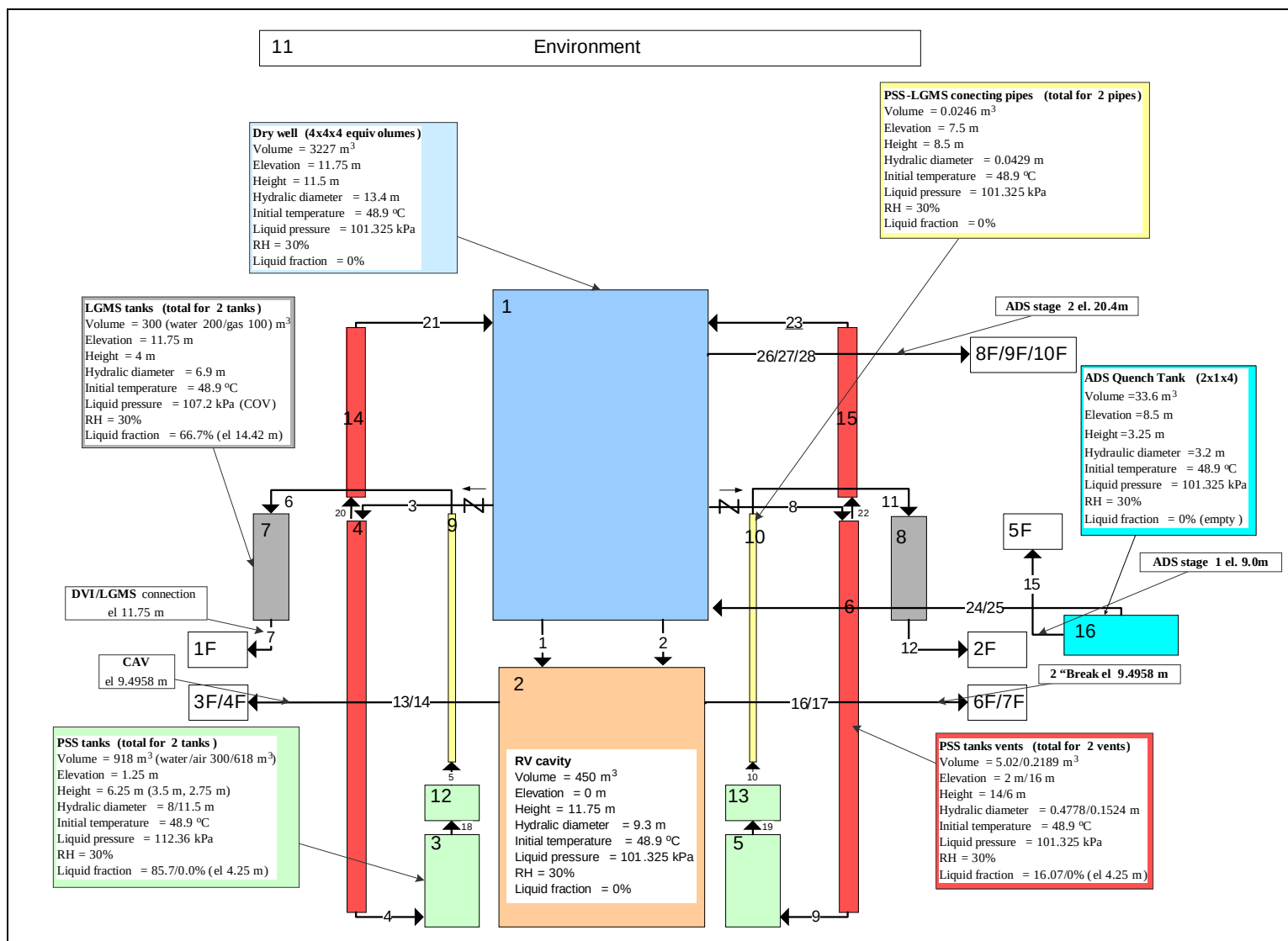
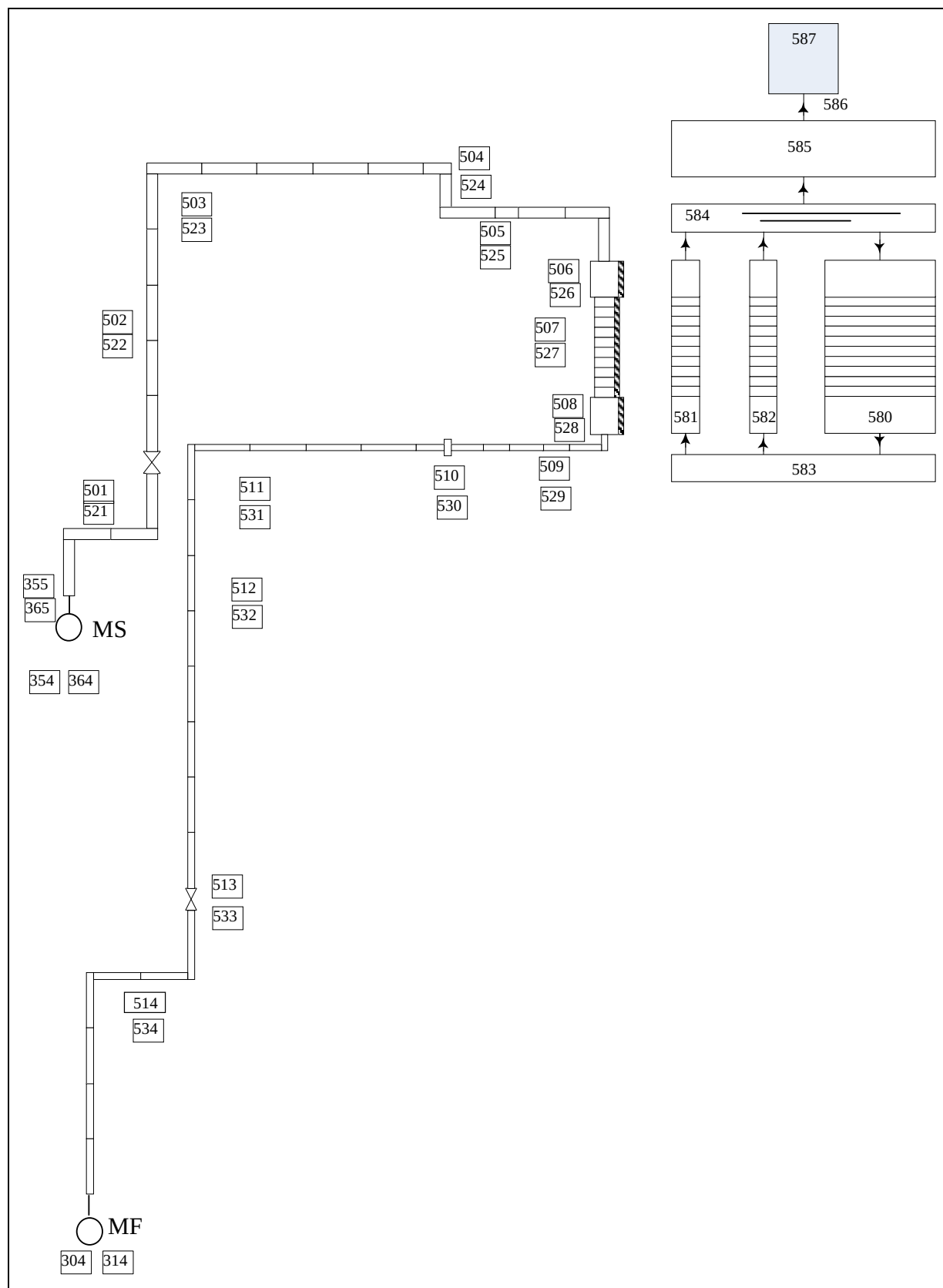


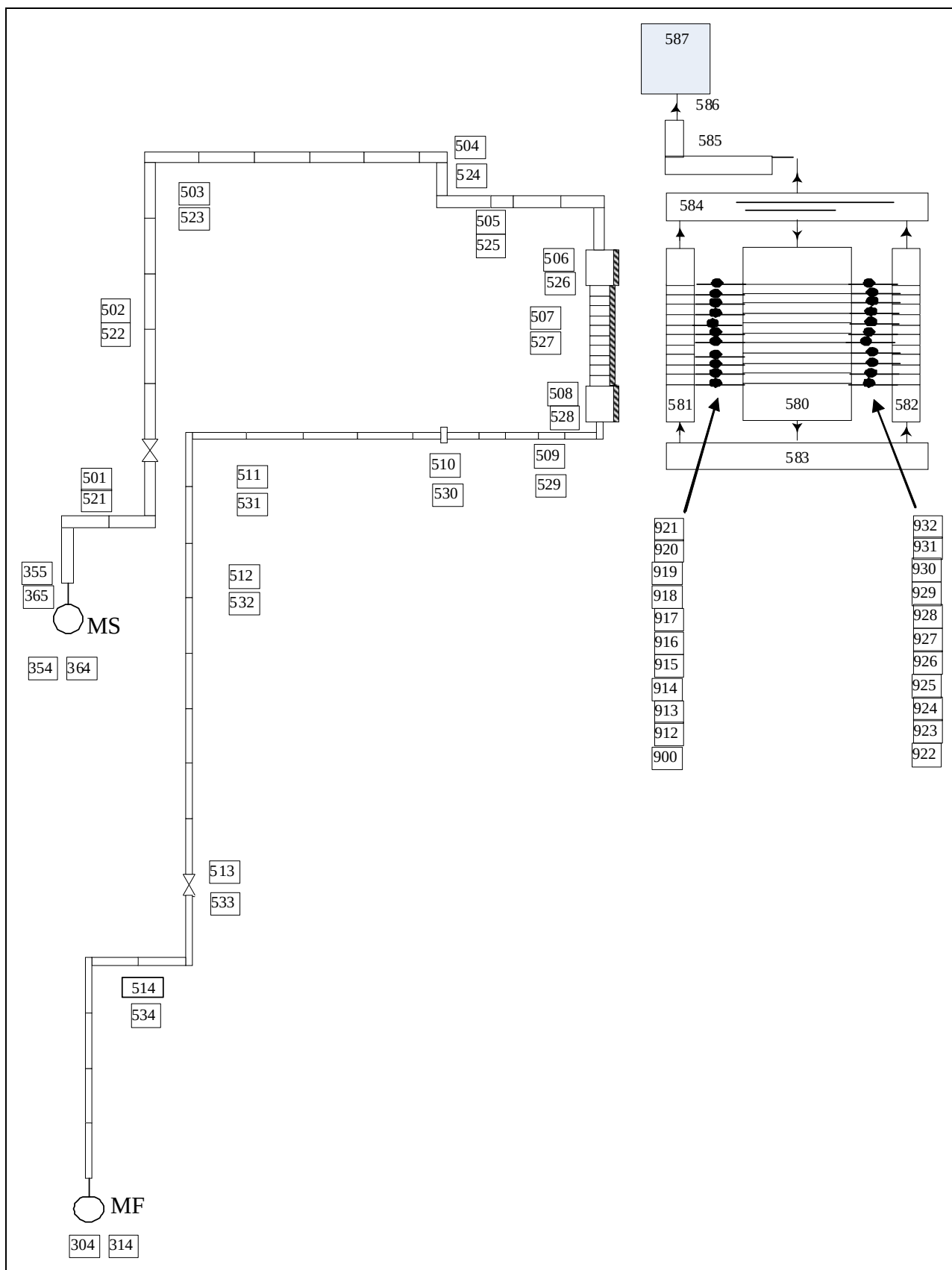
Fig.3. 17 – IRIS containment system GOTHIC model for case HT5 (PSS to DW vent pipe connection)



**Fig.3. 18 – IRIS EHRS and RWST RELAP5 nodalization for case HT5g (RWST)**



**Fig.3. 19 – IRIS EHRS and RWST RELAP5 nodalization for case HT6\_rwstc (EHRS and RWST)**



## 4. DVI DEG BREAK: BASE CASE SPES3-97 AND IRIS30H\_LB\_HT1

The 2 inch DVI DEG break is the largest lowest break that may cause a LOCA in the IRIS plant. It is a break on the liquid side of the primary circuit, above the top of the core.

The following paragraphs describe the comparison between the SPES3 and IRIS results related to the SPES3 base case SPES3-97 and the IRIS case IRIS30h\_LB\_HT1.

SPES3-97 case is an evolution of the SPES3-89 base case described in detail in [5] with some minor modifications and corrections, in particular:

- the heat transfer coefficient with the environment set at  $10 \text{ W}/(\text{m}^2\text{K})$ ;
- corrected a mistake on cntrlvar 585 (RWST-A/B power) that did not affect the results;
- corrected LGMS low mass set point in trip 070 and 071 and set to 198 kg to have 20% of  $1 \text{ m}^3$  water;
- corrected the heat structure geometry of the heater rods.

The SPES3-97 nodalization is shown in Fig.3. 4, Fig.3. 5, Fig.3. 6, Fig.3. 7.

For completeness, the main containment tank characteristics for case SPES3-97 are summarized below:

DW volume  $35.36 \text{ m}^3$  ( $D_i = 1.7 \text{ m}$ );

DW thickness 25 mm;

RC volume  $5 \text{ m}^3$  ( $D_i \text{ top} = 1.022 \text{ m}$ ;  $D_i \text{ bot} = 0.5496 \text{ m}$ );

RC thickness top 10 mm, middle 14 mm;

QT volume  $0.336 \text{ m}^3$  ( $D_i = 0.37 \text{ m}$ );

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  ( $D_i \text{ top} = 1.17 \text{ m}$ ;  $D_i \text{ bot} = 0.78 \text{ m}$ );

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  ( $D_i \text{ top and bot} = 0.57 \text{ m}$ ;  $D_i \text{ mid} = 0.855 \text{ m}$ )

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature  $48.9 \text{ }^\circ\text{C}$ .

The comparison between SPES3 and IRIS variables is performed by scaling 1:100 the IRIS variables (mass flowrate, power, mass) and directly overlapping the curves.

### 4.1 SPES3-97 and IRIS30h\_LB\_HT1

The full power steady conditions, starting point for the transient, are summarized in Tab.4. 1 for SPES3 and IRIS. The differences in the SG outlet temperature,  $4 \text{ }^\circ\text{C}$  more superheated in SPES3 than IRIS, can be justified by small differences in the SG outlet pressure, loop pressure drops, and heat transfer to metal structures.

The list of the main events occurring during the transient with timing and quantities is reported in Tab.4. 2.

#### 4.1.1 Transient phases and description

The first 10 s of SPES3 data (-10 s to 0s) are steady state conditions. The IRIS data start from the break occurrence.

All times of the events are given with respect to the break time assumed as time 0 s.

### *Break*

The break mass flow peaks and flow trends are very similar in SPES3 and IRIS during the phase of critical flow, RV side (identified as SPLIT), Fig.4.1, Fig.4.2, Fig.4.3. Later, some differences are observed mostly related to the containment pressure, lower in SPES3 than IRIS during all phases of the transient, Fig.4.4, Fig.4.5.

The mass flow containment side (identified as DEG) is related to the safety injection of EBT (starting around 180 s) and later of LGMS (starting at 2105 s in SPES3 and 1427 s in IRIS), Fig.4.57, Fig.4.68.

A reverse flow from containment to RV is observed through the SPLIT line after the RC level has reached the DVI elevation, accordingly to phases when the containment pressure is higher than the RV pressure, Fig.4.26, Fig.4.9.

### *Blowdown, RV depressurization, containment pressurization*

The blowdown phase depressurises the RV with mass and energy transfer to the containment.

The SPES3 and IRIS PRZ pressures are shown in Fig.4.6, Fig.4.7 and Fig.4.8. The depressurization rate is very similar until about 1000 s, then after the containment and RV pressures are coupled (2280 s in SPES3 and 1511 in IRIS) the IRIS PRZ pressure stays above, correspondingly to the IRIS containment one, Fig.4.4, Fig.4.5, Fig.4.9, Fig.4.10.

While the PRZ depressurises, the containment pressure increases as shown in Fig.4.4, Fig.4.5. Since the early seconds of transient, the DW heat structures, larger in SPES3 than IRIS, affect the pressure rising. Moreover, the RC, PSS and LGMS structures are not simulated in IRIS while they are in SPES3 and this also limits the SPES3 DW pressurization. The pressure increase around 180 s is due to the ADS Stage-I intervention that discharges mass and energy into the DW, Fig.4.12. After that, pressure increases up to reach a peak of 0.664 MPa in SPES3 at 1800 s and 1.069 MPa in IRIS at 1401 s. When the RV and DW pressure equalize, the ADS Stage-I mass flow stops and the DW pressure decreases thanks to the LGMS injection into the RV (intact loop) and into the RC (broken loop), Fig.4.68.

A faster DW depressurization occurs when a reverse flow from the PSS to the RV starts through the vent lines, at 4790 s in SPES3 and 4138 s in IRIS, Fig.4.14. The mass transferred from the PSS to the DW is shown in Fig.4.15. The final value is similar in SPES3 and IRIS, but the trend is related to the way of injection. The PSS water level is shown in Fig.4.16.

### *Steam dumping into PSS*

The containment space (DW and RC) pressurization causes the transfer of a steam-gas mixture from the DW to the PSS through the vent lines, starting around 20 s and lasting until the mass flow exits the ADS-Stage-I, Fig.4.14.

The non-condensable gas quality in the DW is shown in Fig.4.17 and Fig.4.18 and the way steam sweeps away gas from the DW seems similar between SPES3 and IRIS.

Steam is dumped underwater through the PSS sparger and gas (air in SPES3 and N<sub>2</sub> in IRIS) pressurizes the PSS and LGMS gas space, Fig.4.19, Fig.4.20, Fig.4.21, Fig.4.22. The PSS and LGMS pressure follows the DW pressure trend and it is lower in SPES3 than IRIS, Fig.4.23, Fig.4.24. Anyway, an important difference between SPES3 and IRIS occurs when the PSS injection into the DW stops. In SPES3, all containment volumes reach the same pressure while in IRIS, the LGMS and PSS remain more pressurised than the DW, Fig.4.23, Fig.4.24. In IRIS, the PSS and DW volumes remain separated, from the pressure point of view, as the PSS to DW vent pipes remain full of water after the PSS injection to DW is over, and non-condensable gas cannot flow from PSS to DW and equalize pressure, Fig.4.25.



This is probably due to the different elevation of the PSS vent pipe connection to the DW, in particular of the lowest connection (branch containing the check valve), that in IRIS is at 0.25 m from the DW bottom, while in SPES3 is at 3.785 m. Due to water transfer from PSS to DW, Fig.4.14, a water level forms in the DW, after the RC is full and in IRIS it covers the PSS vent connection, while in SPES3 it does not, Fig.4.26, Fig.4.27. This prevents air to enter the PSS vent pipes from the DW so maintaining in them a certain water level after the PSS injection is over. This leads to have in IRIS the PSS and LGMS more pressurized than the DW, Fig.4.23, Fig.4.24. Another reason to explain the difference in the PSS vent pipe behaviour is the PSS sparger position with respect to the PSS bottom. In IRIS the sparger is at 0.25 m from the bottom, while in SPES3 it is at 0.985 m. Moreover, the PSS to DW vent pipe plus extension total height is 18.5 m in IRIS while it is 22.083 m in SPES3.

Fig.4.16 shows the PSS levels. The initial value is different in SPES3 and IRIS due to the different tank shape with the same liquid mass contained. The final value of level, with respect to the PSS bottom, is similar in the two cases notwithstanding the SPES3 sparger is at a higher elevation than the IRIS one. Differences in modelling and the two-slice approach of the SPES3 PSS nodalization can explain this different behaviour.

The PSS water temperature increases thanks to the mass transfer from the DW, Fig.4.28, Fig.4.29, Fig.4.14. Temperature increases more in IRIS than in SPES3 due to the greater mass transferred from the DW to the PSS during the first phase of injection, Fig.4.30.

Both the liquid and gas temperatures are reported in Fig.4.28, Fig.4.29. In SPES3 gas and liquid temperatures are very similar and so do liquid temperatures in IRIS, relatively to the PSS lower part. Gas temperatures calculated by Gothic in the upper part of PSS show a trend that could be justified by a strong stratification.

Temperatures always remain below saturation (maximum temperature reached in SPES3 is 84 °C and in IRIS 98 °C) at the maximum PSS pressure and also when pressure decreases. In the long term, the SPES3 PSS temperature decreases probably due to the heat losses to the environment, while it remains constant in IRIS as no PSS heat structure is simulated.

#### *S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation*

The high containment pressure set-point (1.7e5 Pa) is reached at 24 s in IRIS and 50.23 s in SPES3 and it triggers the S-signal.

The S-signal (Safeguard) starts the reactor SCRAM, isolates the three secondary loops and actuates the EHRS-A and B.

Power released to the fluid in the core is shown in Fig.4.31 and Fig.4.32. The difference between the curve is only a time shift related to the S-Signal timing.

Power transferred to the steam generators is shown in Fig.4.33 and Fig.4.34. No important difference is observed up to the intervention of the EHRS-C (180.58 s in SPES3 and 173 s in IRIS) when more power is removed in SPES3 due to the faster emptying of the EHRS-C heat exchanger for lower pressure drops on the line. After the natural circulation is established in the EHRS loops, power transferred to the SGs is similar but a little higher in SPES3 than IRIS.

The MFIV and MSIV of the secondary loops are contemporarily closed in 5 s in SPES3 and in 0.1 s in IRIS. The secondary loop mass flows are shown in Fig.4.35 and Fig.4.36. For loops A and B in SPES3, corresponding to loop 1 and 3 in IRIS, the EHRSs are actuated together with the secondary side isolation (10 s delay in IRIS) and the mass flow reduces to the natural circulation flow, driven by the heat transfer between primary side and EHRS through the SG tubes. For loop C in SPES3, corresponding to loop 2 and 4 in IRIS, the mass flow re-starts with EHRS-C actuation occurring later on LM-signal. For a direct comparison of the eight SG mass flow in IRIS and three SGs in SPES3 (loop C is split into two tube rows), the SG mass flow curves have been summed in IRIS. The comparison shows that each SG tube row of loop C in SPES3 removes about 1.75 times power removed by SG A and B tube rows which is instead very similar to that of IRIS.

The SPES3 EHRS-A and B and the EHRS-1 and 3 in IRIS are actuated by opening in 2 s the related isolation valves. The peak flowrate of 0.307 kg/s is reached at 57 s in SPES3 while in IRIS it is of 0.283 kg/s at 39 s. Between 500 s and 10000 s, a steady condition is reached with the SPES3 natural circulation higher than IRIS one, probably due to smaller pressure drops in SPES3 loops, Fig.4.37 and Fig.4.38.

Power removed by the EHRS-A and B is shown in Fig.4.39 and Fig.4.40. The SPES3 EHRS-A and B peak of removed power occurs at about 192 s with a value of 408 kW each, while the IRIS EHRS-1 and 3 power peak of 374 kW occurs at 150 s. The average power removed by the SPES3 EHRS-A and B in the long term is around 11 kW each, while the IRIS EHRS-1 and 3 is about 2.5 kW each.

The secondary side pressures are shown in Fig.4.41 and Fig.4.42. After isolation, pressure increases due to the heat transfer from the primary side that makes water contained in the SG tubes evaporate. The SG tube levels decrease until water stored in EHRS heat exchangers is poured into the loops and power begins to be removed, Fig.4.43 Fig.4.44, Fig.4.33. The SG-A in SPES3 and SG-1 tube collapsed levels are compared in Fig.4.43 and Fig.4.44. Similar trends are observed for SPES3 and IRIS, even if during the natural circulation, the SPES3 level stays always about 1 m below IRIS level. SG pressure peaks are reached around 91 s in SPES3 and 49 s in IRIS, then pressure decreases, Fig.4.41. Such decrease is related to two factors: a) the pump coastdown (start at 90.98 s in SPES3 and 143 s in IRIS on Low PRZ level signal, delayed of 15 s) that, reducing the circulation in the primary side, dumps the heat transfer from the primary to the SGs and b) the primary side cooling by the heat removal through the EHRS-A and B. In the long term, pressure of IRIS secondary sides stabilizes at a higher value than SPES3, related to the higher pressure in IRIS which the primary side and the containment stabilize at, Fig.4.42, Fig.4.10.

#### *Pump coastdown and primary circulation through RI-DC check valves*

The PRZ levels of SPES3 and IRIS are shown in Fig.4.45. The early phase of level decrease, until the ADS Stage-I intervention (180 s in SPES3 and 173 s in IRIS), is due to the loss of mass from the break. In this phase, mass lost from the break, RV side (DVI split) is exactly the same in IRIS and SPES3, Fig.4.46. The observed difference in PRZ level can be explained hypothesizing flow instabilities due to steam bubbles at the PRZ surge holes in IRIS, not occurring in SPES3. The level increase after the ADS Stage-I actuation is similar in the two cases until the ADS stop when the containment and RV pressure equalize (1511 s in IRIS and 2280 s in SPES3). The liquid fraction at the pump inlet is reported in Fig.4.47. Due to the loss of mass from the break, the pump uncovers soon. Water sucked at the ADS Stage-I maintains a certain liquid fraction at the pump suction until about 400 s in IRIS, while the SPES3 pump is uncovered soon after the PRZ early emptying. This can be explained considering the different position of the pump in the two plants, inside the RV in IRIS and outer and connected by piping in SPES3, less interested by the water path to the ADS through the PRZ surge holes.

The pump coastdown is triggered by a Low PRZ level signal delayed of 15 s (90.98 s in SPES3 and 143 s in IRIS). Soon after the pump suction is uncovered, the RV natural circulation through the pump interrupts.

The core inlet flow is shown in Fig.4.48 and Fig.4.49 and it is similar for IRIS and SPES3 in the early 25000 s, except for a period between 1200 s and 3000 s where it stops in SPES3 due to low water level in the RV and low liquid fraction fluid at the RI-DC check valves (see below). Around 26000 s, the IRIS mass flow increases with respect to the SPES3 one, probably sustained by water entering the RV from the containment through the DVI, Fig.4.62.

The pump stop and pressure decreasing in the DC, let the RI-DC check valves open at 109÷111 s in SPES3 and 183÷186 s in IRIS and allow the natural circulation from riser to SG annuli at a lower level in the RV. The RI-DC check valve mass flows are shown in Fig.4.50 and Fig.4.51 for each SG (for SG-A in SPES3 it is the sum of mass flows through the check valves 161 and 164, for SG-B of mass flow through the check valves 162 and 165 and for SG-C of mass flow through the check valves 163 and 166; for IRIS, the mass flows are combined for a direct comparison with SPES3). The trend and value of the RI-DC check valve mass flow is strictly related to the core inlet flow, Fig.4.49.

The fast RV depressurization, rapidly causes flashing of the primary circuit and void begins at the core outlet at 119 s in SPES3 and 184 s in IRIS, Fig.4.52, Fig.4.53. The low liquid fraction period in the core lasts until about 3000 s in IRIS and 6000 s in SPES3. This is due to the larger mass discharged in SPES3 through the ADS Stage-I, Fig.4.54, Fig.4.55 that causes a greater RV mass decrease, Fig.4.56, later made-up by the safety systems.

#### *LM-Signal: EHRS-C, ADS Stage-I and EBT actuation*

The LM-Signal (LOCA mitigation) occurs at 180.58 s in SPES3 and 173 s in IRIS when the low PRZ pressure set-point (11.72e6 Pa) is reached, Fig.4.7.

The LM-signal actuates the EHRS-C in SPES3 and EHRS-2 and 4 in IRIS, opens the ADS stage-I, and opens the EBT actuation valves.

The SPES3 EHRS-C and the IRIS EHRS 2 and 4 are actuated by opening in 2 s the related isolation valves. The peak flow rate of 1.15 kg/s is reached at 184 s in SPES3 while the IRIS peak of 0.570 kg/s is reached at 189 s. After the peak, a quite steady natural circulation flow of about 0.6 kg/s is reached in SPES3 between 350 s and 6000 s, while in IRIS the average flow is 0.313 kg/s until about 10000 s, Fig.4.37. The SPES3 mass flow is higher than in IRIS in the long term, Fig.4.38.

Power removed by SPES3 EHRS-C and IRIS EHRS 2 and 4 is shown in Fig.4.39 and Fig.4.40. The SPES3 EHRS-C peak of removed power occurs at 260 s with a value of 959 kW, while the IRIS EHRS 2 and 4 power peak occurs at 305 s with a value of 718 kW. The average power removed by the SPES3 EHRS-C in the long term is 21.4 kW, while that removed by IRIS EHRS 2 and 4 is 5 kW.

The Stage-I of the ADS trains are actuated contemporarily on LM-signal, 180.58 s in SPES3 and 173 s in IRIS. The SPES3 mtrvlv 153 on the Single Train (ST) and 143 on the Double Train (DT) are fully open in 10 s and so do the three IRIS ADS train valves. The ADS Stage-I mass flows are shown in Fig.4.12 and Fig.4.13. For a direct comparison between SPES3 and IRIS, two of the IRS trains are condensed in one. SPES3 and IRIS show similar trends, but the mass flow is quantitatively greater in SPES3 than IRIS. Both IRIS and SPES3 show a two-peak trend flow, with the first SPES3 peak of 1.914 kg/s at 191 s and the second peak of 2.685 kg/s at 234 s and the first IRIS peak of 1.298 kg/s at 184 s and the second peak of 2.102 kg/s at 245 s.

When the ADS intervene, the PRZ is empty in SPES3 and almost empty in IRIS, Fig.4.45, and the first ADS flow peak is due to steam flowing toward the QT. At the ADS intervention, water is sucked upwards and the PRZ level increases. The second ADS mass flow peak is caused by an increasing liquid fraction at the PRZ top that decreases when the PRZ empties.

The ADS integral flow is shown in Fig.4.54 and mass flowed out from the RV through the ADS in SPES3 is about 1.6 times than flowed out from IRIS. This justifies the difference in the RV mass trend observed in the early 2000 s, Fig.4.56.

The LM-signal triggers the EBT valves. Both in SPES3 and IRIS, the EBT actuation valves are fully open in 15 s. The EBT injection mass flows are shown in Fig.4.57 and Fig.4.58 and they are similar in SPES3 and IRIS until about 1500 s. The EBT injection into the broken DVI is initially about 14 times larger than injection into the intact DVI, due to the presence of the break. After the RV and containment pressure equalization and inversion (1511 s in IRIS and 2280 s in SPES3), Fig.4.9, the differential pressure in IRIS is sufficient to push back water into the RV through the ADS pipe until about 2000 s, Fig.4.12, and also through the broken loop EBT, Fig.4.57 (no check valve seems installed on such EBT discharge line). In SPES3, the EBT injection does not undergo instabilities until the EBTs are empty, Fig.4.60. The IRIS EBT trend of level in the long term, Fig.4.61, and the EBT injection mass flow, Fig.4.58, show that no check valve is installed also on the intact loop EBT.

Soon after the EBT actuation, a liquid circulation from the RV toward the EBT starts at the EBT to RV connections, Fig.4.59, then, after such connection is uncovered, steam replaces water contained in the EBT top lines and tanks. The SPES3 broken loop EBT is empty at 500 s while the corresponding IRIS EBT is

empty at 600 s. The SPES3 intact loop EBT is empty at 3030 s while IRIS one at 22320 s to be partially re-filled later, Fig.4.60, Fig.4.61.

The EBT actuation is responsible for the mass flow through the break line, containment side, starting at 198 s in SPES3 and at 206 s in IRIS, Fig.4.1. The EBT injected mass enters the RV through the intact DVI, while a reverse flow occurs through the broken DVI towards the break, Fig.4.62, Fig.4.63. Such reverse flow lasts until the RV and containment pressures equalize, Fig.4.9, Fig.4.10. After that, the DVI mass flow in SPES3 and IRIS is driven by the differential pressure between RV and containment and by the amount of water in one or the other side of the plant.

#### *RV saturation*

The RV mass decreases due to the loss of mass from the break, Fig.4.56. The fast RV depressurization leads to reach the saturation conditions (core inlet T = core outlet T) at 275 s in SPES3 and 236 s in IRIS. A two-phase mixture occurs in the core, Fig.4.52, but the natural circulation through the RI-DC check valves allows to remove the decay heat and a temperature difference establishes again between core inlet and outlet when the core is under liquid single-phase, after 3000 s in IRIS and 6000 s in SPES3. The inlet and outlet core temperatures are shown in Fig.4.64 and Fig.4.65.

According to pressure, Fig.4.10, the IRIS temperature establishes at a higher value than SPES3 ones (about 25 °C until 40000 s) and in the long term they tend to diverge due to the unbalance between core decay power and EHRS removed power (core power: 45.2 kW in SPES3 and 52.7 kW in IRIS; EHRS power: 43.4 kW in SPES3 and 10 kW in IRIS).

The core heater rod temperatures are shown in Fig.4.66, Fig.4.67. Notwithstanding the core liquid void fraction decrease, the rod surface temperatures never overcome the maximum steady state temperature. Corresponding to the fluid temperature, even the heater rod temperatures stabilize at a higher value in IRIS than SPES3.

#### *Low DP RV-Containment signal, LGMS and RC to DVI valve actuation*

The containment pressure peak of 0.664 MPa occurs at 1800 s in SPES3 and of 1.069 MPa at 1401 s in IRIS, Fig.4.4.

The “Low DP RV-Containment” signal set point of 50 kPa is reached at 2105.73 s in SPES3 and 1427 s in IRIS.

The combination of LM-signal AND Low DP RV-Containment signal actuates the LGMSs and opens the valves on the lines connecting the RC to the DVIs.

The SPES3 and IRIS LGMS isolation valves are fully open in 2 s as well as the RC to DVI line isolation valves.

LGMS injection is related both to gravity and to LGMS air space pressurization (through PSS to LGMS balance lines) by non-condensable gas entering the PSS from the DW. The broken loop LGMS injection into the DVI starts at 2140 s in SPES3 and 1463 s in IRIS, while the intact loop LGMS injection into the DVI starts at 2220 s in SPES3 and 1527 in IRIS. The LGMS injection mass flow is shown in Fig.4.68. Consequently to the LGMS injection into the broken DVI, a mass flow from the DEG break line restarts around at 2000 s and lasts until the LGMS is empty, Fig.4.2.

Fig.4.68 shows that a great difference exists between the IRIS and the SPES3 LGMS injection trend. The SPES3 mass flow is stronger than IRIS in the first phase of injection (~0.16 kg/s in SPES3 and ~0.08 kg/s in IRIS) and then it decreases to about one fourth of its value until the LGMS are empty. In IRIS, the injection remains quite steady since the beginning and it stops when the LGMS are empty, Fig.4.69. The reason is the different pressurization of LGMS with respect to DVI due to the emptying of the PSS vent pipes in SPES3 and non-emptying of the same pipe in IRIS (see section *Steam dumping into PSS*), Fig.4.70, Fig.4.71.

*Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV*

The RV and containment pressure equalize at 2280 s in SPES3 and 1511 s in IRIS, Fig.4.9. After this, the loss of mass through the break, RV side, depends on the periods when the RV pressure is higher than the containment pressure, Fig.4.2, Fig.4.3, Fig.4.9, Fig.4.10 s.

After the peak, the containment pressure decreases for steam condensation on the containment wall and, after the RV and containment pressure are coupled, pressures decreases due to the EHRS heat removal from the primary side, Fig.4.39. At 2380 s in SPES3 and 1786 s in IRIS, the DW pressure decreases below the PSS pressure, Fig.4.23. When the differential pressure between PSS and DW is sufficient to overcome the hydrostatic head of the PSS vent pipes, a reverse flow starts from the PSS to the DW through the vent lines, lasting between 4150 s and 7800 s in IRIS and 5140 s to 7000 s in SPES3, Fig.4.14.

The RC level, initially increased for break and ADS mass flow collection, rapidly increases in correspondence of the PSS injection up to the complete fill-up at 6760 s in SPES3 and 6864 s in IRIS (11 m level from bottom in SPES3 and 11.75 m in IRIS), Fig.4.26.

When the RC level is above the DVI connection and the containment pressure overcomes the RV pressure, water enters the RV through the RC to DVI connections, Fig.4.72, Fig.4.73. The mass injected from RC to DVI is shown in Fig.4.74 and it is larger in SPES3 than IRIS due to a greater mass flow between 7000 s and 14000 s, Fig.4.72, when the containment pressure is higher than the RV pressure, Fig.4.9.

The QT, initially empty, is partially filled-up by the ADS discharge, Fig.4.75. The later fill-up around 9000 s in IRIS and 20000 s in SPES3 s is related to the rapid increase of the DW level after the RC fill-up, Fig.4.26, Fig.4.27.

#### *Low LGMS mass signal: ADS Stage-II actuation*

The intact loop LGMS low mass signal is reached at 8765.54 s in SPES3 (LGMS-A) and 13079 s in IRIS (LGMS-2) when mass reaches 198 kg (20% of 1 m<sup>3</sup> water at 48.9 °C), while the broken loop signal is reached at 14244.5 s in SPES3 (LGMS-B) and 12388 s in IRIS (LGMS-1), Fig.4.69.

The reaching of both LGMS low mass signals actuates the ADS Stage-II valves, fully open in 10 s both in SPES3 and IRIS, to allow steam circulation between RV and DW in the upper part of the plant and enhance condensation on the SG tubes in the long term of the transient, Fig.4.76 and Fig.4.77. Due to the pressure difference between DW and RV, Fig.4.11, a mass flow is observed in IRIS from the DW to the RV, while it is not observed in SPES3 where DW and RV pressure are very similar.

The SPES3 RWST-A/B begins to heat-up at 80 s (after the EHRS-A and B actuation at 49.7 s) and IRIS RWST-1 begins to heat up at 90 s (after EHRS-1 and 3 actuation at 24 s). The SPES3 RWST-C begins to heat-up at 202 s (after the EHRS-C actuation at 180.58 s) while IRIS RWST-2 begins to heat up together with RWST-1 as they are connected in the IRIS model (EHRS-2 and 4 actuation at 173 s). In SPES3, water reaches the maximum temperature of 94 °C at the end of the transient, while in IRIS temperature increases up to 127 °C, Fig.4.78. The difference is due to the lower RWST water mass in IRIS than SPES3, Fig.4.79, and to the RWST model in IRIS that allows pressure to increase, so increasing the corresponding saturation temperature, Fig.4.80.

The difference on the RWST models in SPES3 and IRIS limits the heat removal from the RV through the EHRS in IRIS with respect to SPES3, as shown in Fig.4.81, Fig.4.82. The lower heat removal in IRIS causes the RV and containment pressurization in the long term and explains the difference from SPES3. In the long term, total power transferred to the RWST in IRIS is 10 kW while total power in SPES3 is 43.4 kW.



#### 4.1.2 Dry-Well metal structures

The large difference between the DW pressure in IRIS and SPES3, since the early phases of the transient up to the pressure peak, is investigated to search for possible reasons of the qualitative and quantitative differences between the plants.

Based on the IRIS test specification [1], the SPES3 Drywell volume is 35.36 m<sup>3</sup> with AISI 304 25 mm thickness, suitable to resist to 2 MPa design pressure. The IRIS DW volume, scaled 1:100, is 32.27 m<sup>3</sup>, [1]. The initial wall temperature is 48.9 °C.

The IRIS DW structure model is described in detail in [14] and it fundamentally consists of a lower concrete plate and carbon steel parts as the lower shell, the upper shell, the PCCS tubes and the RV missile shield.

Moreover, the RC, PSS and LGMS heat structures are not simulated in IRIS, while they are in SPES3.

Fig.4.83 and Fig.4.84 compare power released to the DW structures in SPES3 and IRIS, until a thermal equilibrium is reached on the walls, Fig.4.85, Fig.4.86. At the peak, the SPES3 power (2 MW) is about 27 times the IRIS power (75 kW) transferred to the DW structures and this put in evidence the need to search a possible solution to limit the DW metal mass and surface effect in SPES3, Fig.4.83.

Fig.4.85 and Fig.4.86 shows the SPES3 and IRIS DW wall temperatures at the inner and outer surface. In SPES3, inside temperatures are indicated with label 01 and outside ones with label 13. Moreover, temperatures are taken at various axial levels in the DW (lower 01, intermediate 07, and upper 17). In IRIS, TA is the inside temperature and TB the outside one with heat structure 01 for the lower shell, 02 for the concrete and 03 for the upper shell. To be noted that the SPES3 DW is thermally insulated with the environment and the outer surface temperature increases slightly during all the transient, while IRIS is not and the inner and outer surface temperatures are very similar.

Starting from similar initial conditions (48.9 °C), the IRIS DW temperatures increase more than the SPES3 ones, due to the differently scaled mass, but all of them reach the maximum before 2000 s. After that, the heat losses to the environment and the pressure and temperature decrease in the DW, make them decrease accordingly, Fig.4.85, Fig.4.86.

#### 4.1.3 Case conclusions

The analysis of the DVI DEG break transient by the comparison between the SPES3-97 base case and the IRIS HT1 reference case has shown a general agreement in the occurring phenomena from the qualitative point of view, instead it has put in evidence quantitative discrepancies that need to be reduced for a good simulation of the IRIS plant with the SPES3 facility.

The largest difference is in the containment pressure, considered one of the most important parameters affecting the sequence of events and transient evolution. Differences are evidenced both in the first part of the transient, when pressure rises for the break and ADS discharge, and also in the long term.

As geometrical differences exist between SPES3 and 1:100 scaled IRIS, especially in the containment compartment volumes, related metal masses, surfaces and joining pipes, attention is focused on these parameters to explain the differences and find a solution to improve the simulation.

The DW heat structures, oversized with respect to IRIS ones, become the first investigated item of the analyses described in the following chapters.

**Tab.4. 1 – SPES3-97 and IRIS30h\_LB\_HT1 steady state conditions**

| <b>SPES3-97</b>          | <b>Primary/Core</b>              | <b>SG-A</b>       | <b>SG-B</b>       | <b>SG-C</b>  | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSAB</b> | <b>RWSTAB</b> | <b>RWSTC</b> |
|--------------------------|----------------------------------|-------------------|-------------------|--------------|---------------|-----------|-----------|---------------|-----------|---------------|---------------|--------------|
| Pressure (MPa)           | 15.55 (PRZ)<br>0.104 (pump head) | 5.83 (out)        | 5.83 (out)        | 5.88 (out)   | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.         | 0.1013        | 0.1013       |
| Tin (°C)                 | 292                              | 224               | 224               | 224          | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9          | 20            | 20           |
| Tout (°C)                | 330                              | 322               | 320               | 320          |               |           |           |               |           |               |               |              |
| DT (°C)                  | 38                               | 98                | 96                | 96           |               |           |           |               |           |               |               |              |
| Superheating (°C)        |                                  | 48.3 (Tsat 273.7) | 46.3 (Tsat 273.7) | 45.7 (274.3) |               |           |           |               |           |               |               |              |
| Mass flow (kg/s)         | 45.64<br>(2.14 in by-pass)       | 1.25              | 1.25              | 2.5          |               |           |           |               |           |               |               |              |
| Power (MW)               | 10                               | 2.5               | 2.5               | 5            |               |           |           |               |           |               |               |              |
| Level (m)<br>-collapsed- | 1.91 (PRZ)                       | 1.62              | 1.78              | 1.81         | 3.14 full     | empty     | empty     | 3.91          | empty     | 2.30          | 6.97          | 6.97         |
| Mass (kg)                | 3290 (RV)                        |                   |                   |              | 127           |           |           |               |           | 936           | 11888         | 11888        |

| <b>IRIS HT1</b>          | <b>Primary/Core</b>             | <b>SG 1</b>       | <b>SG 2</b>       | <b>SG 3</b>       | <b>SG 4</b>       | <b>SG 5</b>       | <b>SG 6</b>       | <b>SG 7</b>       | <b>SG 8</b>       | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWST1</b> | <b>RWST2</b> |
|--------------------------|---------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------------|-----------|-----------|---------------|-----------|----------------|--------------|--------------|
| Pressure (MPa)           | 15.5 (PRZ)<br>0.128 (pump head) | 5.81 (out)        | 5.79 (out)        | 5.79 (out)        | 5.78 (out)        | 5.78 (out)        | 5.79 (out)        | 5.79 (out)        | 5.81 (out)        | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013       | 0.1013       |
| Tin (°C)                 | 292                             | 224               | 224               | 224               | 224               | 224               | 224               | 224               | 224               | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20           | 20           |
| Tout (°C)                | 330                             | 318.3             | 314.7             | 318.5             | 315.0             | 317.8             | 315.2             | 318.3             | 314.7             |               |           |           |               |           |                |              |              |
| DT (°C)                  | 38                              | 94.3              | 90.7              | 94.5              | 91                | 93.8              | 91.2              | 94.3              | 90.7              |               |           |           |               |           |                |              |              |
| Superheating (°C)        |                                 | 44.7 (Tsat 273.6) | 41.4 (Tsat 273.3) | 45.2 (Tsat 273.3) | 41.8 (Tsat 273.2) | 44.5 (Tsat 273.2) | 41.8 (Tsat 273.3) | 44.9 (Tsat 273.3) | 41.2 (Tsat 273.6) |               |           |           |               |           |                |              |              |
| Mass flow (kg/s)         | 45.17<br>(1.99 in by-pass)      | 0.63              | 0.63              | 0.63              | 0.63              | 0.63              | 0.63              | 0.63              | 0.63              |               |           |           |               |           |                |              |              |
| Power (MW)               | 10                              | 1.24              | 1.26              | 1.24              | 1.26              | 1.26              | 1.24              | 1.26              | 1.24              |               |           |           |               |           |                |              |              |
| Level (m)<br>-collapsed- | 2.02 (PRZ)                      | 2.09              | n.a.              | n.a.              | n.a.              | n.a.              | n.a.              | n.a.              | n.a.              | 3.14 full     | empty     | empty     | 3.00          | empty     | 2.668          | n.a.         | n.a.         |
| Mass (kg)                | 3250 (RV)                       |                   |                   |                   |                   |                   |                   |                   |                   | 127           |           |           | 1483          |           | 989            | 4067         | 4067         |

Tab.4. 2 – SPES3-97 and IRIS-HT1 list of the main events

| DVI-B DEG break 2 inch equivalent                                                        |                                                         | SPES3-97 |                                        |                                                      | IRIS-HT1 |                  |                                                                   |
|------------------------------------------------------------------------------------------|---------------------------------------------------------|----------|----------------------------------------|------------------------------------------------------|----------|------------------|-------------------------------------------------------------------|
| N.                                                                                       | Phases and events                                       | Time (s) | Quantity                               | Notes                                                | Time (s) | Quantity         | Notes                                                             |
| <b>Break</b>                                                                             |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 1                                                                                        | Break initiation                                        | 0        |                                        | break valves stroke 2 s                              | 0        |                  | Instantaneous stroke 0.02 s delay                                 |
| 2                                                                                        | Break flow peak (Containment side)                      | 1        | 0.688 kg/s                             | Break flow = 0 kg/s at 10 s                          | 0.03     | 0.50 kg/s        | Break flow = 0 kg/s at 1.1 s                                      |
| 3                                                                                        | Break flow peak (RV side)                               | 2        | 1.33 kg/s                              |                                                      | 0.1      | 1.35 kg/s        |                                                                   |
| <b>Blowdown, RV depressurization, containment pressurization. Steam dumping into PSS</b> |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 4                                                                                        | Steam-air mixture begins to flow from DW to PSS         | 20       |                                        |                                                      | 9.8      |                  | 0 to 10 s water empties the vent pipe into the PSS                |
| <b>S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation</b>         |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 5                                                                                        | High Containment pressure signal                        | 50.23    | 1.7e5 Pa                               | S-signal. Set-point for safety analyses              | 24       | 1.7e5 Pa         | S-signal. Set-point for safety analyses                           |
| 6                                                                                        | SCRAM begins                                            | 50.23    |                                        |                                                      | 24       |                  |                                                                   |
| 7                                                                                        | MFIV-A,B,C closure start                                | 50.23    |                                        | MFIV-A,B,C stroke 5 s                                | 24       |                  | MFIV-1,2,3,4 stroke 0.1 s                                         |
| 8                                                                                        | MSIV-A-B-C closure start                                | 50.23    |                                        | MSIV-A,B,C stroke 5 s.                               | 24       |                  | MSIV-1,2,3,4 stroke 0.1 s.                                        |
| 9                                                                                        | EHRS-A and B opening start (EHRS 1 and 3 in IRIS)       | 50.23    |                                        | EHRS-A,B IV stroke 2 s.                              | 34       |                  | EHRS-1,3 IV stroke 2 s.<br>S-signal + 10 s delay                  |
| 10                                                                                       | EHRS-A and B peak mass flow                             | 57       | 0.307 kg/s                             |                                                      | 39       | 0.283 kg/s       |                                                                   |
| 11                                                                                       | High SG pressure signal                                 | 64.18    | 9e6 Pa                                 |                                                      | 37       | 9e6 Pa           |                                                                   |
| 12                                                                                       | SG-A high pressure reached                              | 64.18    |                                        |                                                      | 37       |                  |                                                                   |
| 13                                                                                       | SG-B high pressure reached                              | 65.04    |                                        |                                                      | 37       |                  |                                                                   |
| 14                                                                                       | SG-C high pressure reached                              | 65.02    |                                        |                                                      | 37       |                  |                                                                   |
| 15                                                                                       | RWST-A/B begins to heat-up                              | 80       |                                        |                                                      | 90       |                  |                                                                   |
| 16                                                                                       | EHRS-A power peak                                       | 192      | 408 kW                                 |                                                      | 150      | 374 kW           | EHRS-1                                                            |
| 17                                                                                       | EHRS-B power peak                                       | 192      | 408 kW                                 |                                                      | 150      | 374 kW           | EHRS-3                                                            |
| <b>Pump coastdown and primary circulation through RI-DC check valves</b>                 |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 18                                                                                       | Low PRZ water level signal                              | 75.98    | 1.189 m                                |                                                      | 128      | 1.189 m          |                                                                   |
| 19                                                                                       | RCP coastdown starts                                    | 90.98    |                                        | Low PRZ level signal + 15 s delay                    | 143      |                  | Low PRZ level signal + 15 s delay                                 |
| 20                                                                                       | Secondary loop pressure peak                            | 91       | 104e5 Pa A<br>107e5 Pa B<br>112e5 Pa C |                                                      | 49       | 110.8e5 Pa       | All SGs                                                           |
| 21                                                                                       | Natural circulation begins through shroud valves        | 109, 111 |                                        | SG-A,B 109 s,<br>SG-C 111 s                          | 183, 186 |                  | SG-1+2, 5+6+7+8 183 s,<br>SG-3+4 186 s                            |
| 22                                                                                       | Flashing begins at core outlet                          | 119      | voidf 110 (core)                       | <1                                                   | 184      | voidf 110 (core) | <1                                                                |
| <b>LM-Signal: EHRS-C, ADS Stage-I and EBT actuation. RV saturation</b>                   |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 23                                                                                       | Low PRZ pressure signal                                 | 180.58   | 11.72e6 Pa                             | LM-Signal (High P cont + Low P PRZ)                  | 173      | 11.72e6 Pa       | LM-Signal (High P cont + Low P PRZ)                               |
| 24                                                                                       | EHRS-C opening start (EHRS 2 and 4 in IRIS)             | 180.58   |                                        | EHRS-C IV stroke 2 s.                                | 173      |                  | EHRS-2+4 IV stroke 2 s.<br>LM-signal                              |
| 25                                                                                       | EHRS-C peak mass flow                                   | 184      | 1.15 kg/s                              |                                                      | 189      | 0.570 kg/s       | EHRS-2+4                                                          |
| 26                                                                                       | RWST-C begins to heat-up                                | 202      |                                        |                                                      | 92       |                  | RWST-1 and 2 connected                                            |
| 27                                                                                       | EHRS-C power peak                                       | 260      | 959 kW                                 |                                                      | 305      | 718 kW           |                                                                   |
| 28                                                                                       | ADS Stage I start opening (3 trains)                    | 180.58   |                                        | ADS valve stroke 10 s                                | 173      |                  | ADS valve stroke 10 s                                             |
| 29                                                                                       | ADS Stage I first peak flow (3 trains)                  | 191      | 1.914 kg/s                             | ST 0.634 kg/s; DT 1.28 kg/s                          | 184      | 1.298 kg/s       | ST (1) 0.438 kg/s;<br>DT (2+3) 0.860 kg/s                         |
| 30                                                                                       | ADS Stage I second peak flow (3 trains)                 | 234      | 2.685 kg/s                             | ST 0.875 kg/s; DT 1.81 kg/s. Due to liquid fraction. | 245      | 2.102 kg/s       | ST (1)0.709 kg/s;<br>DT (2+3) 1.393 kg/s. Due to liquid fraction. |
| 31                                                                                       | EBT-A and B valve opening start                         | 180.58   |                                        | EBT valve stroke 15 s                                | 173      |                  | EBT valve stroke 15 s                                             |
| 32                                                                                       | Break flow peak (Containment side)                      | 198      | 0.697 kg/s                             | Due to EBT intervention                              | 206      | 0.631 kg/s       | Due to EBT intervention                                           |
| 33                                                                                       | EBT-RV connections uncovered                            | 223      |                                        |                                                      | 385      |                  |                                                                   |
| 32                                                                                       | Natural circulation interrupted at SGs top              | 230      |                                        | Pump inlet uncovered (voidf 176-01 ~0)               | 385      |                  | Pump inlet uncovered (voidf 176-01 ~0)                            |
| 36                                                                                       | Core in saturation conditions                           | 275      |                                        |                                                      | 236      |                  |                                                                   |
| 37                                                                                       | EBT-B empty (broken loop)                               | 500      |                                        | 500 s almost empty (600 s completely empty)          | 600      |                  | EBT-1 broken loop. Level oscillations between 1600-70000 s        |
| <b>Low DP RV-Containment signal, LGMS and RC to DVI valve actuation</b>                  |                                                         |          |                                        |                                                      |          |                  |                                                                   |
| 38                                                                                       | Containment pressure peak                               | 1800     | 6.64e5 Pa                              |                                                      | 1401     | 10.69e5 Pa       |                                                                   |
| 39                                                                                       | Low DP RV-Containment                                   | 2105.73  | 50e3 Pa                                |                                                      | 1427     | 50e3 Pa          |                                                                   |
| 40                                                                                       | LGMSA/B valve opening start                             | 2105.73  |                                        | LM + low DP RV-cont . LGMS valve stroke 2 s.         | 1427     |                  | LM + low DP RV-cont . LGMS valve stroke 2 s.                      |
| 41                                                                                       | RC to DVI line valve opening                            | 2105.73  |                                        | RC to DVI valve stroke 2 s.                          | 1427     |                  | RC to DVI valve stroke 2 s.                                       |
| 42                                                                                       | LGMS-B starts to inject into RC through DVI broken loop | 2140     |                                        |                                                      | 1463     |                  | LGMS-1 broken loop                                                |
| 43                                                                                       | LGMS-A starts to inject into RV through DVI intact loop | 2220     |                                        |                                                      | 1527     |                  | LGMS-2 intact loop                                                |

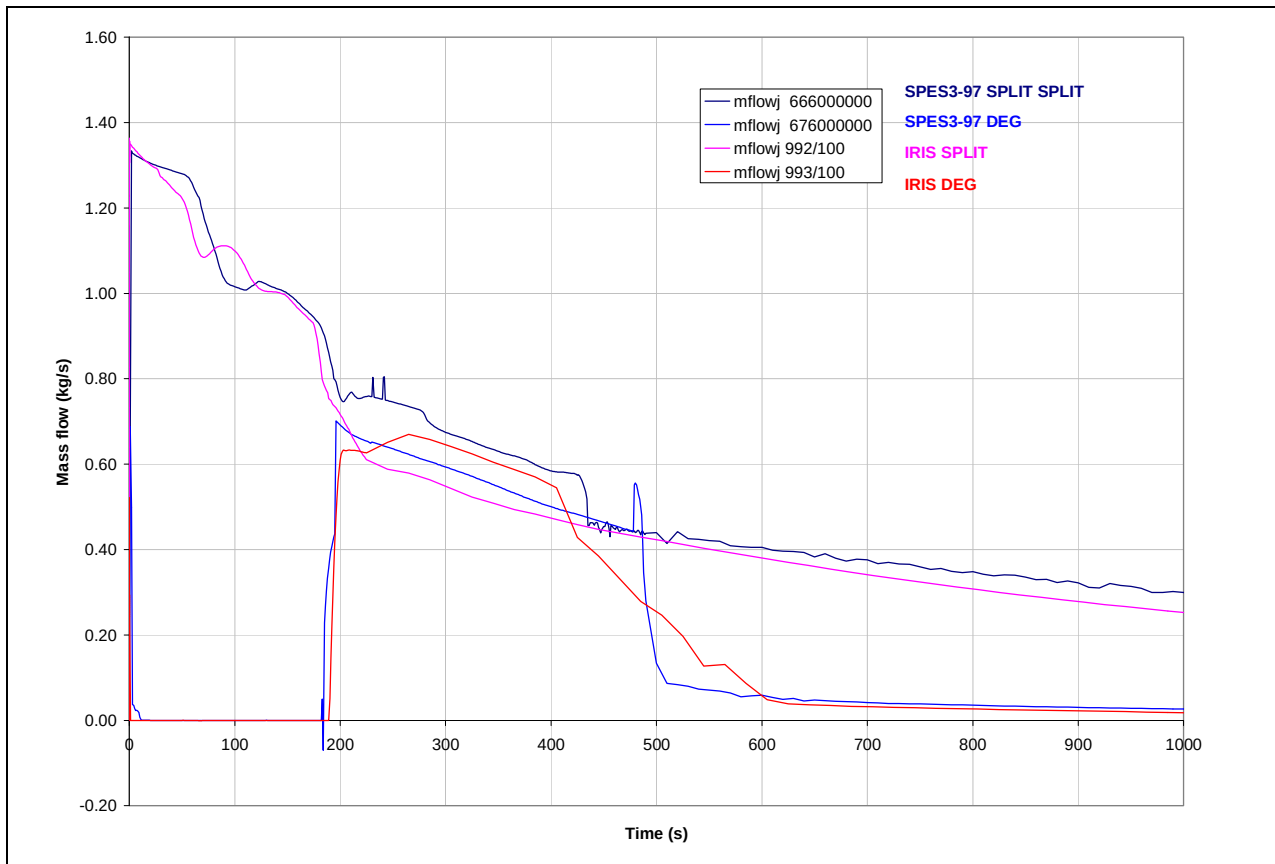
....continues



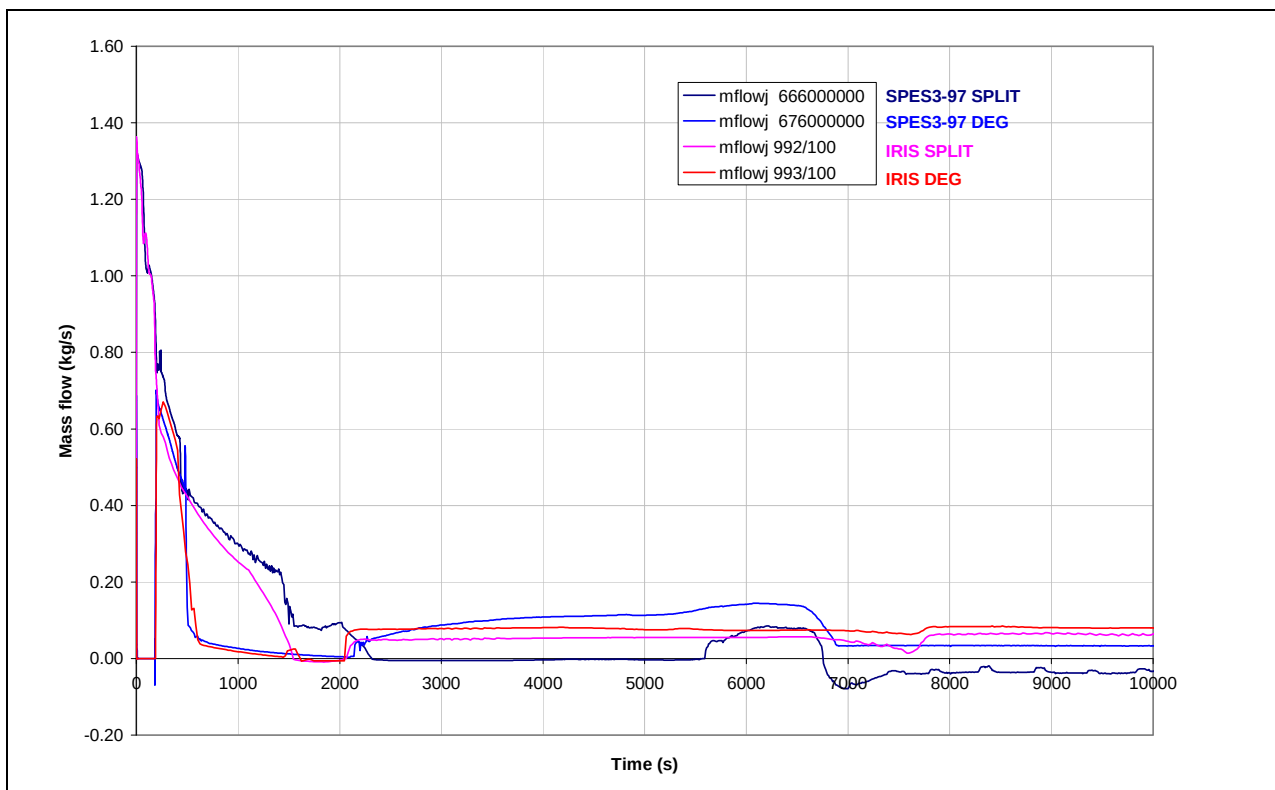
....continued

| <b>DVI-B break 2 inch equivalent DEG</b>                                                                                |                                                 | <b>SPES3-97</b> |                      |                                 | <b>IRIS-HT1</b> |                      |                                                      |
|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|-----------------|----------------------|---------------------------------|-----------------|----------------------|------------------------------------------------------|
| <b>N.</b>                                                                                                               | <b>Phases and events</b>                        | <b>Time (s)</b> | <b>Quantity</b>      | <b>Notes</b>                    | <b>Time (s)</b> | <b>Quantity</b>      | <b>Notes</b>                                         |
| <b>Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV</b> |                                                 |                 |                      |                                 |                 |                      |                                                      |
| 44                                                                                                                      | Containment and RV pressure equalization        | 2380            |                      |                                 | 1511            |                      |                                                      |
| 45                                                                                                                      | Mixture starts to flow from RC to DVI-A         | 1354            |                      |                                 | -               |                      | Negligible until 18940 s.                            |
| 46                                                                                                                      | DW pressure lower than PSS pressure             | 2330            |                      |                                 | 1786            |                      |                                                      |
| 47                                                                                                                      | EBT-A empty (intact loop)                       | 3030            |                      |                                 | 22320           |                      | EBT-2 (intact loop) level oscillations until 71900 s |
| 48                                                                                                                      | Water starts to flow from PSS to DW             | 4790            |                      |                                 | 4138            |                      |                                                      |
| 49                                                                                                                      | Steam and gas mixture flows again from RV to QT | 5700            |                      | 5500 to 6800 s<br>(RV P > DW P) | 7690            |                      | 7690 to 15500 s<br>(RV P > DW P)                     |
| 50                                                                                                                      | RC level at DVI elevation                       | 6130            |                      |                                 | 6634            |                      |                                                      |
| 51                                                                                                                      | RC full of water                                | 6760            |                      |                                 | 6864            |                      |                                                      |
| 52                                                                                                                      | QT fill-up starts from DW connection            | 7650            |                      |                                 | 7634            |                      |                                                      |
| <b>Low LGMS mass signal: ADS Stage-II actuation</b>                                                                     |                                                 |                 |                      |                                 |                 |                      |                                                      |
| 53                                                                                                                      | <b>Low LGMS mass</b>                            | 8765.5          | 20% mass<br>(198 kg) | LGMS A (intact loop)            | 13079           | 20% mass<br>(198 kg) | LGMS-2 (intact loop)                                 |
| 54                                                                                                                      |                                                 | 14244.5         | 20% mass<br>(198 kg) | LGMS B (broken loop)            | 12338           | 20% mass<br>(198 kg) | LGMS-1 (broken loop)                                 |
| 55                                                                                                                      | ADS stage-II start opening                      | 14244.5         |                      | ADS stage II valve stroke 10 s. | 13079           |                      | ADS stage II valve stroke 10 s.                      |
| 56                                                                                                                      | LGMS-A empty (intact loop)                      | 14480           |                      |                                 | 17036           |                      | LGMS-2 (intact loop)                                 |
| 56                                                                                                                      | LGMS-B empty (broken loop)                      | 25390           |                      |                                 | 17756           |                      | LGMS-1 (broken loop)                                 |
| 57                                                                                                                      | Flow from RC to RV (intact loop) start          | 28803           |                      |                                 | 19200           |                      |                                                      |
| <b>Long Term conditions</b>                                                                                             |                                                 |                 |                      |                                 |                 |                      |                                                      |
| 58                                                                                                                      | RWST-A/B temperature                            | 100000          | 95 °C                | 1e5 Pa pressure                 | 100000          | 127 °C               | 3.73e5 Pa pressure RWST-1                            |
| 59                                                                                                                      | RWST-C temperature                              | 100000          | 95 °C                | 1e5 Pa pressure                 | 100000          | 127 °C               | 3.73e5 Pa pressure RWST-2                            |
| 60                                                                                                                      | Core power                                      | 100000          | 45.2 kW              |                                 | 100000          | 52.7 kW              |                                                      |
| 61                                                                                                                      | EHRS-A power                                    | 100000          | 10.7 kW              |                                 | 100000          | 2.5 kW               |                                                      |
| 62                                                                                                                      | EHRS-B power                                    | 100000          | 11.3 kW              |                                 | 100000          | 2.5 kW               |                                                      |
| 63                                                                                                                      | EHRS-C power                                    | 100000          | 21.4 kW              |                                 | 100000          | 5 kW                 |                                                      |

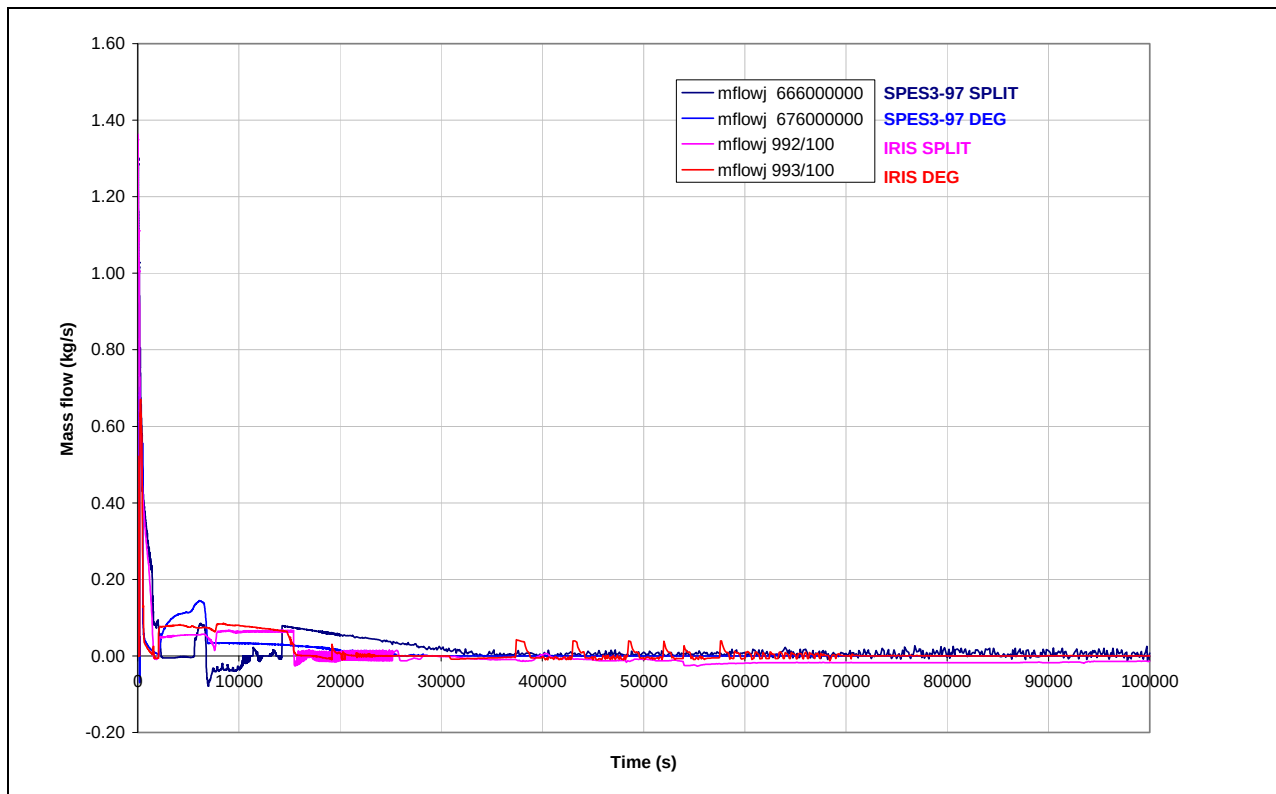
**Fig.4.1 – SPES3-97 and IRIS HT1 DVI break flow (window)**



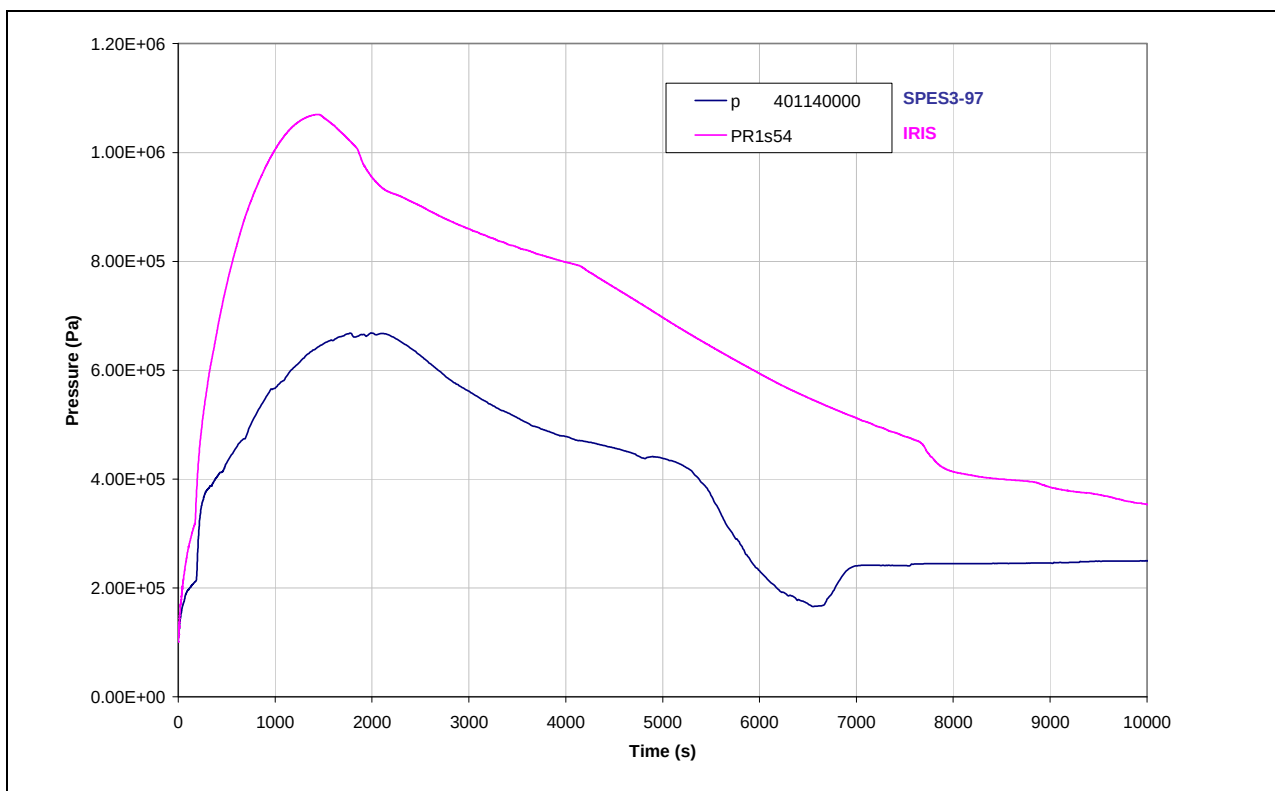
**Fig.4.2 – SPES3-97 and IRIS HT1 DVI break flow (window)**



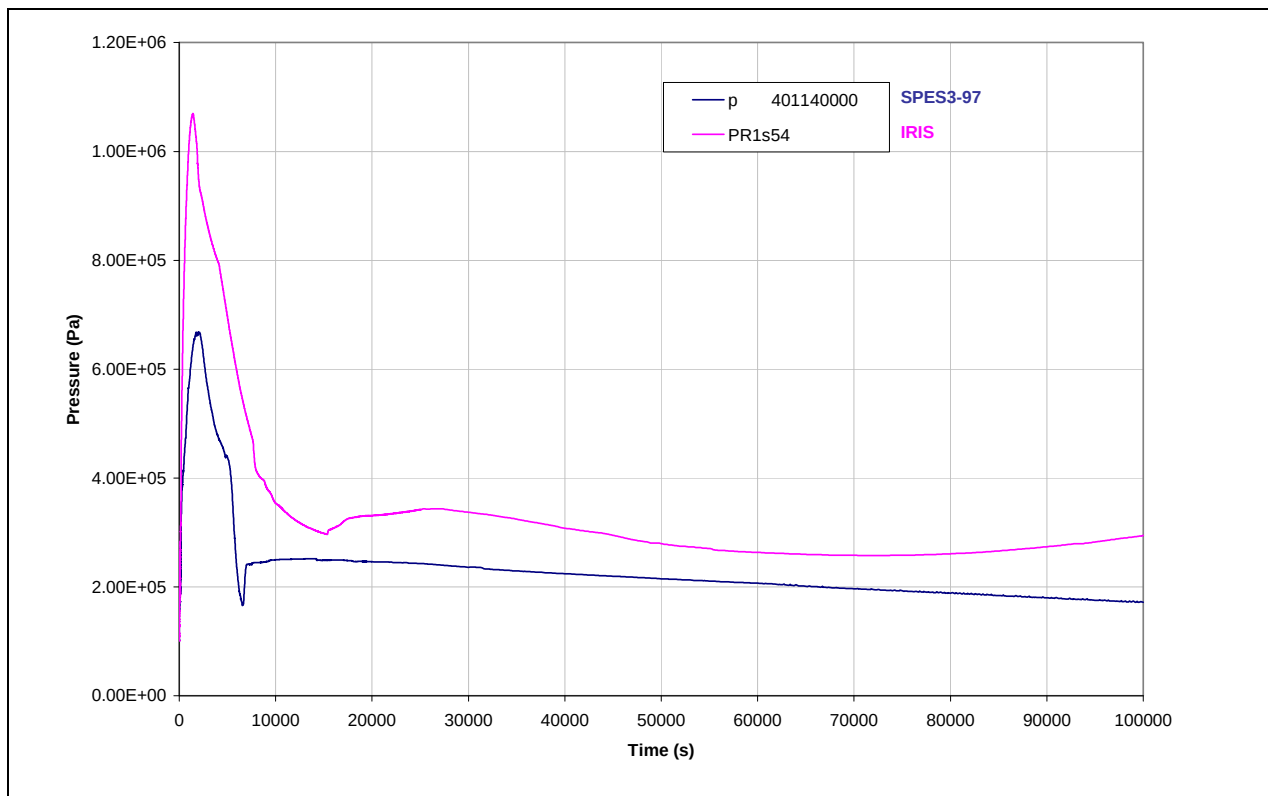
**Fig.4.3 – SPES3-97 and IRIS HT1 DVI break flow**



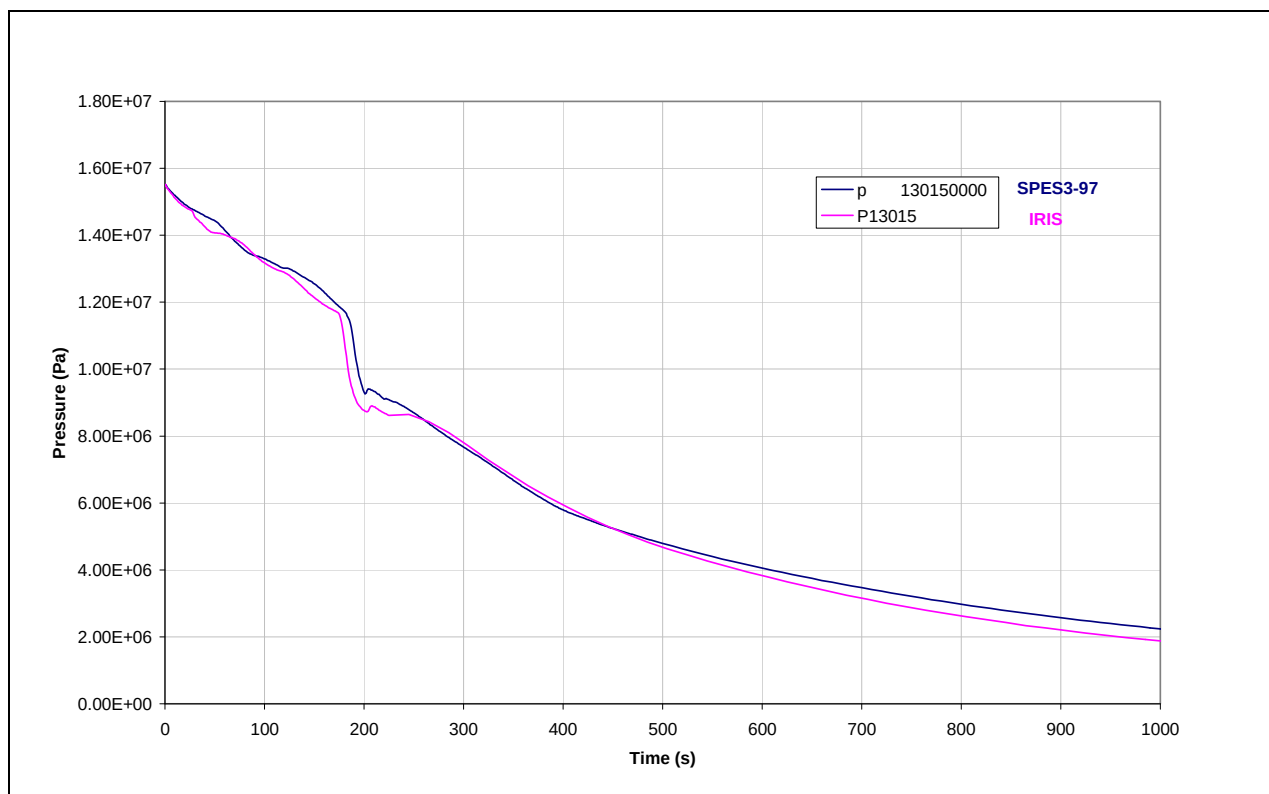
**Fig.4.4 – SPES3-97 and IRIS HT1 DW pressure (window)**



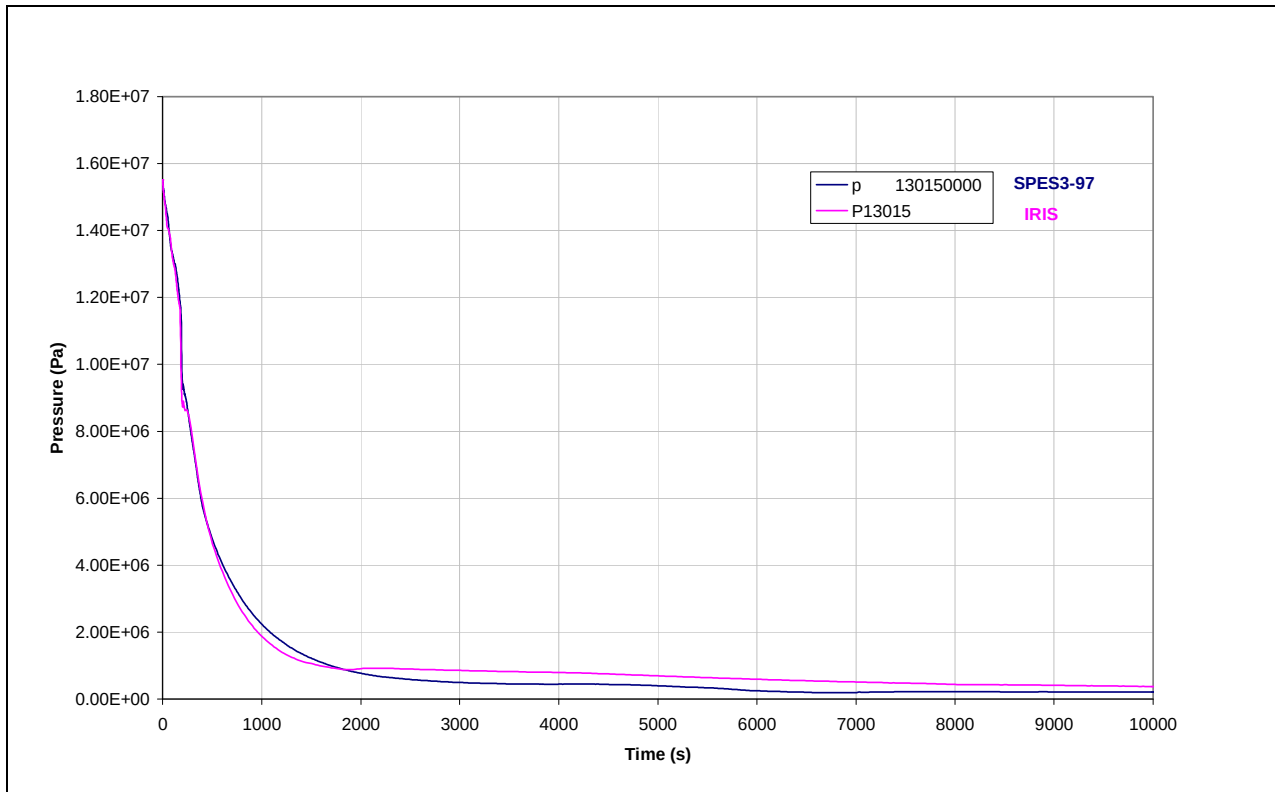
**Fig.4.5 – SPES3-97 and IRIS HT1 DW pressure**



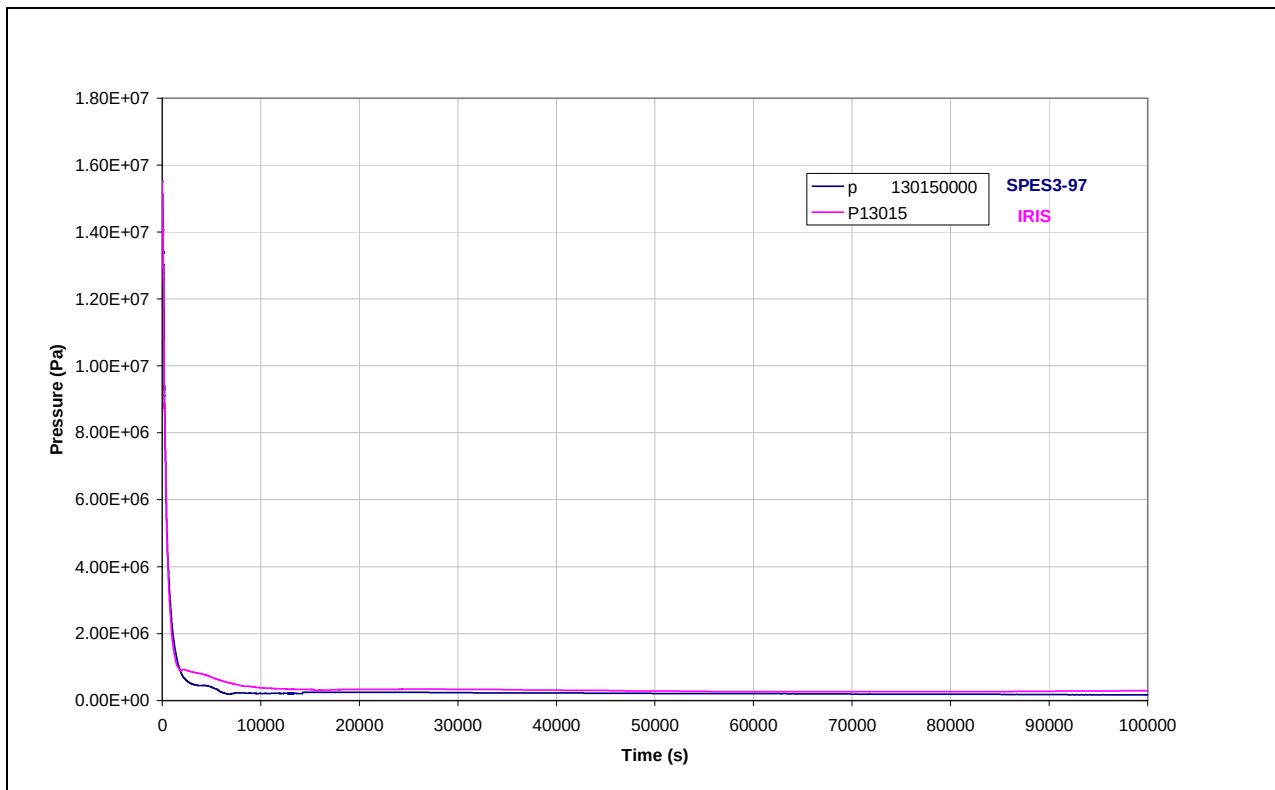
**Fig.4.6 – SPES3-97 and IRIS HT1 PRZ pressure (window)**



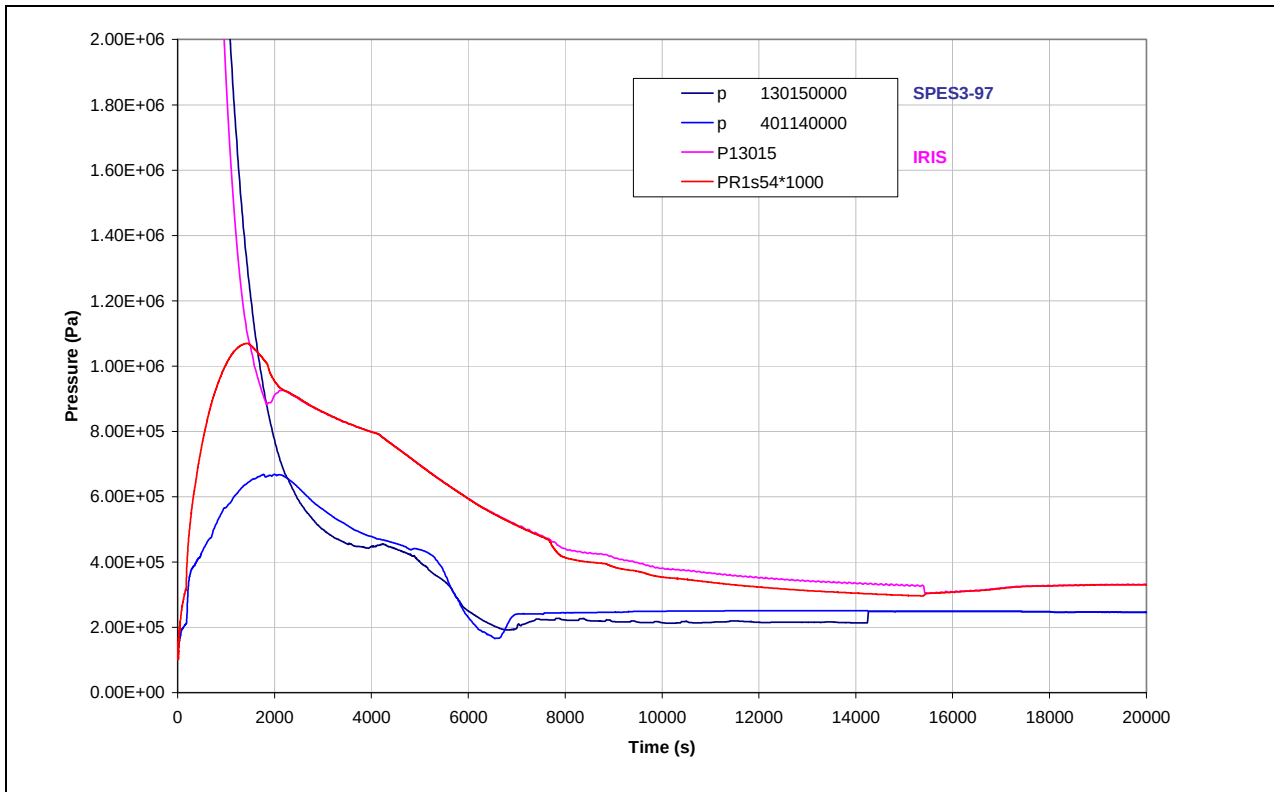
**Fig.4.7 – SPES3-97 and IRIS HT1 PRZ pressure (window)**



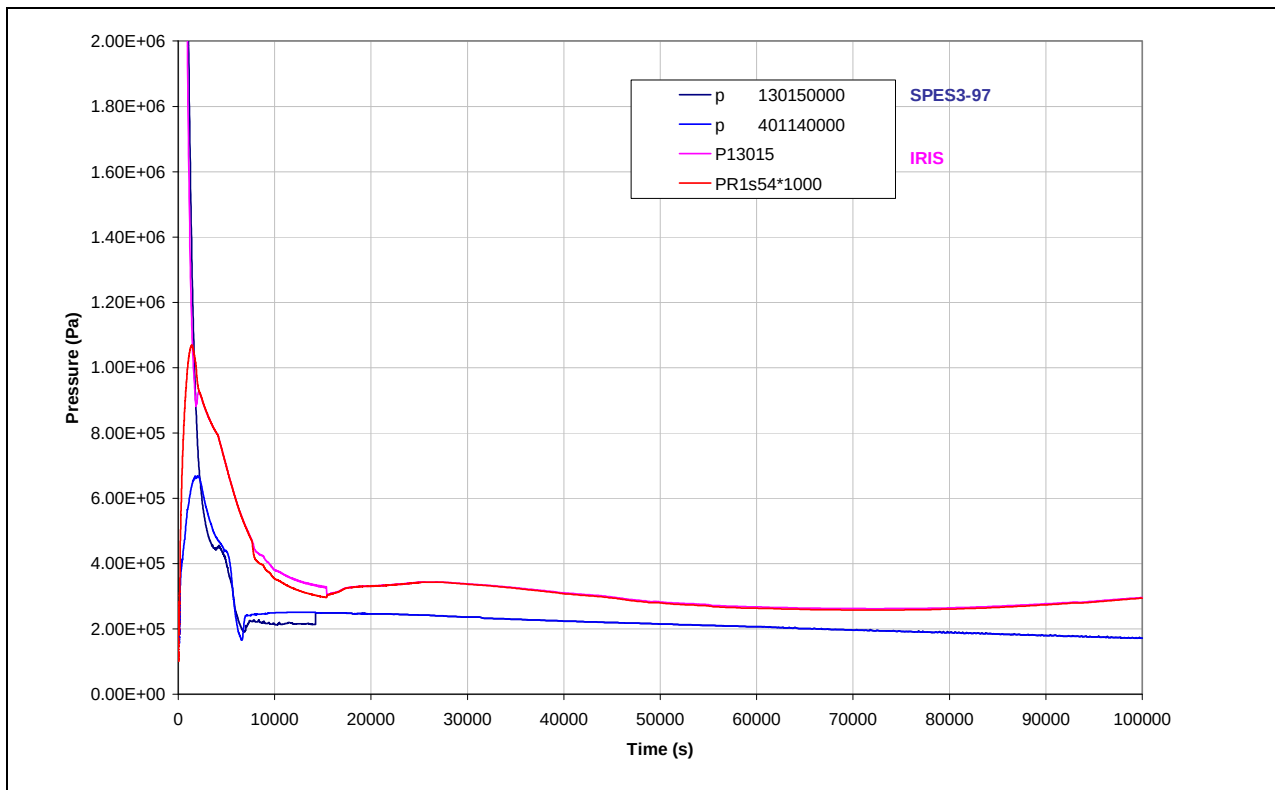
**Fig.4.8 – SPES3-97 and IRIS HT1 PRZ pressure**



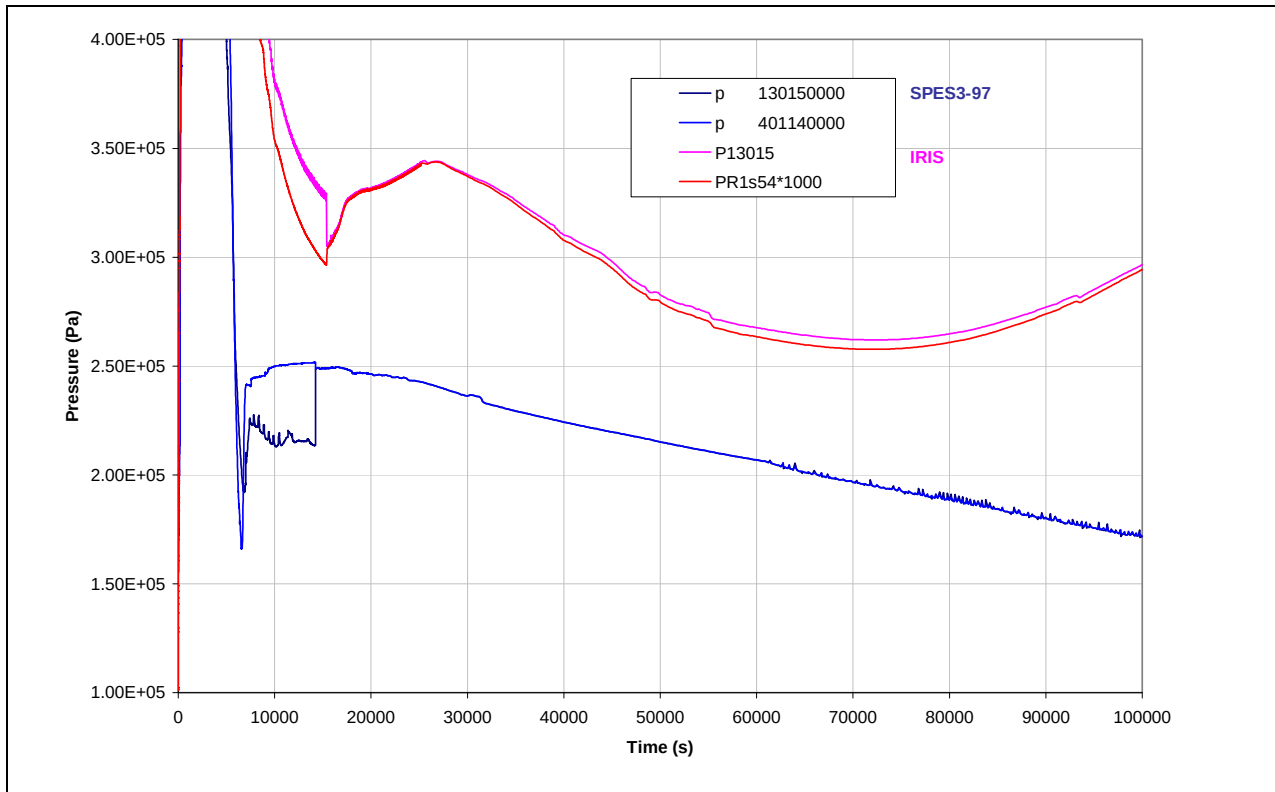
**Fig.4.9 – SPES3-97 and IRIS HT1 PRZ and DW pressures (window)**



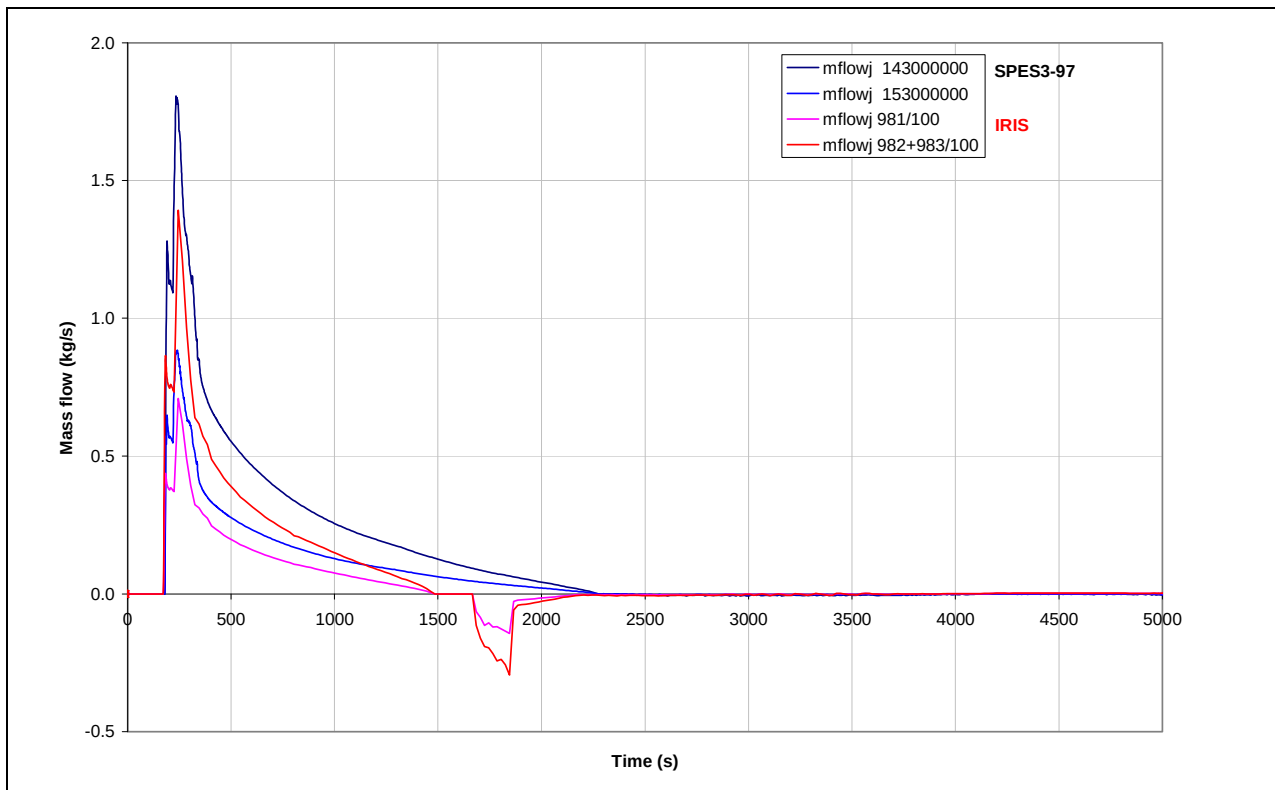
**Fig.4.10 – SPES3-97 and IRIS HT1 PRZ and DW pressures**



**Fig.4.11 – SPES3-97 and IRIS HT1 PRZ and DW pressures (detail)**

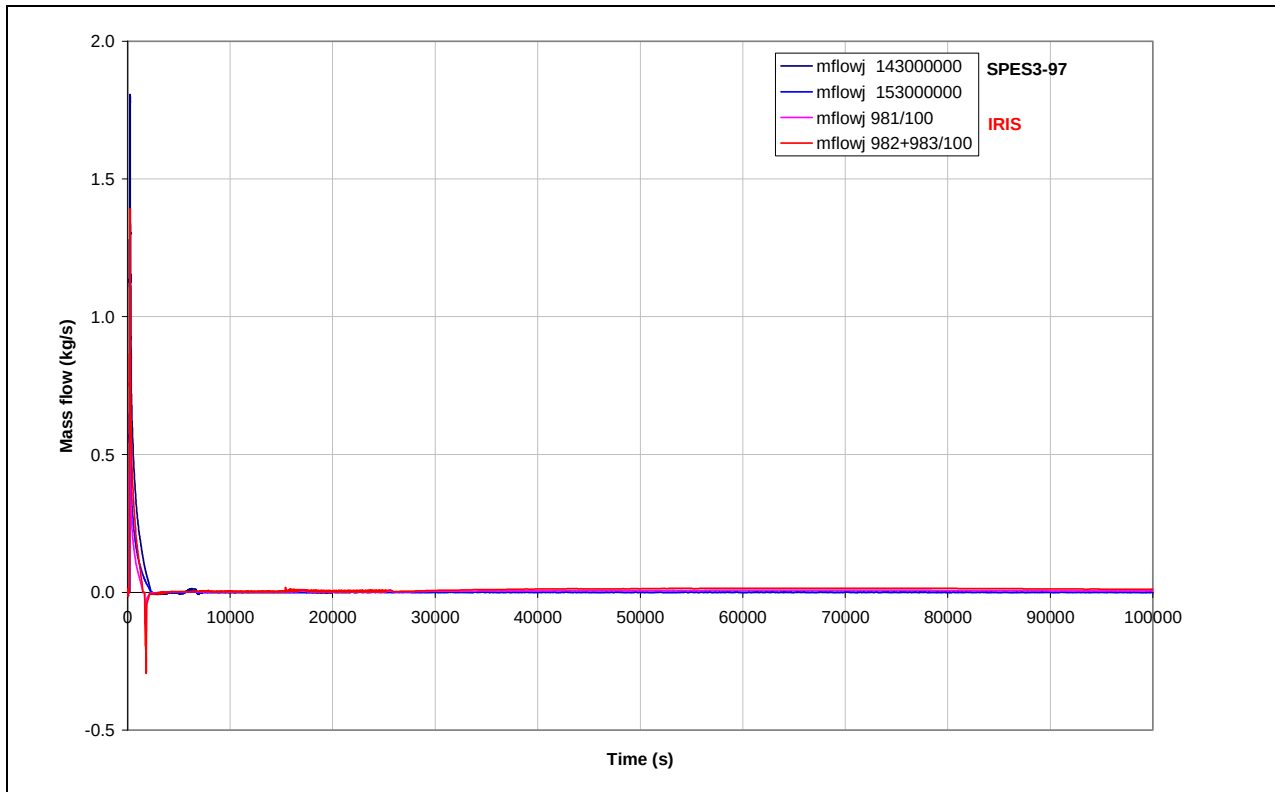


**Fig.4.12 – SPES3-97 and IRIS HT1 ADS Stage-I mass flow (window)**

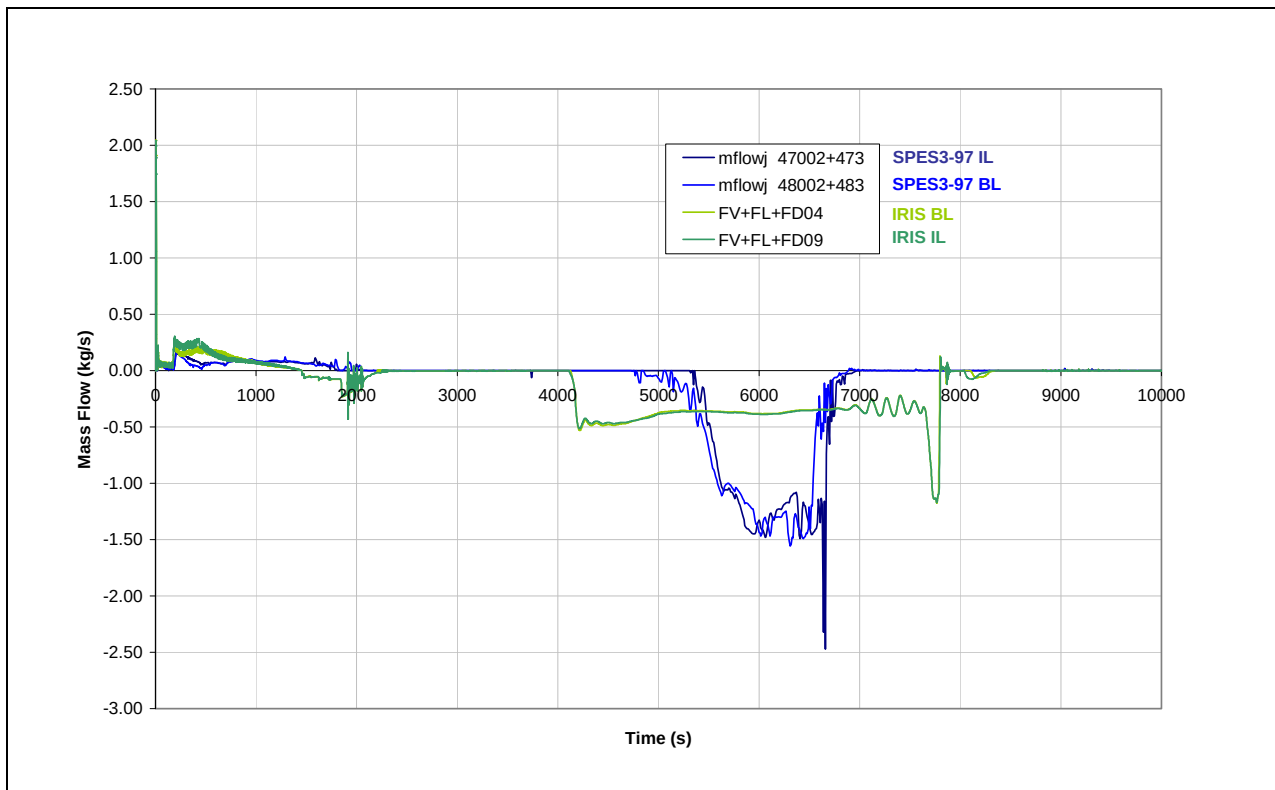




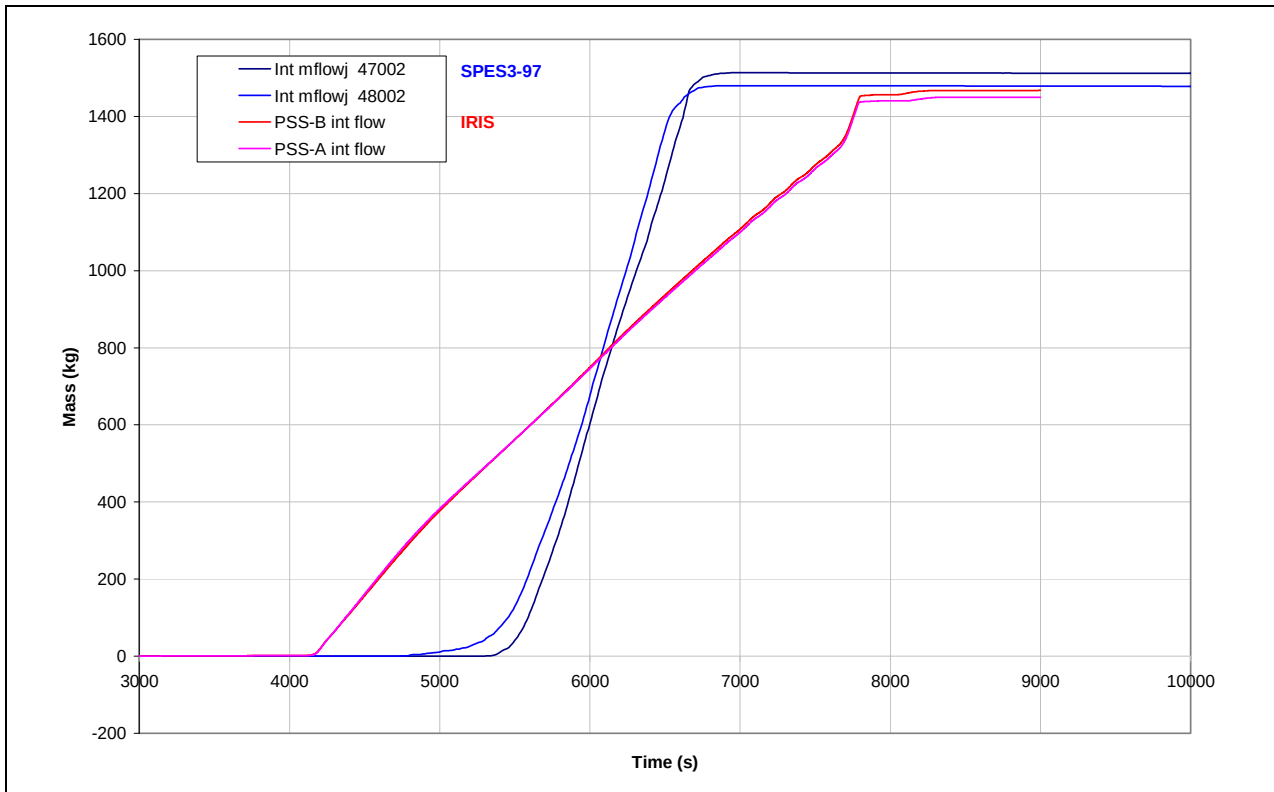
**Fig.4.13 – SPES3-97 and IRIS HT1 ADS Stage-I mass flow**



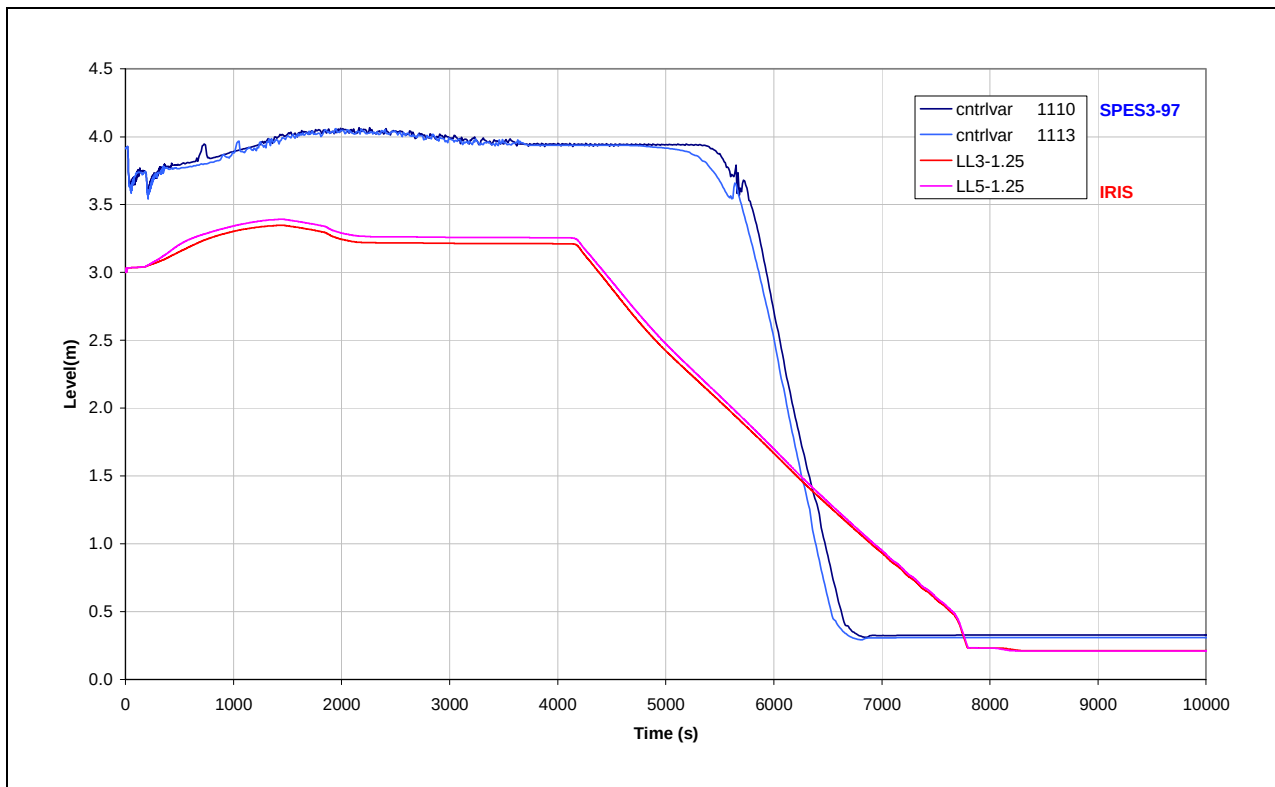
**Fig.4.14 – SPES3-97 and IRIS HT1 DW to PSS mass flow (window)**



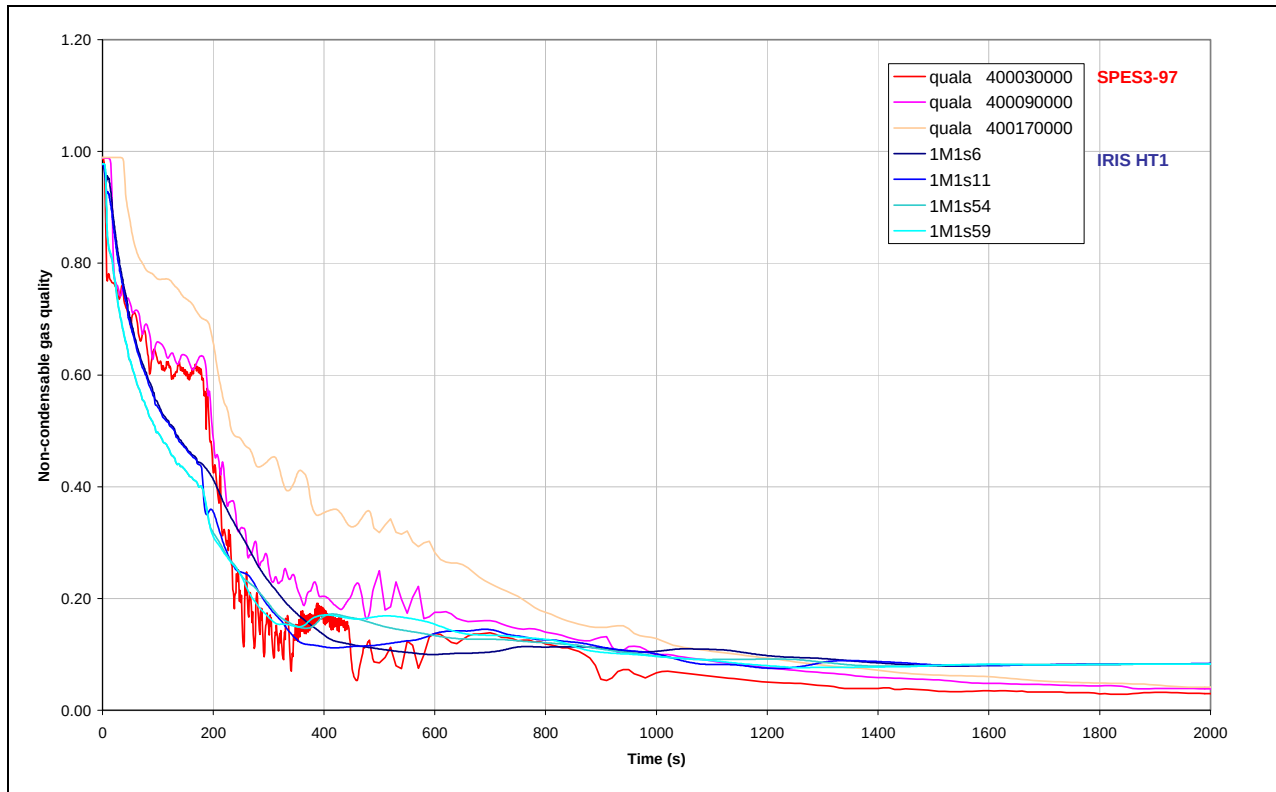
**Fig.4.15 – SPES3-97 and IRIS HT1 PSS to DW integral flow (window)**



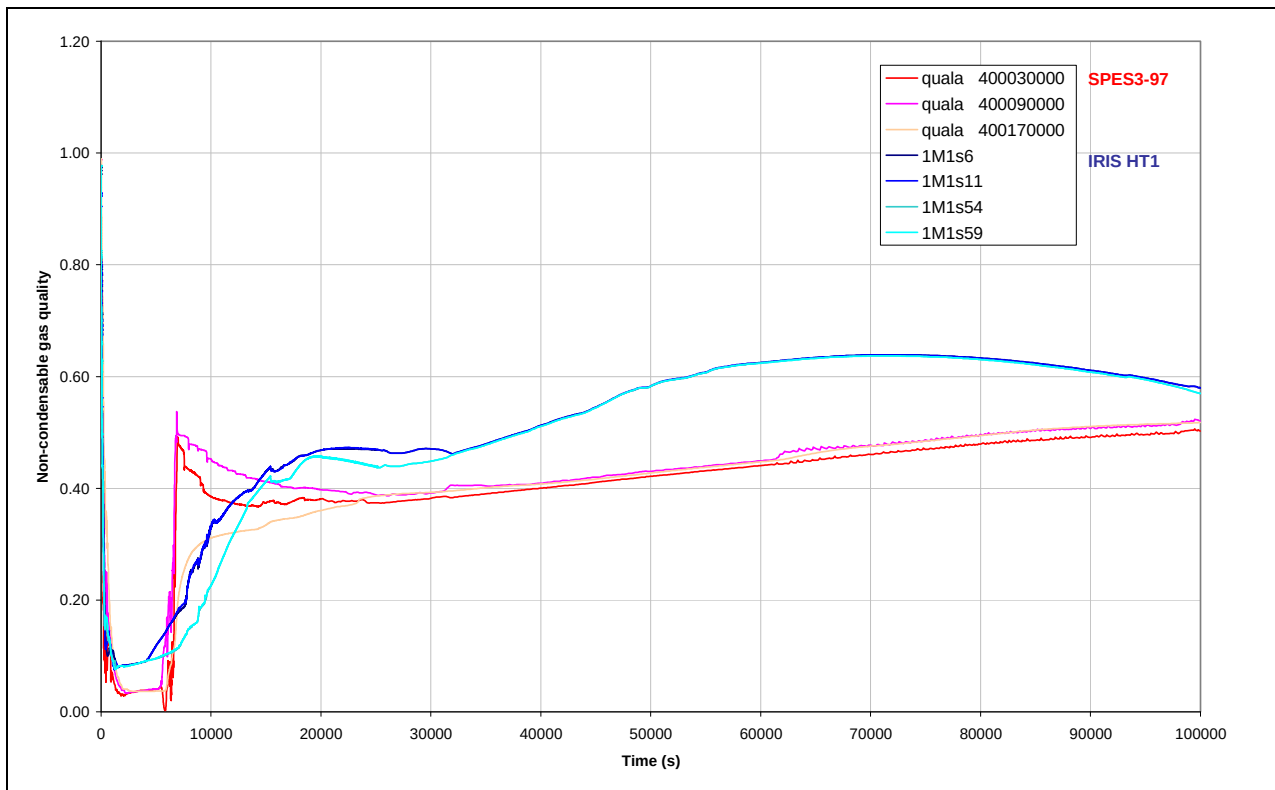
**Fig.4.16 – SPES3-97 and IRIS HT1 PSS level (window)**



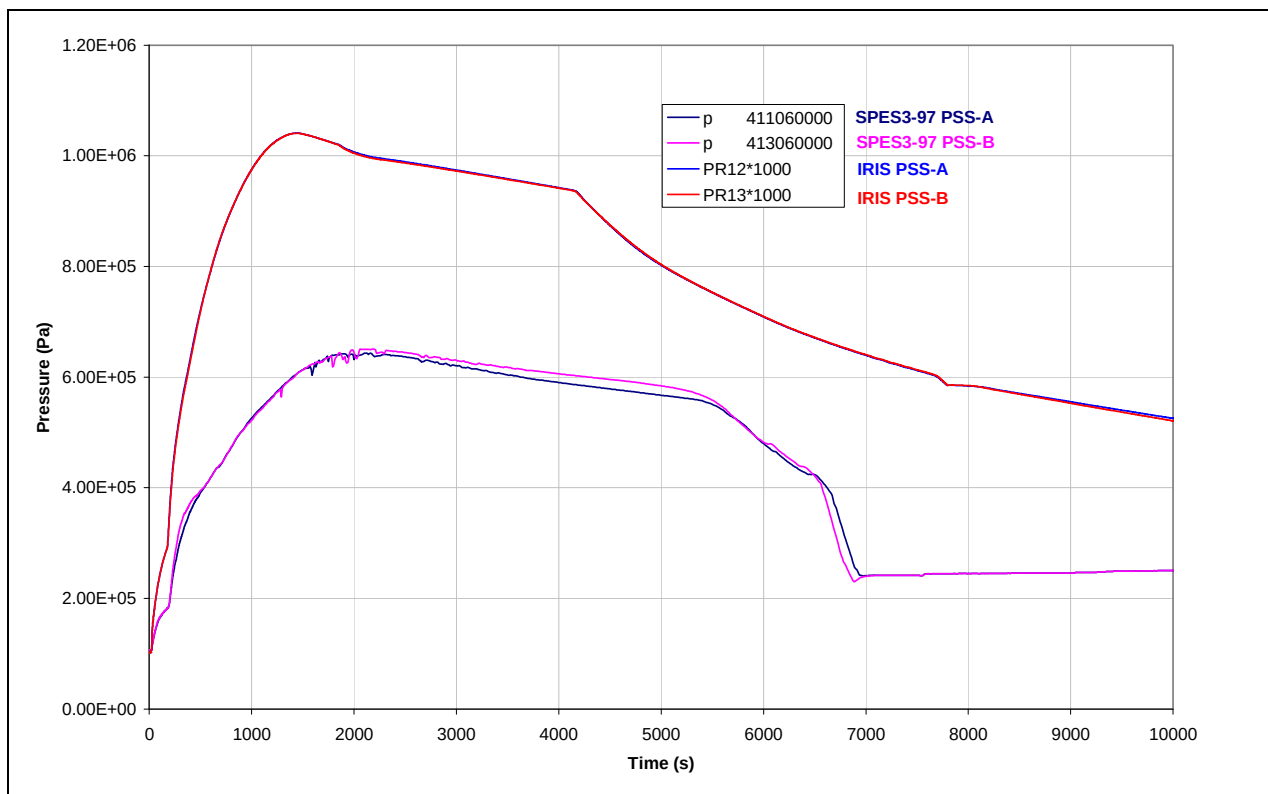
**Fig.4.17 – SPES3-97 and IRIS HT1 DW non-condensable gas quality (window)**



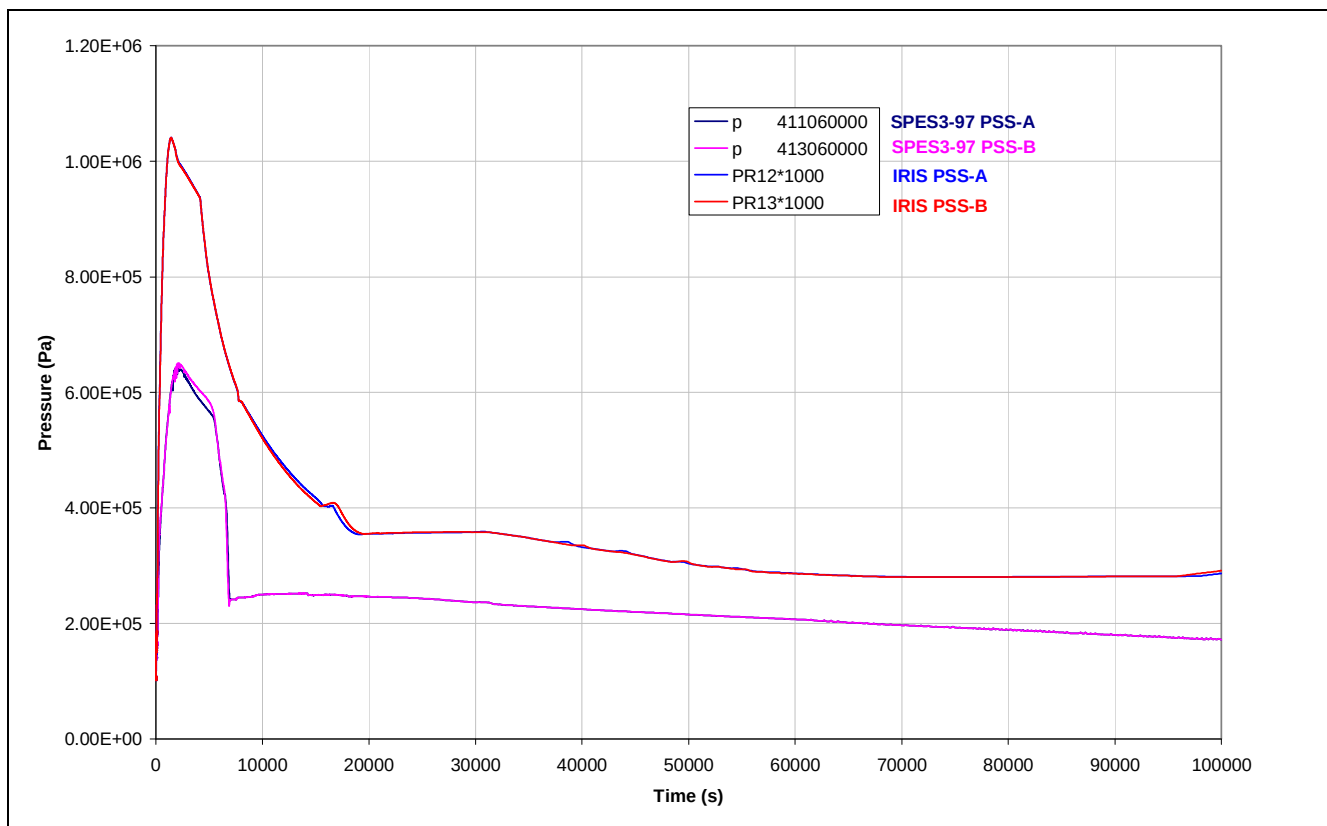
**Fig.4.18 – SPES3-97 and IRIS HT1 DW non-condensable gas quality**



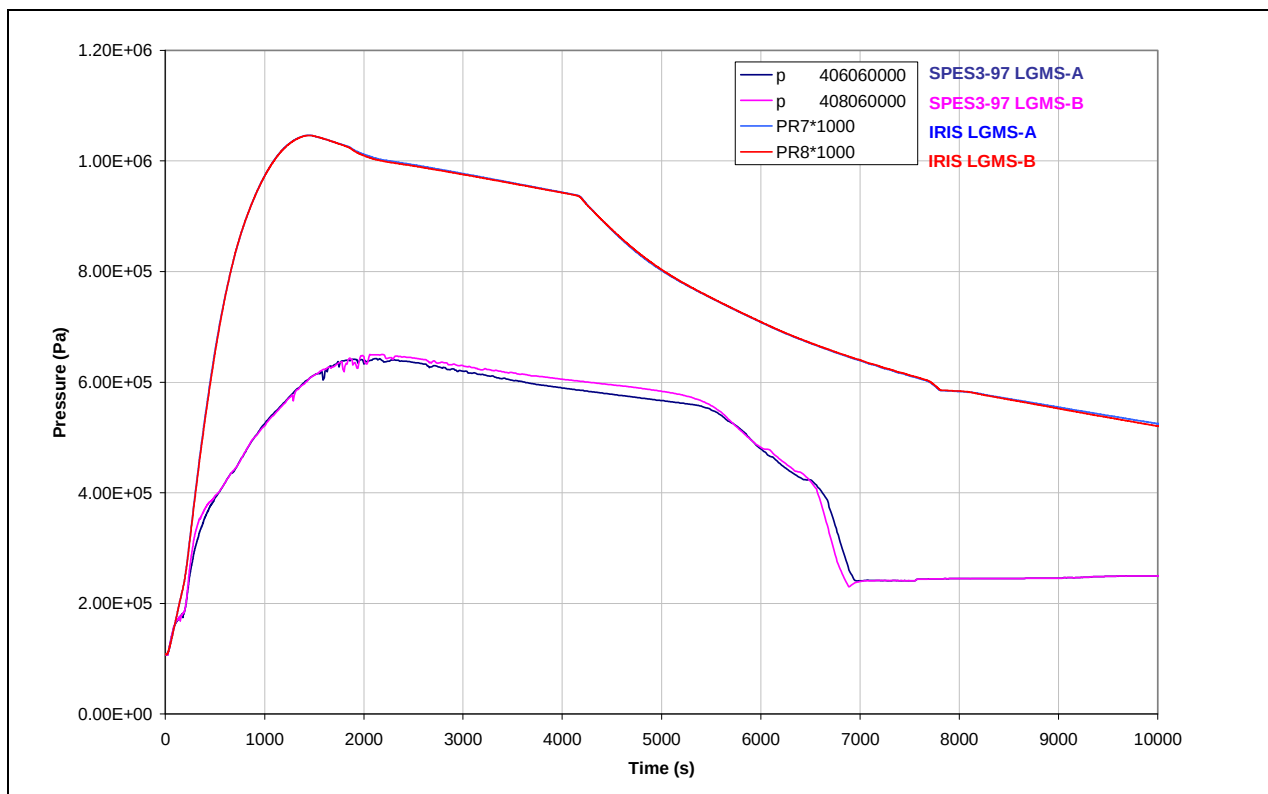
**Fig.4.19 – SPES3-97 and IRIS HT1 PSS pressure (window)**



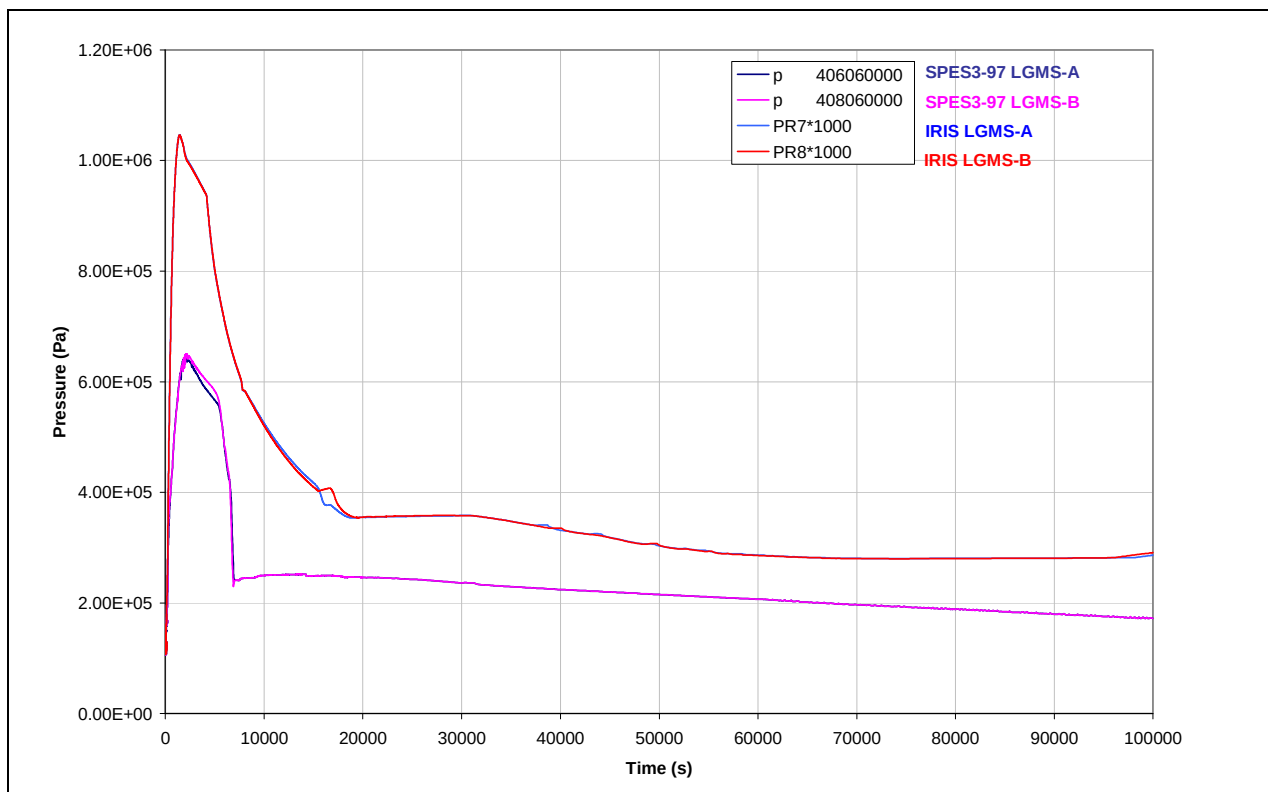
**Fig.4.20 – SPES3-97 and IRIS HT1 PSS pressure**



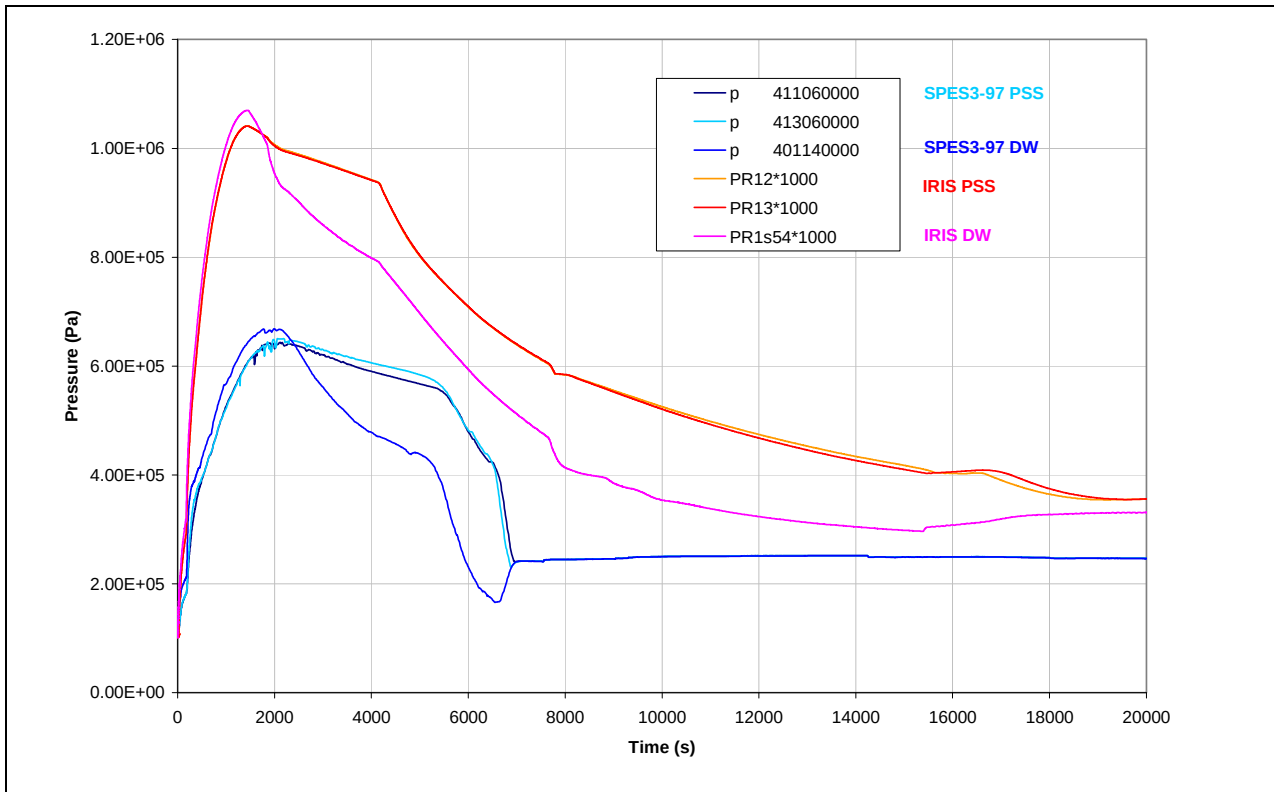
**Fig.4.21 – SPES3-97 and IRIS HT1 LGMS pressure (window)**



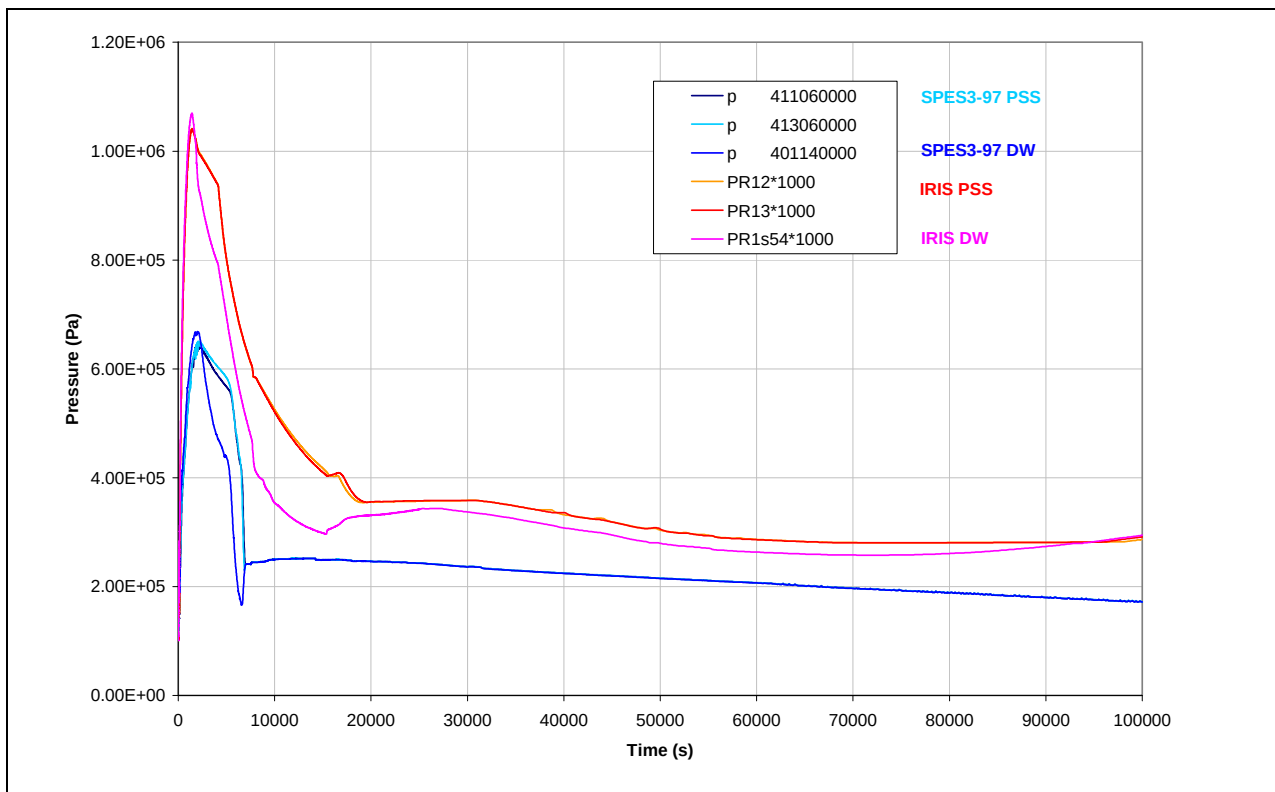
**Fig.4.22 – SPES3-97 and IRIS HT1 LGMS pressure**



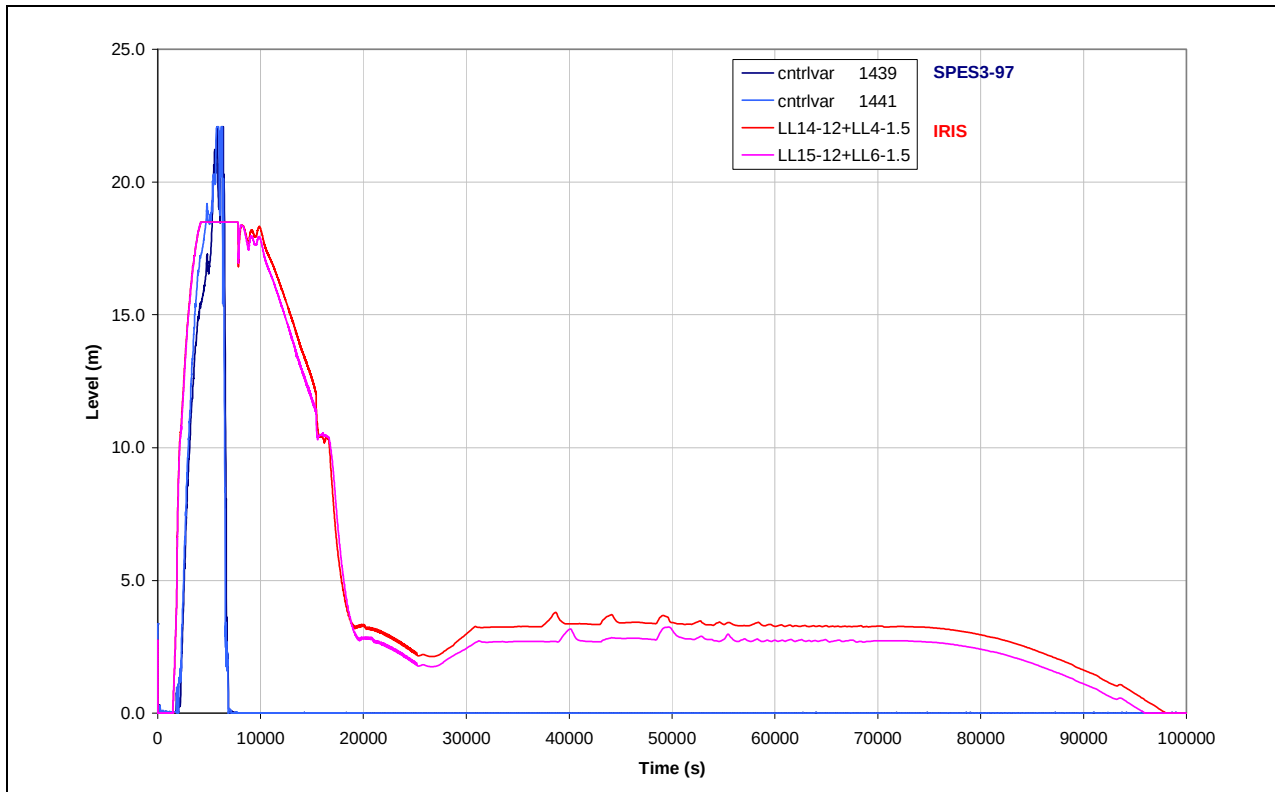
**Fig.4.23 – SPES3-97 and IRIS HT1 DW and PSS pressure (window)**



**Fig.4.24 – SPES3-97 and IRIS HT1 DW and PSS pressure**



**Fig.4.25 – SPES3-97 and IRIS HT1 PSS to DW pipe level**



**Fig.4.26 – SPES3-97 and IRIS HT1 RC level (window)**

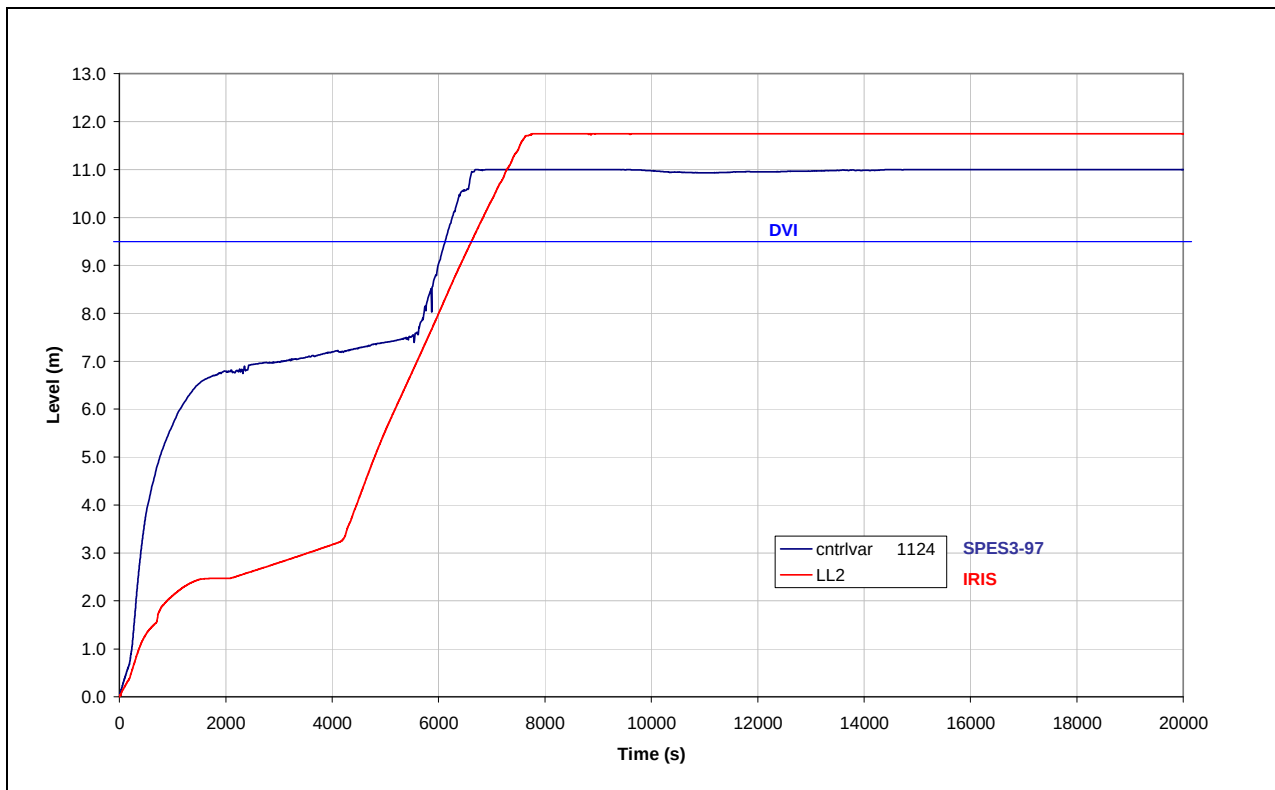


Fig.4.27 – SPES3-97 and IRIS HT1 DW level

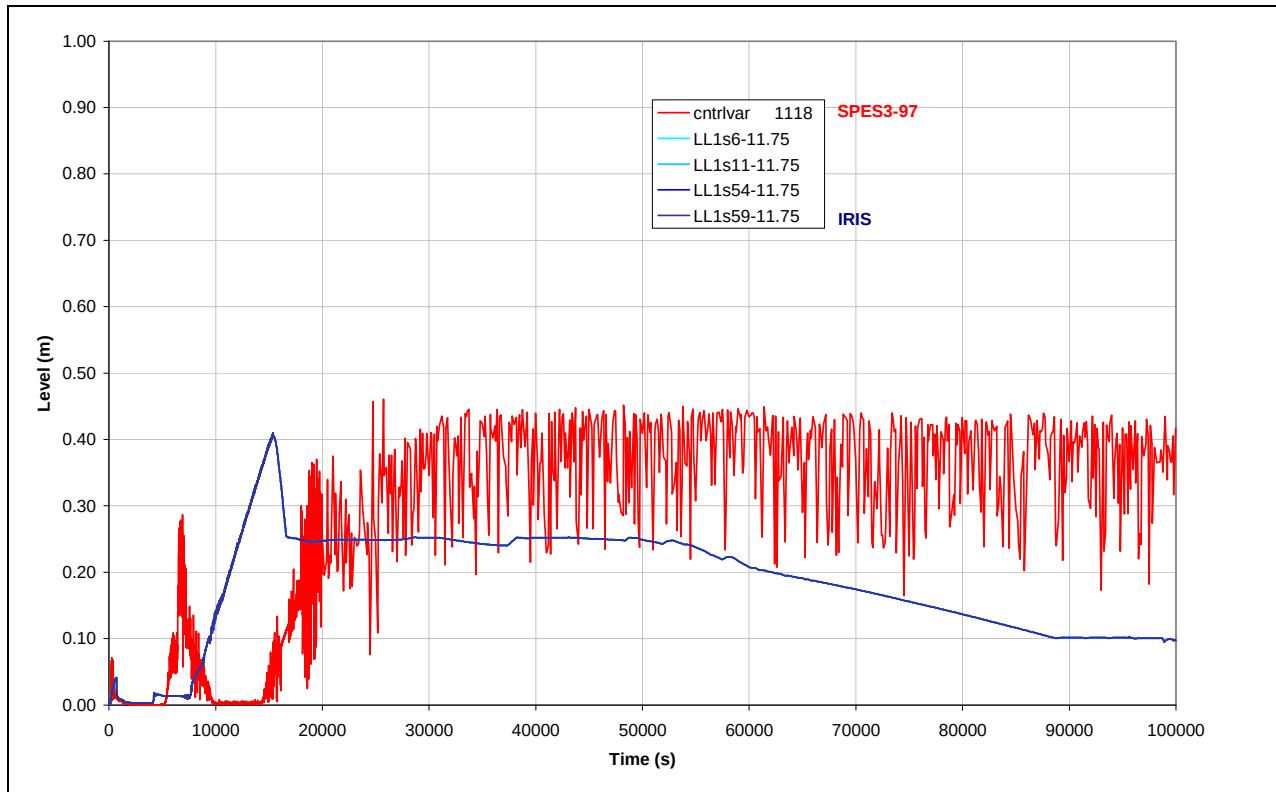


Fig.4.28 – SPES3-97 and IRIS HT1 PSS liquid and gas temperature (window)

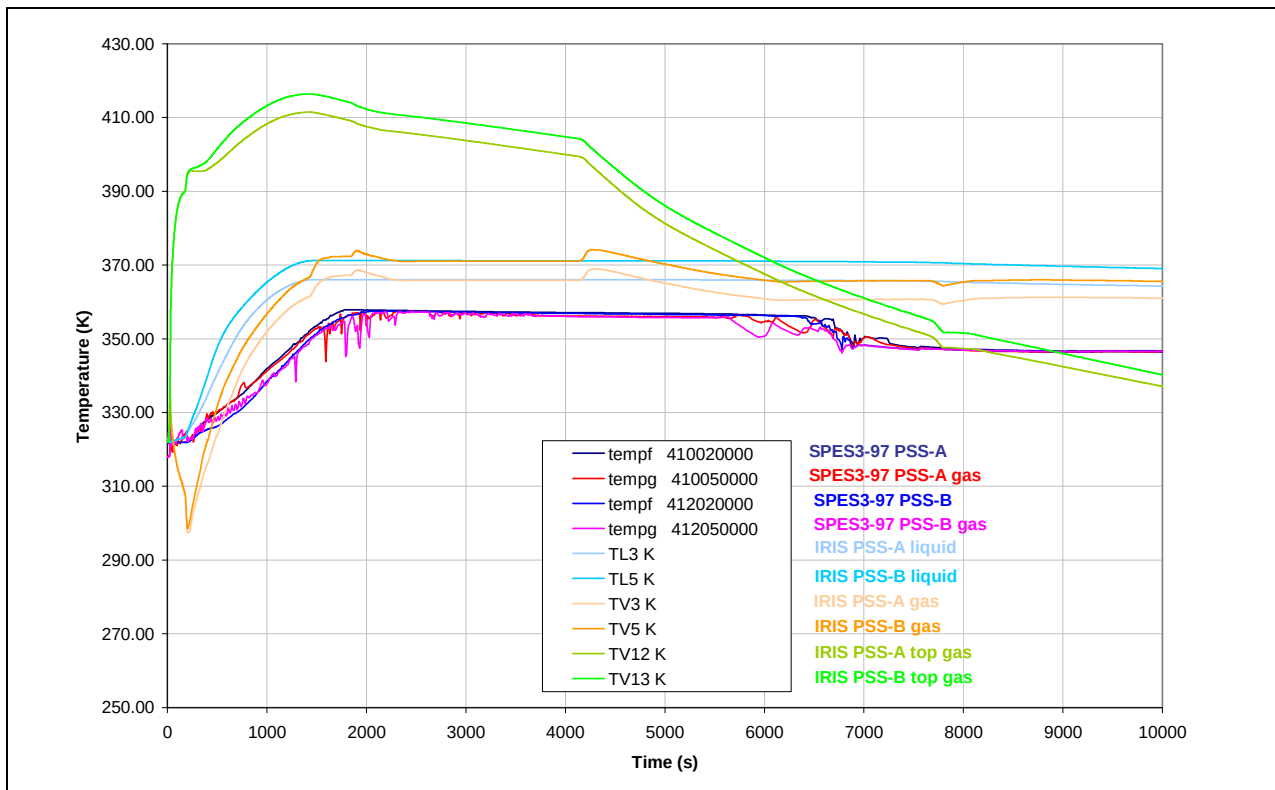




Fig.4.29 – SPES3-97 and IRIS HT1 PSS liquid and gas temperature

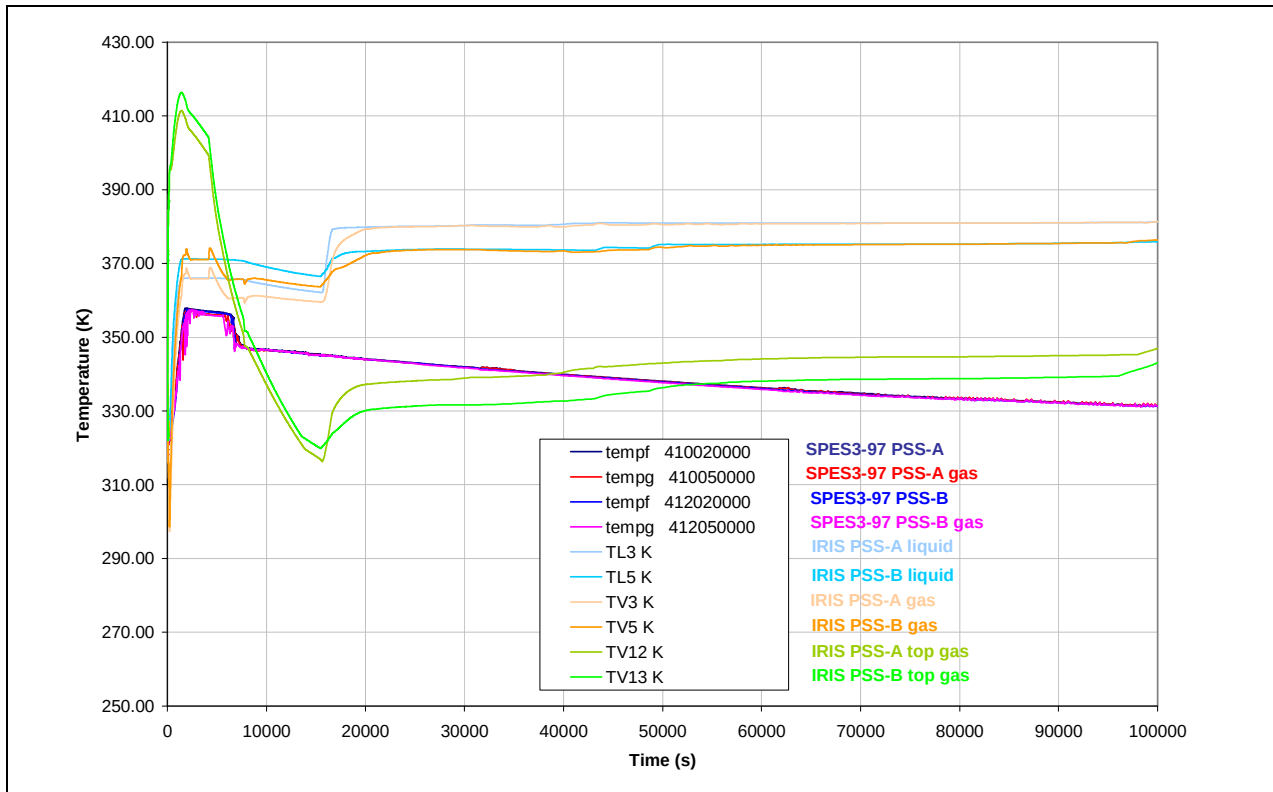
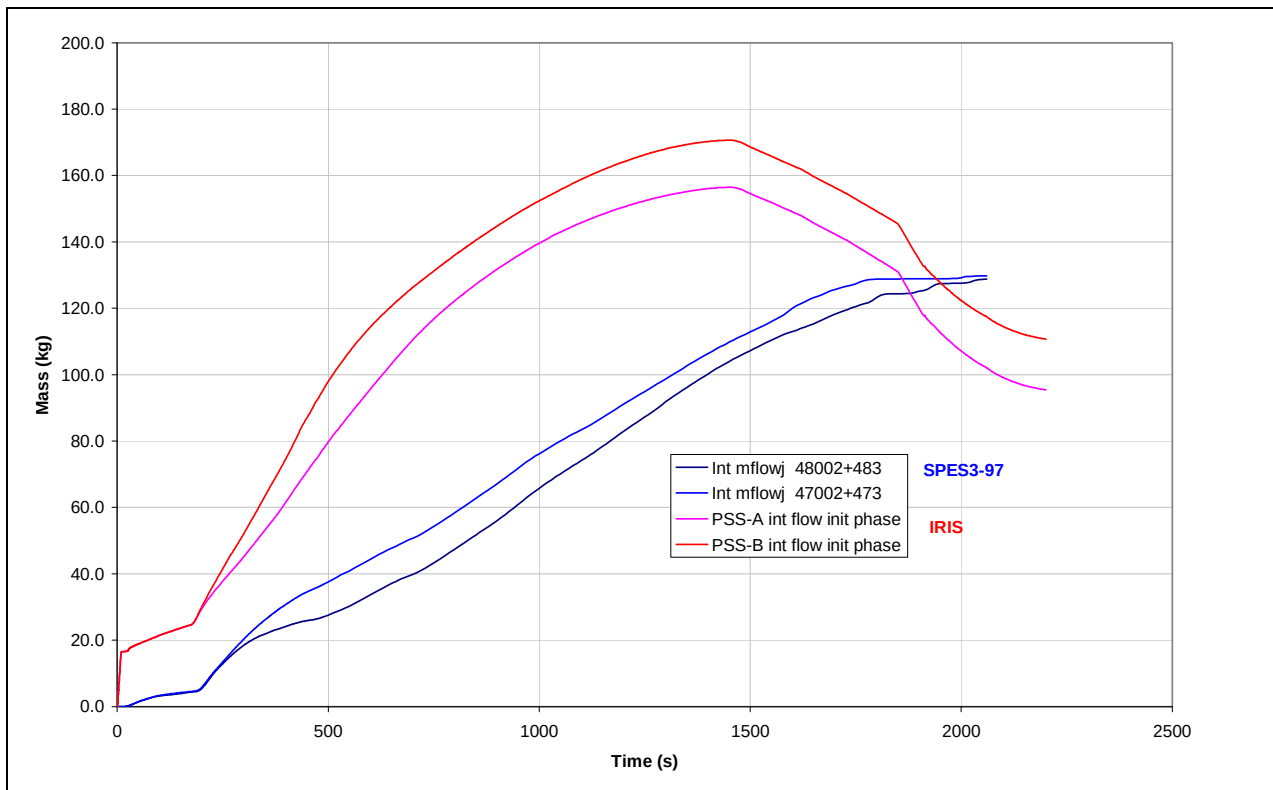
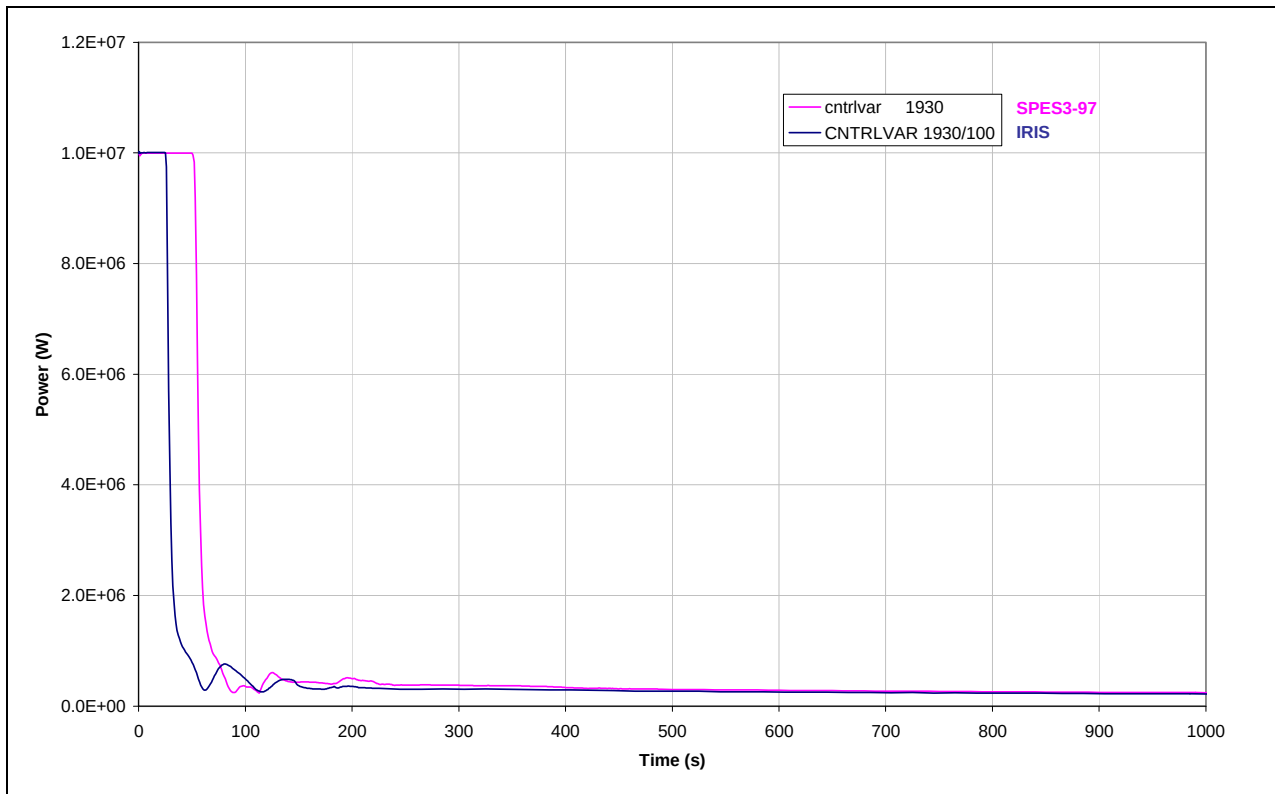


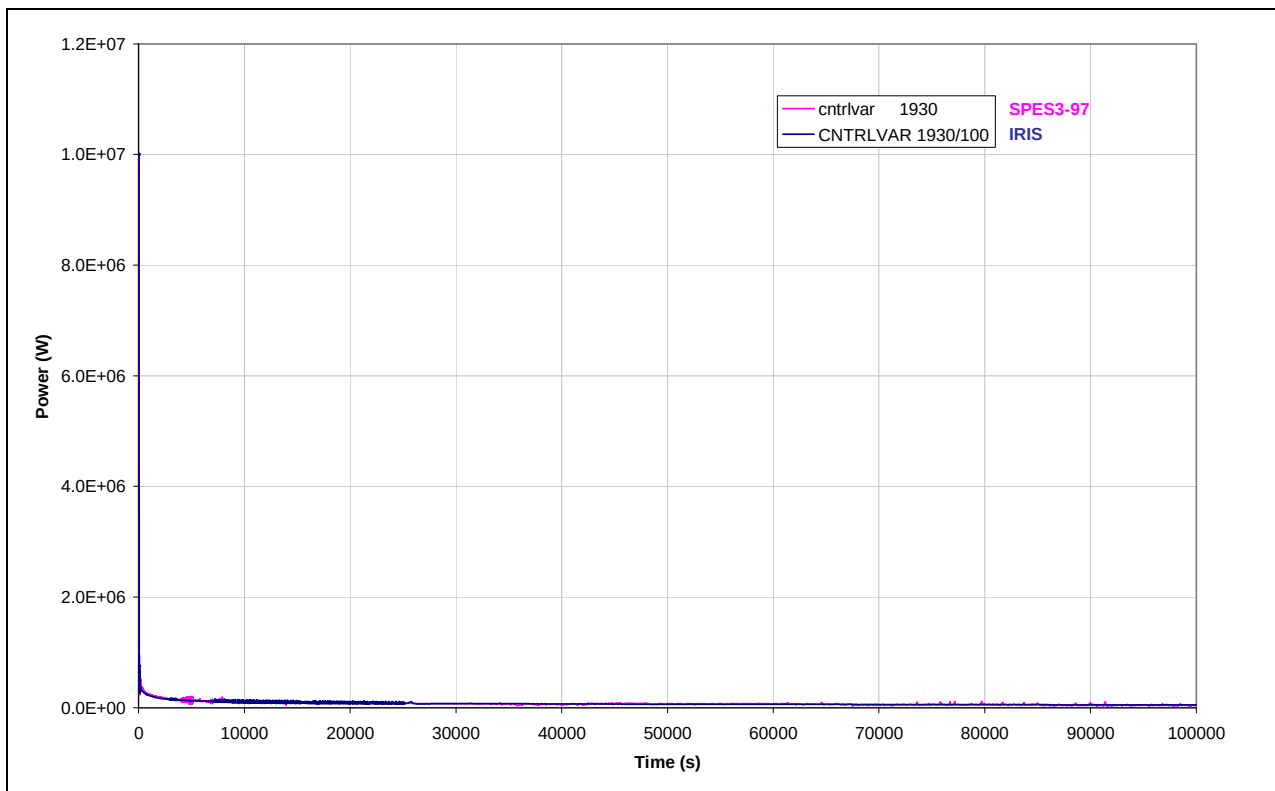
Fig.4.30 – SPES3-97 and IRIS HT1 DW to PSS integral flow (first phase of injection)



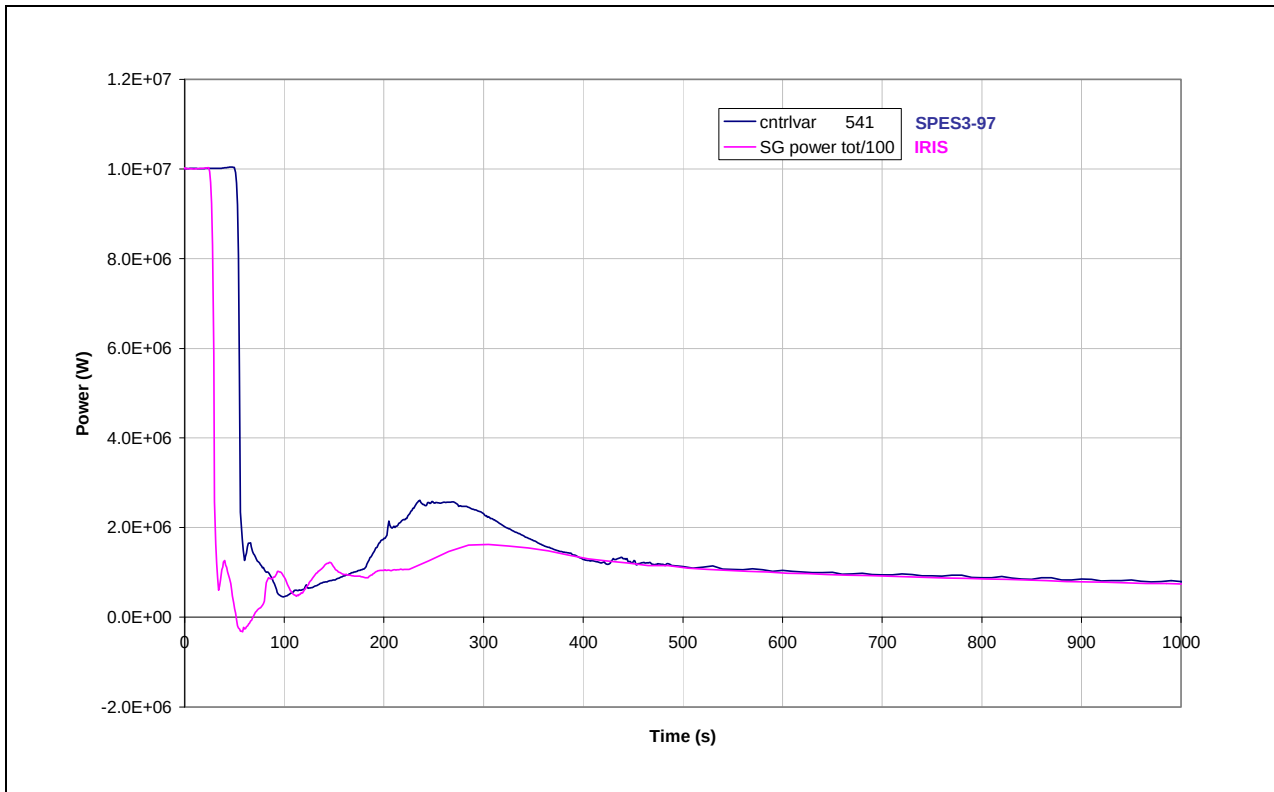
**Fig.4.31 – SPES3-97 and IRIS HT1 core power (window)**



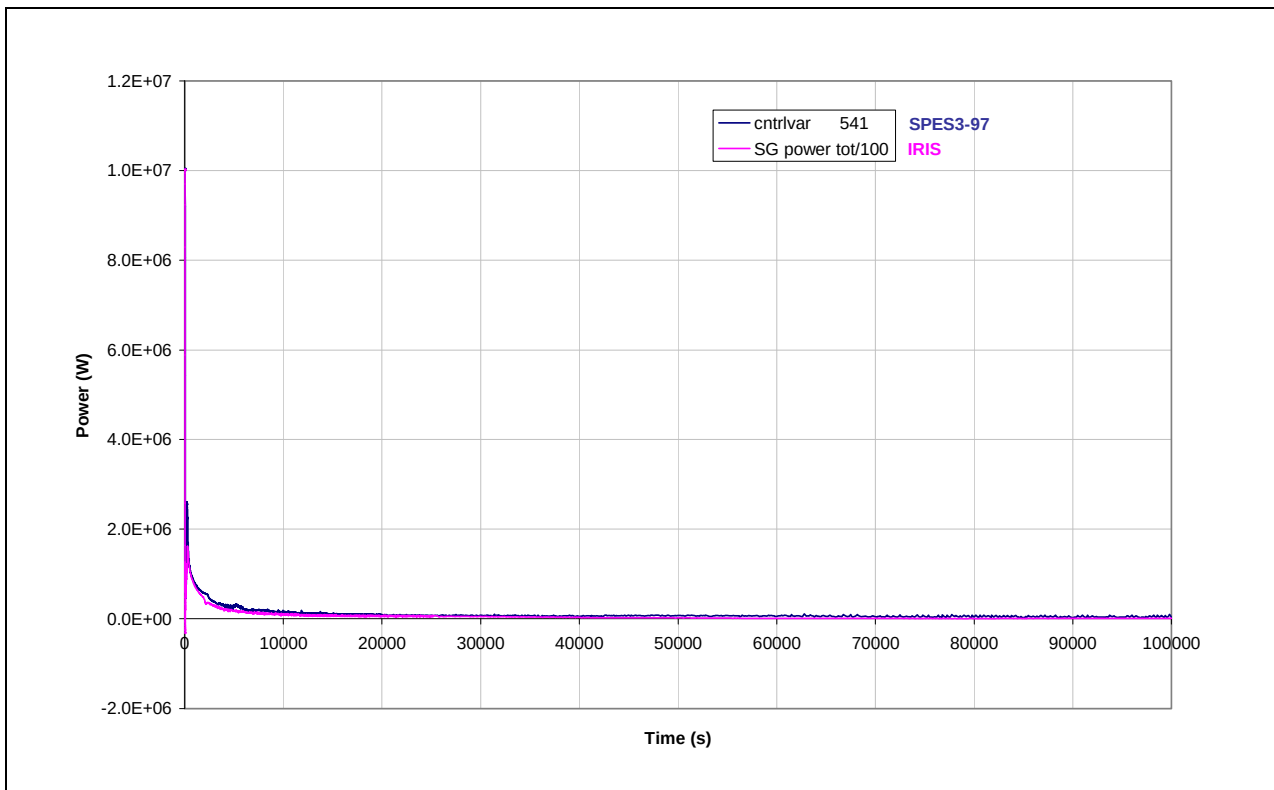
**Fig.4.32 – SPES3-97 and IRIS HT1 core power**



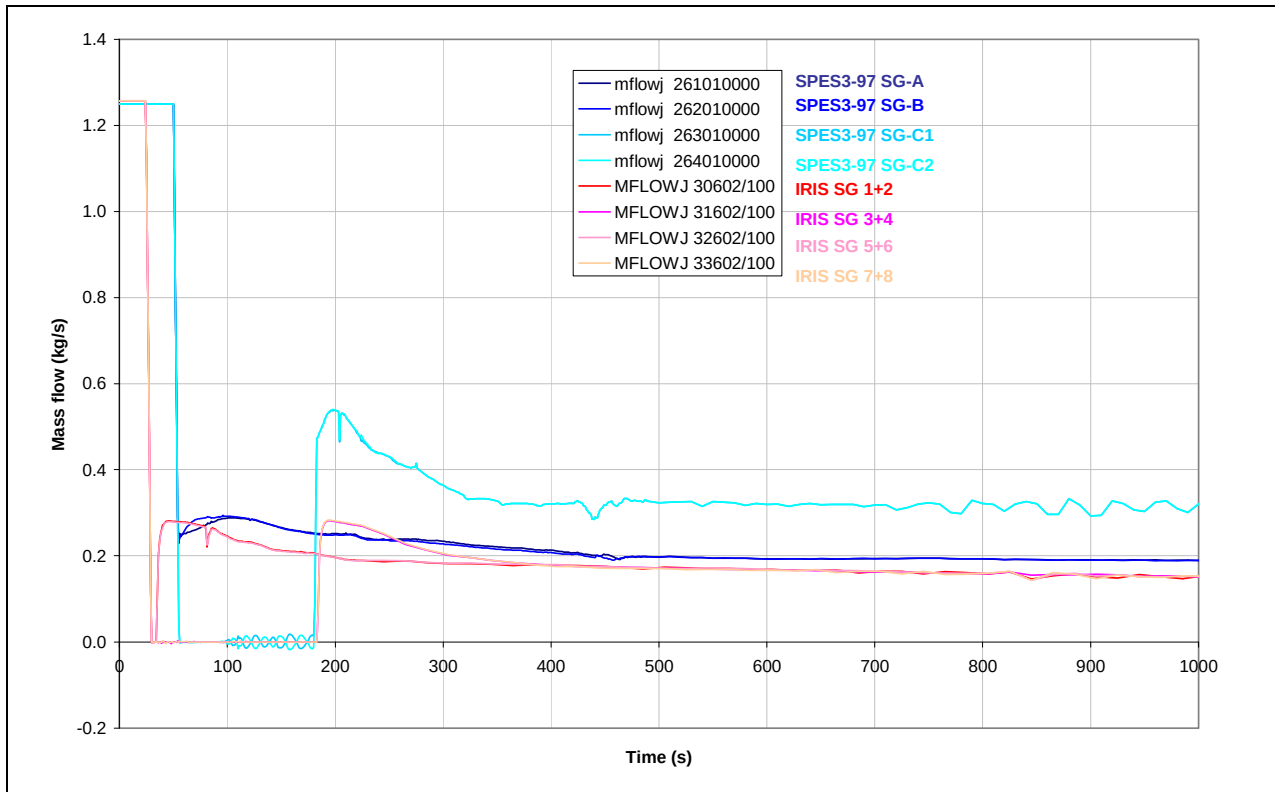
**Fig.4.33 – SPES3-97 and IRIS HT1 SG power (window)**



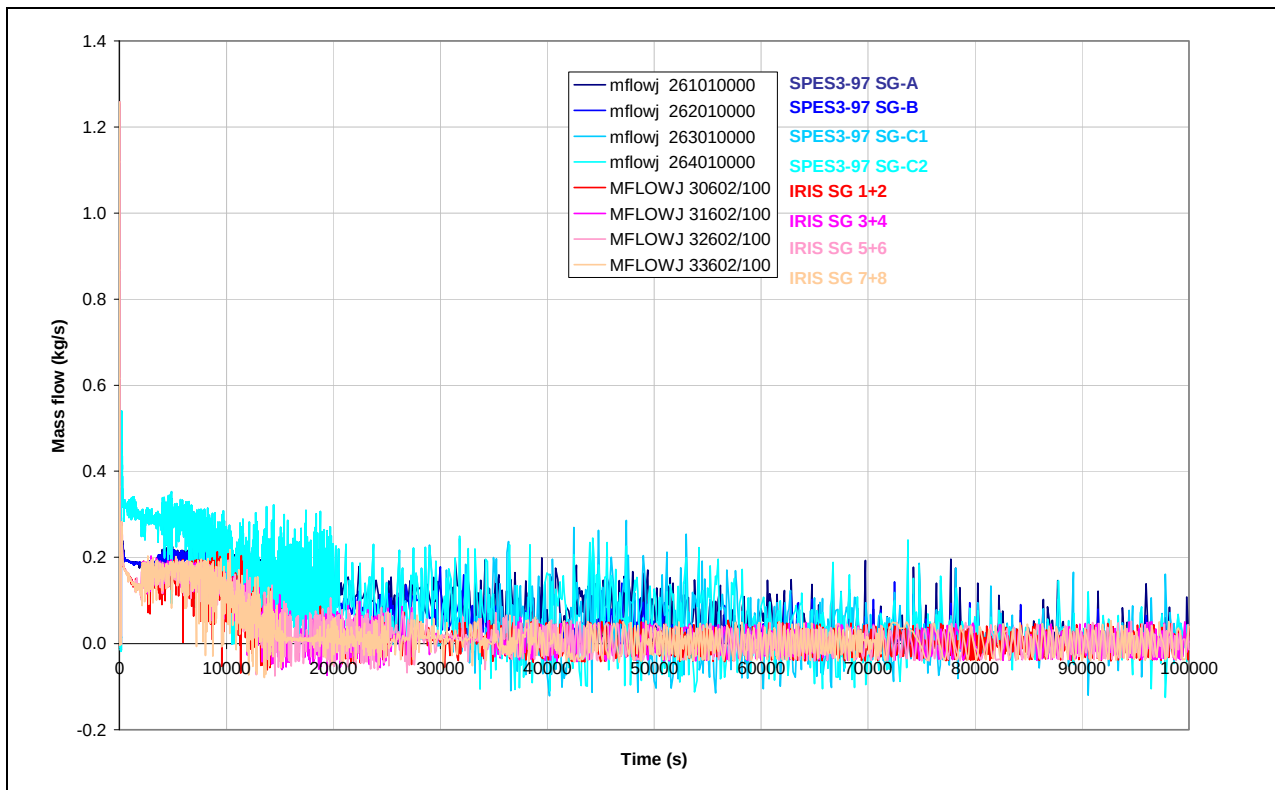
**Fig.4.34 – SPES3-97 and IRIS HT1 SG power**



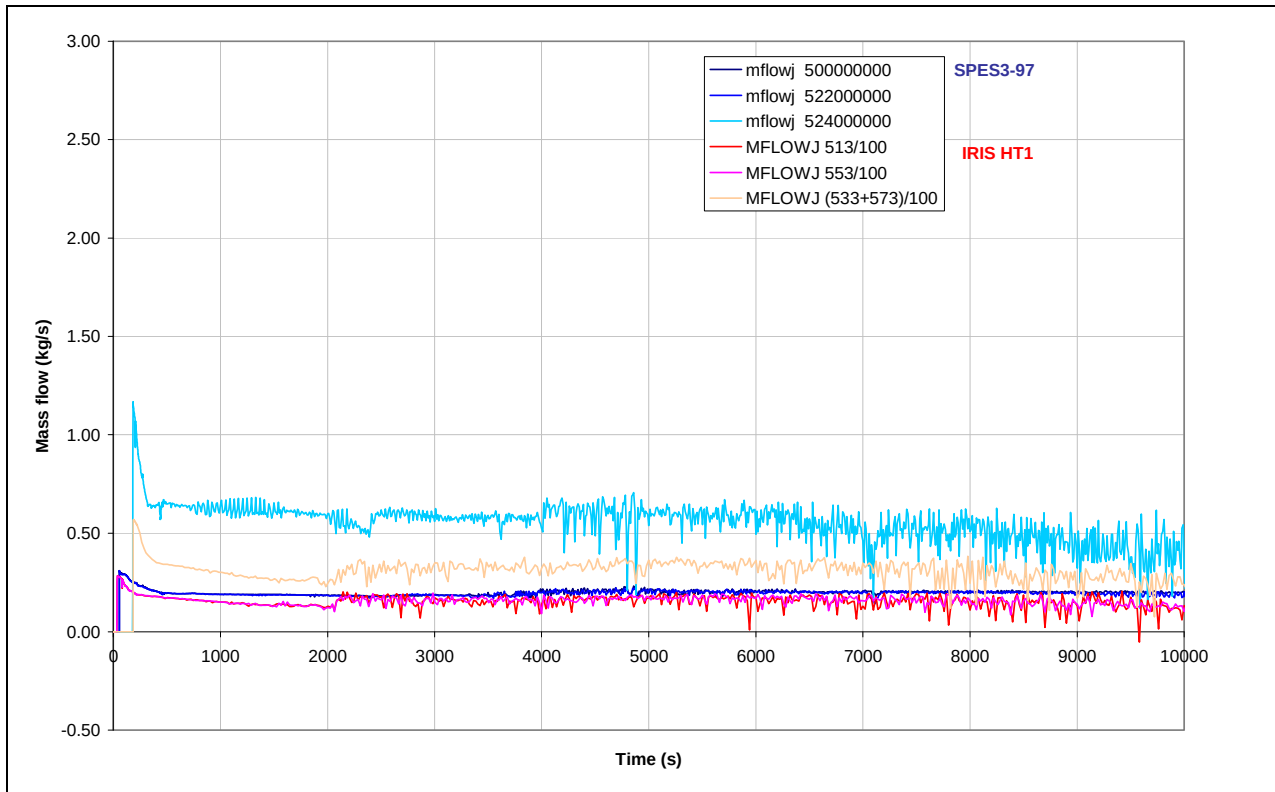
**Fig.4.35 – SPES3-97 and IRIS HT1 SG ss mass flow (window)**



**Fig.4.36 – SPES3-97 and IRIS HT1 SG ss mass flow**



**Fig.4.37 – SPES3-97 and IRIS HT1 EHRS cold leg mass flow (window)**



**Fig.4.38 – SPES3-97 and IRIS HT1 EHRS cold leg mass flow**

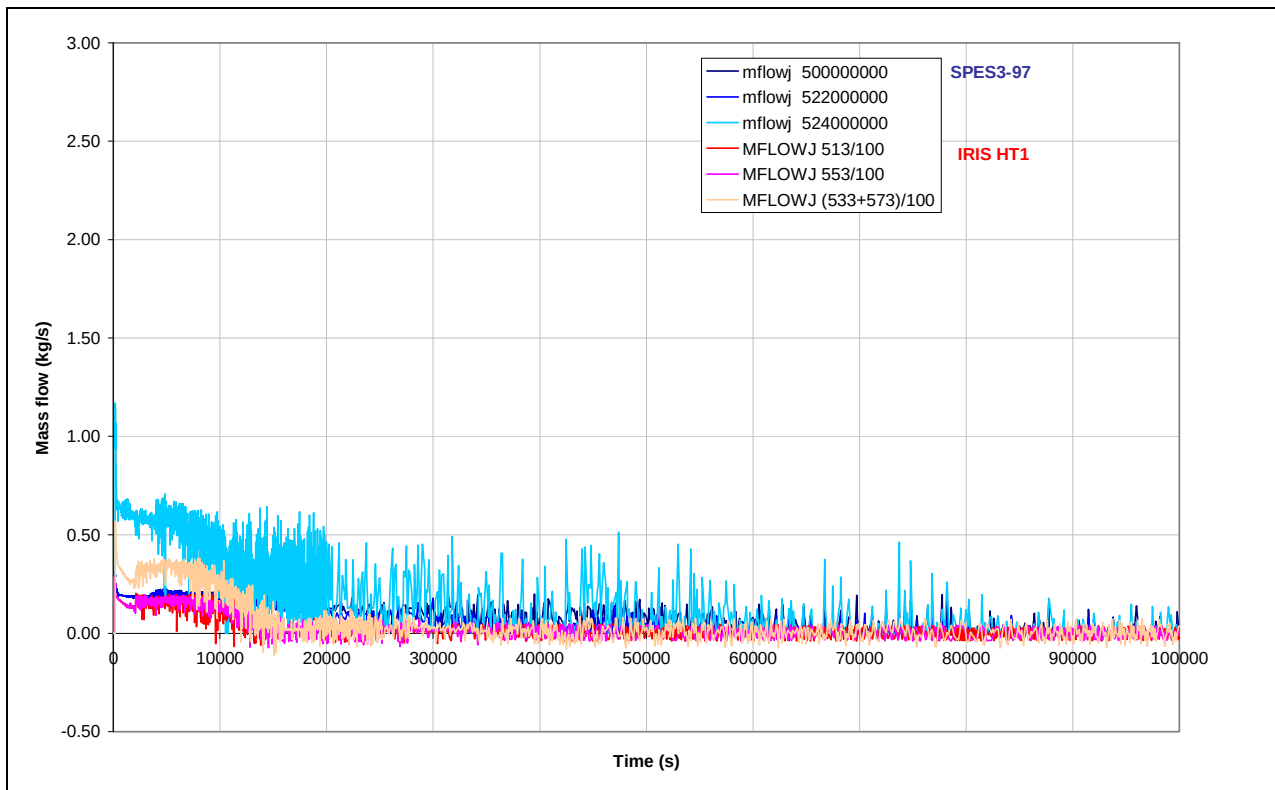


Fig.4.39 – SPES3-97 and IRIS HT1 EHRS power (window)

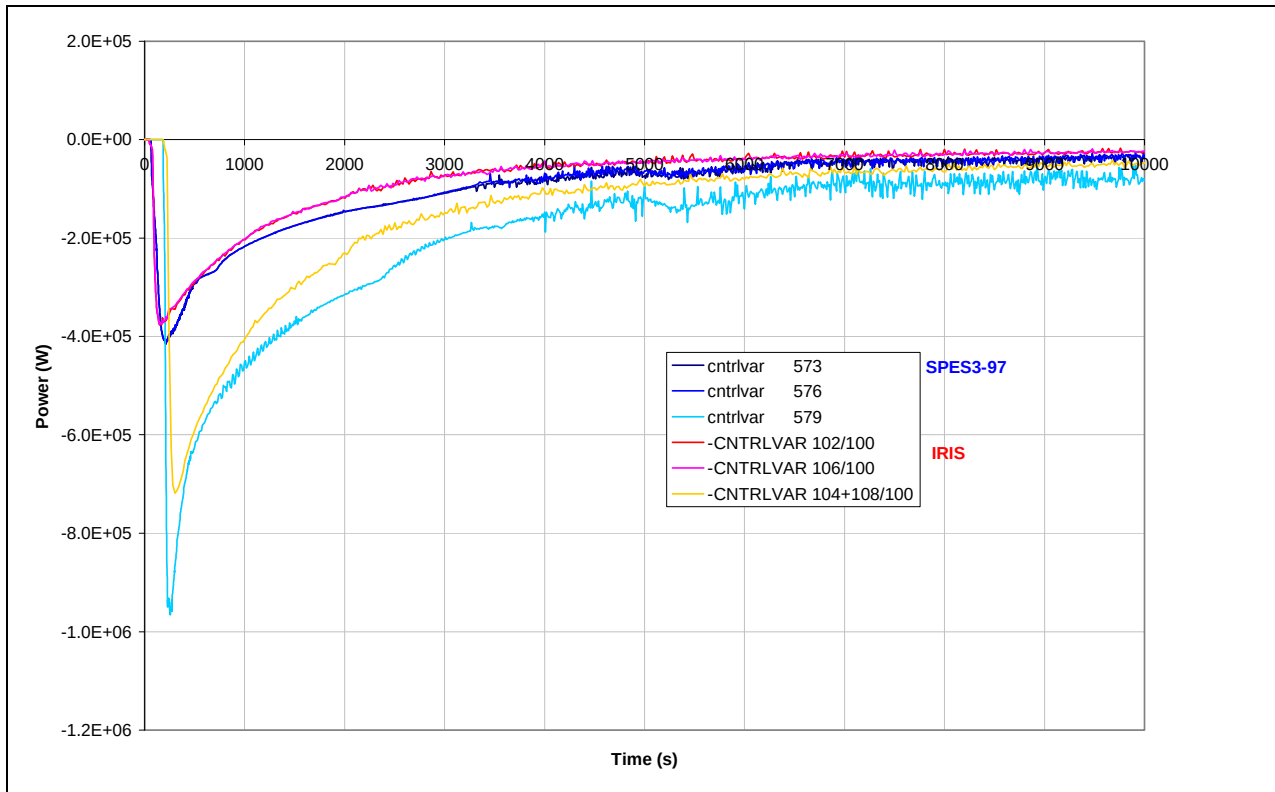
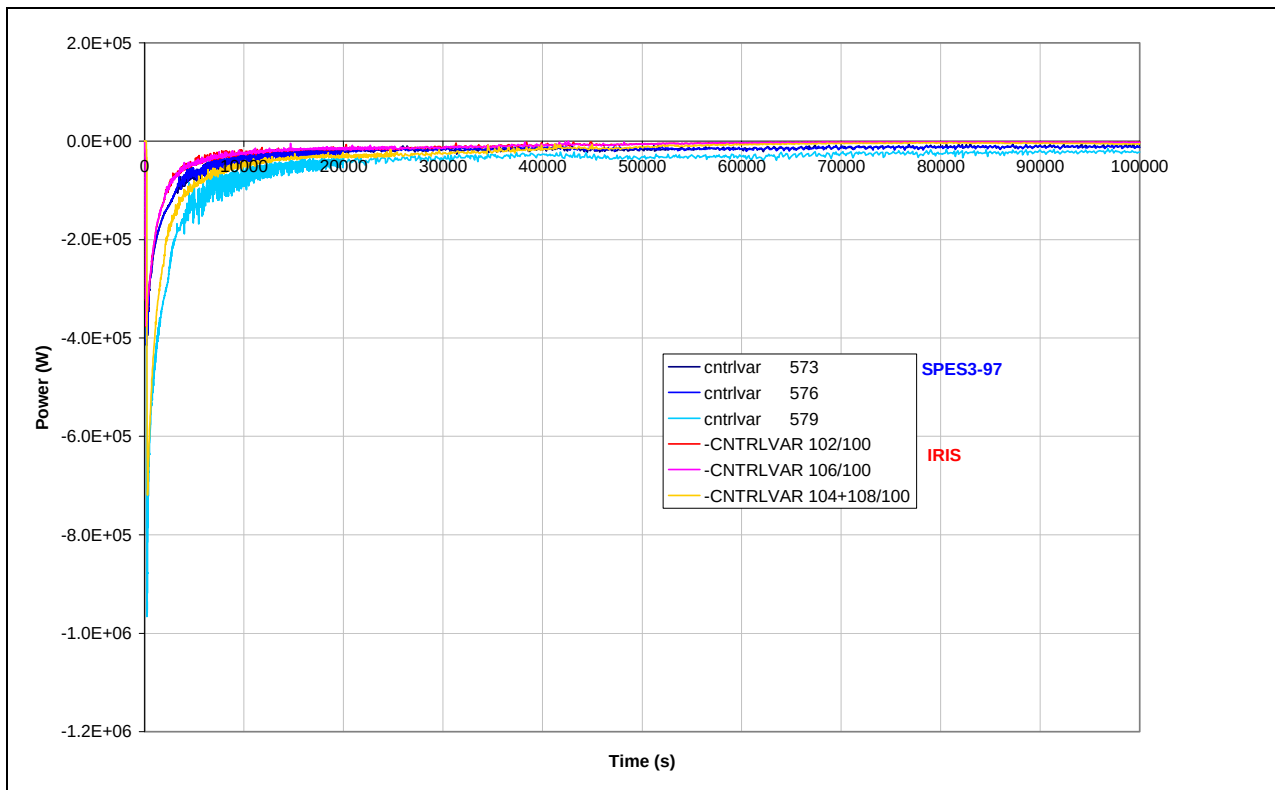
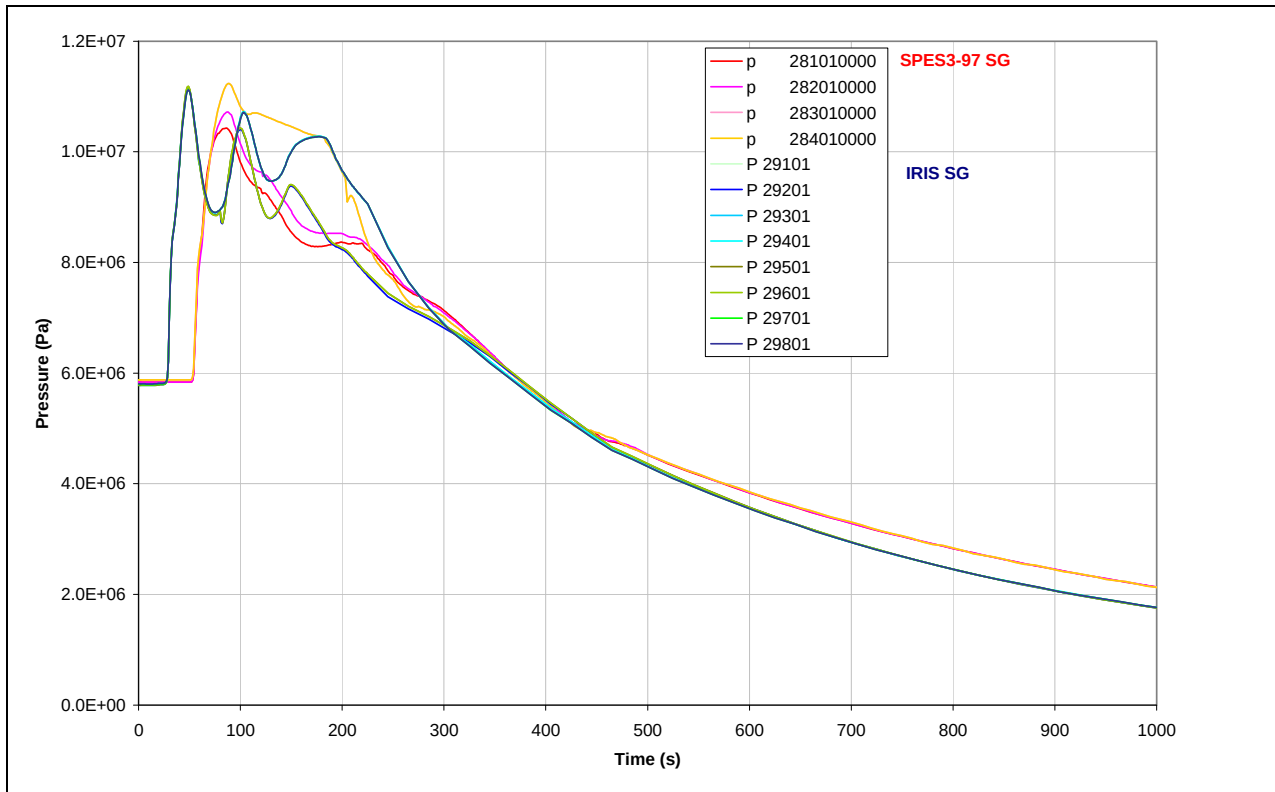


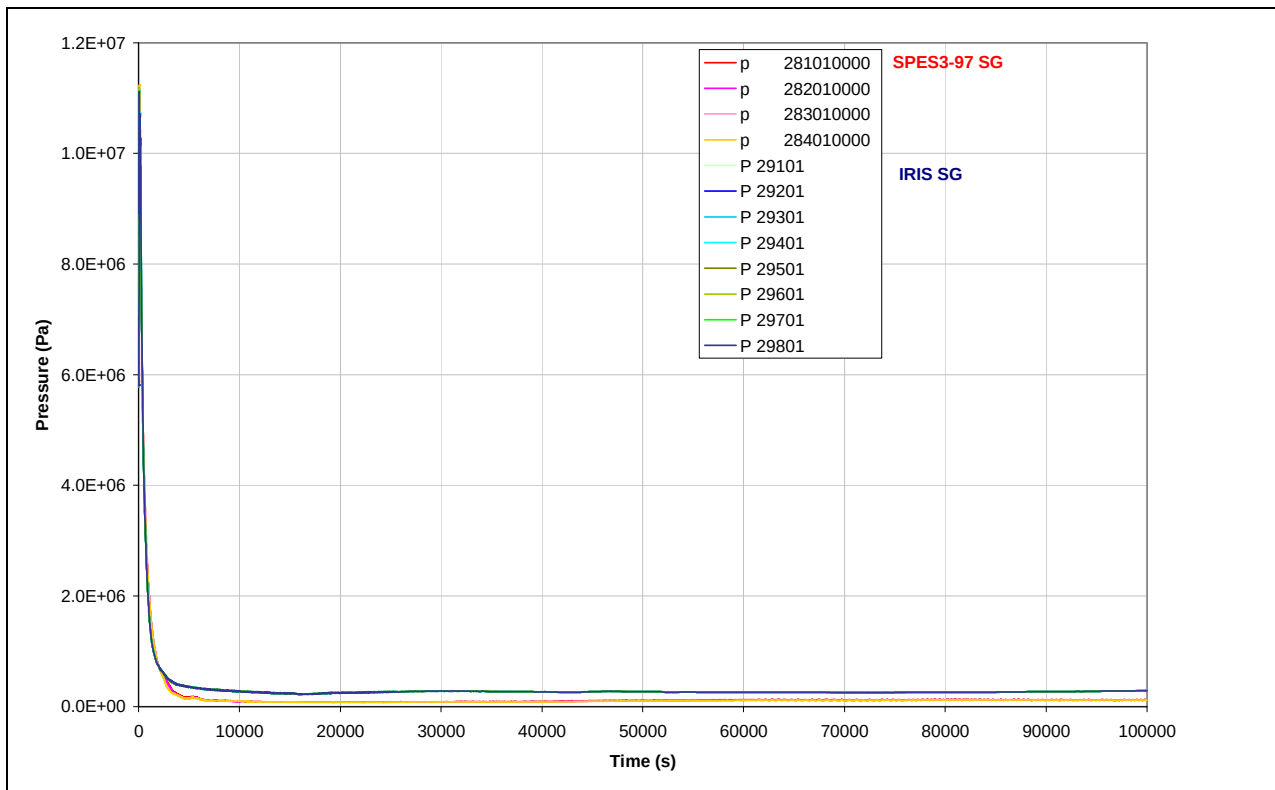
Fig.4.40 – SPES3-97 and IRIS HT1 EHRS power



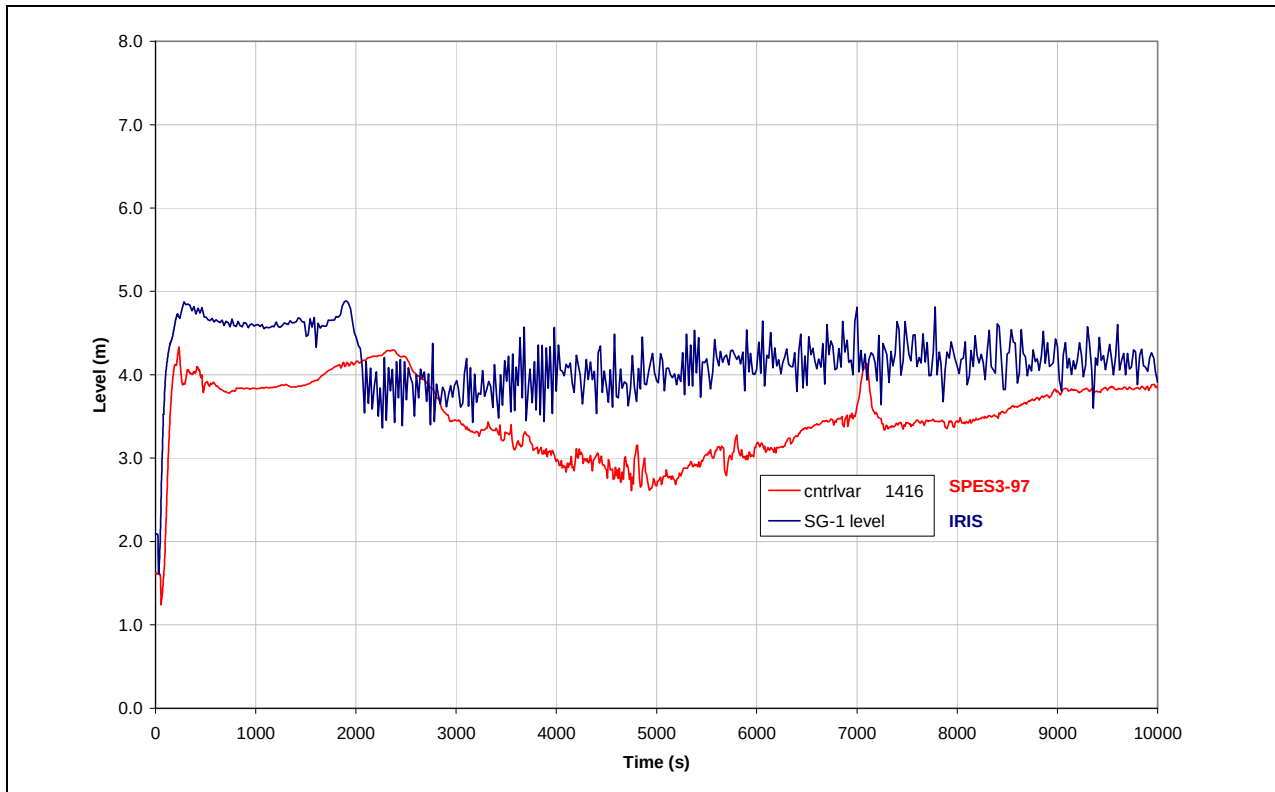
**Fig.4.41 – SPES3-97 and IRIS HT1 SG ss outlet pressure (window)**



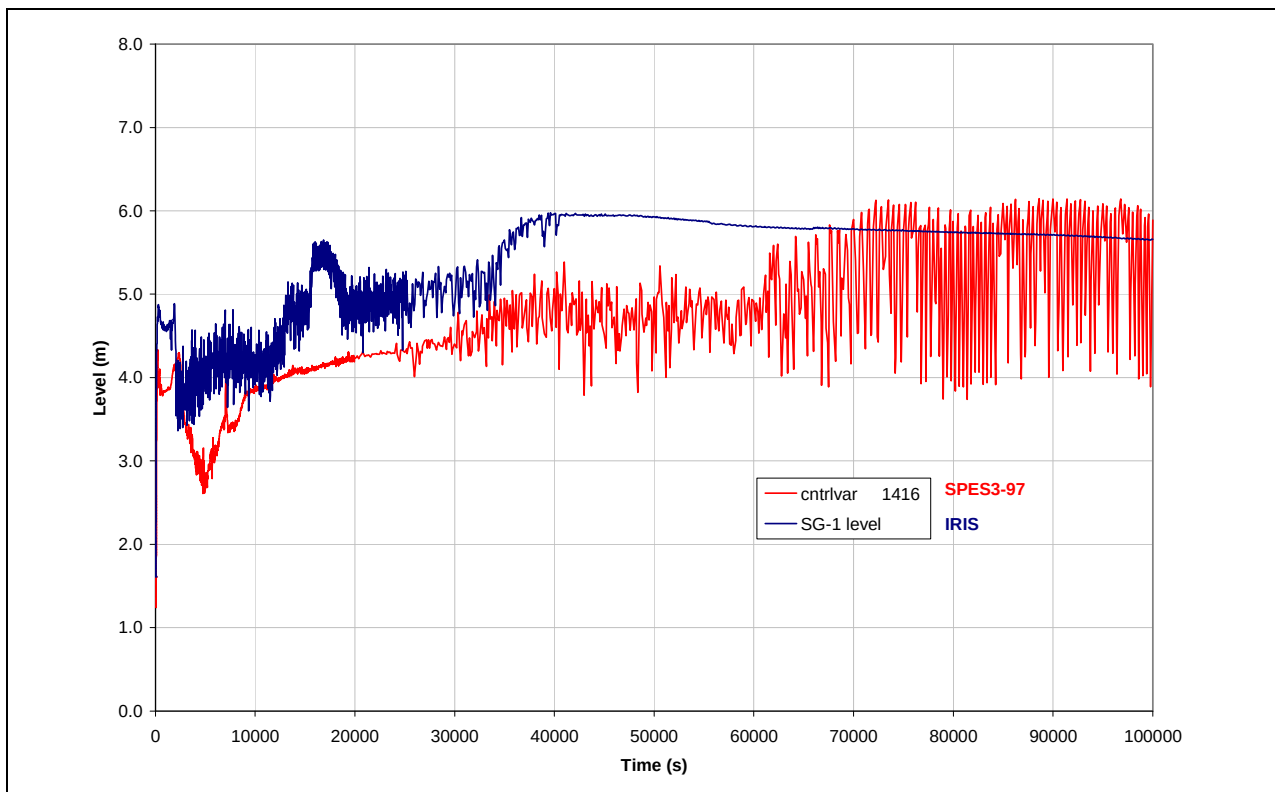
**Fig.4.42 – SPES3-97 and IRIS HT1 SG ss outlet pressure**



**Fig.4.43 – SPES3-97 and IRIS HT1 SG-1 ss level (window)**

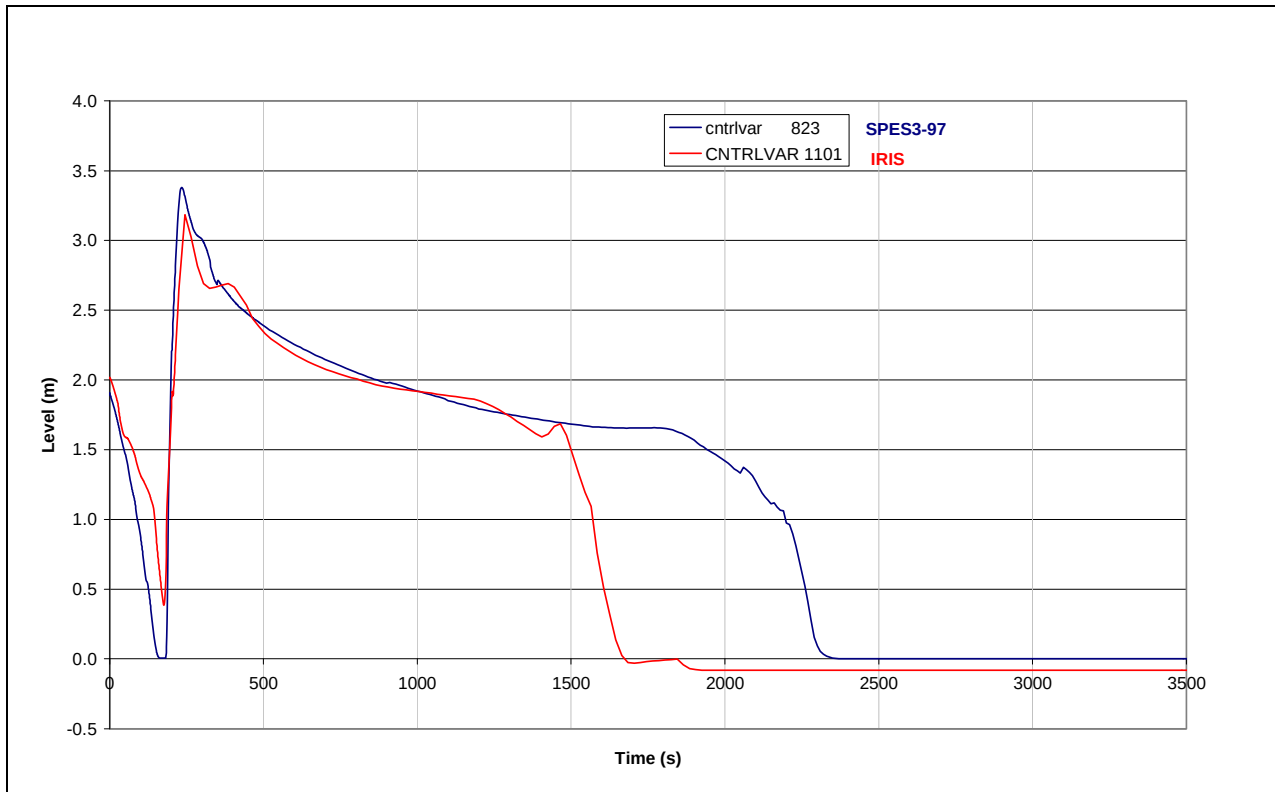


**Fig.4.44 – SPES3-97 and IRIS HT1 SG-1 ss level**

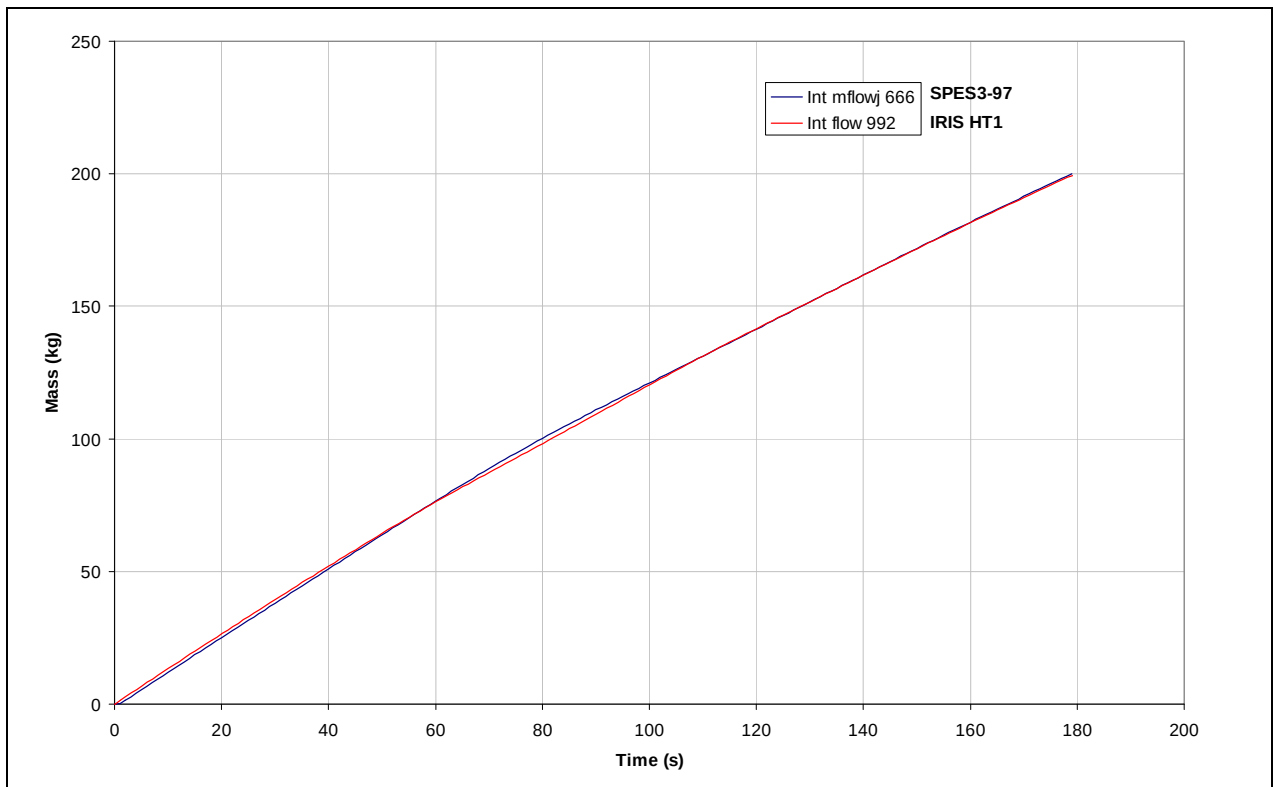




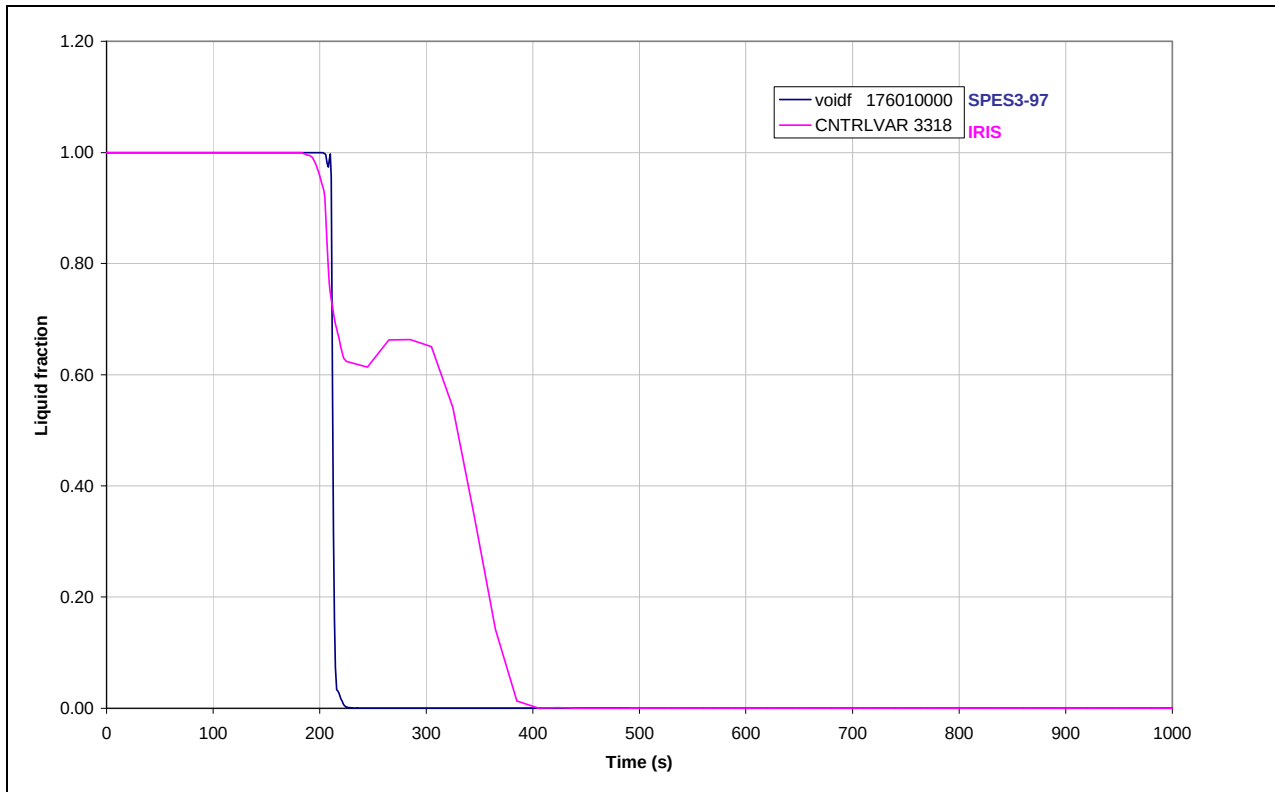
**Fig.4.45 – SPES3-97 and IRIS HT1 PRZ level**



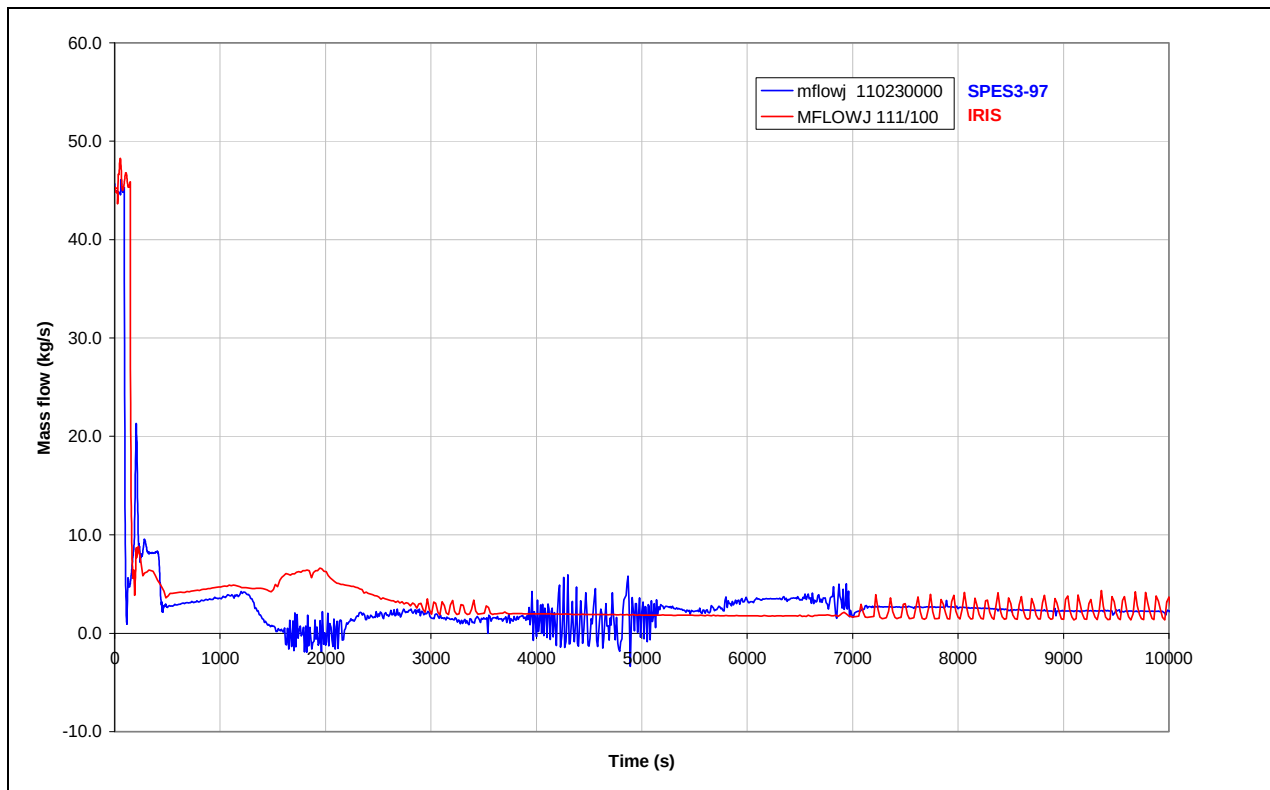
**Fig.4.46 – SPES3-97 and IRIS HT1 DVI break SPLIT integral flow**



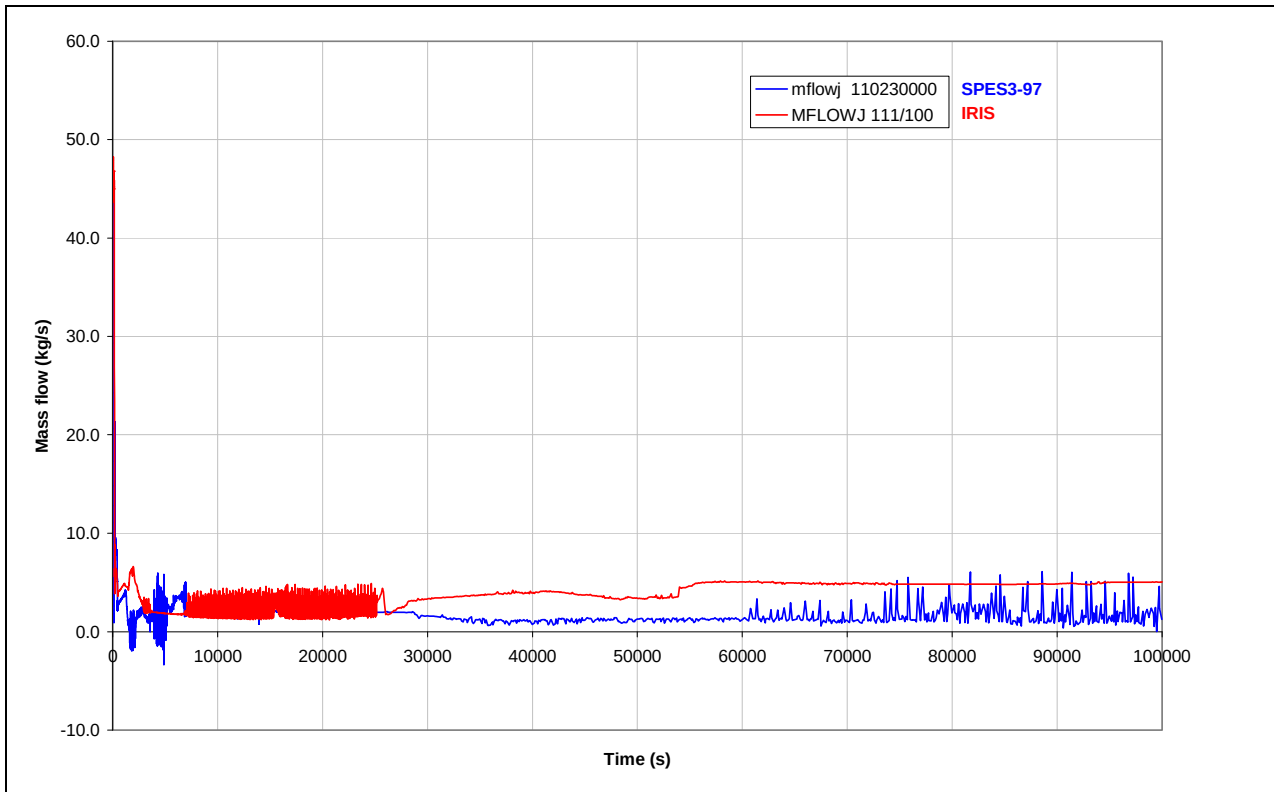
**Fig.4.47 – SPES3-97 and IRIS HT1 pump inlet liquid fraction**



**Fig.4.48 – SPES3-97 and IRIS HT1 core inlet flow (window)**



**Fig.4.49 –SPES3-97 and IRIS HT1 core inlet flow**



**Fig.4.50 – SPES3-97 and IRIS HT1 RI-DC check valve mass flow (window)**

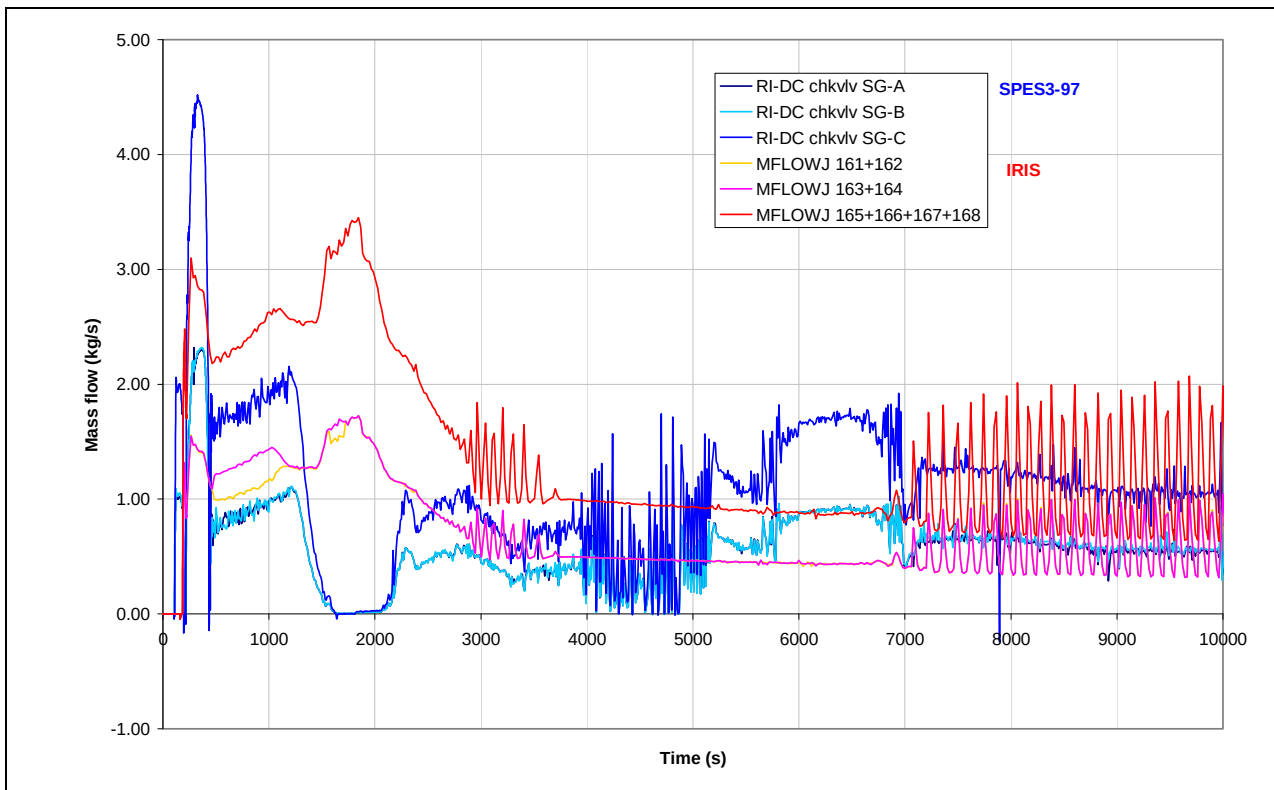


Fig.4.51 – SPES3-97 and IRIS HT1 RI-DC check valve mass flow

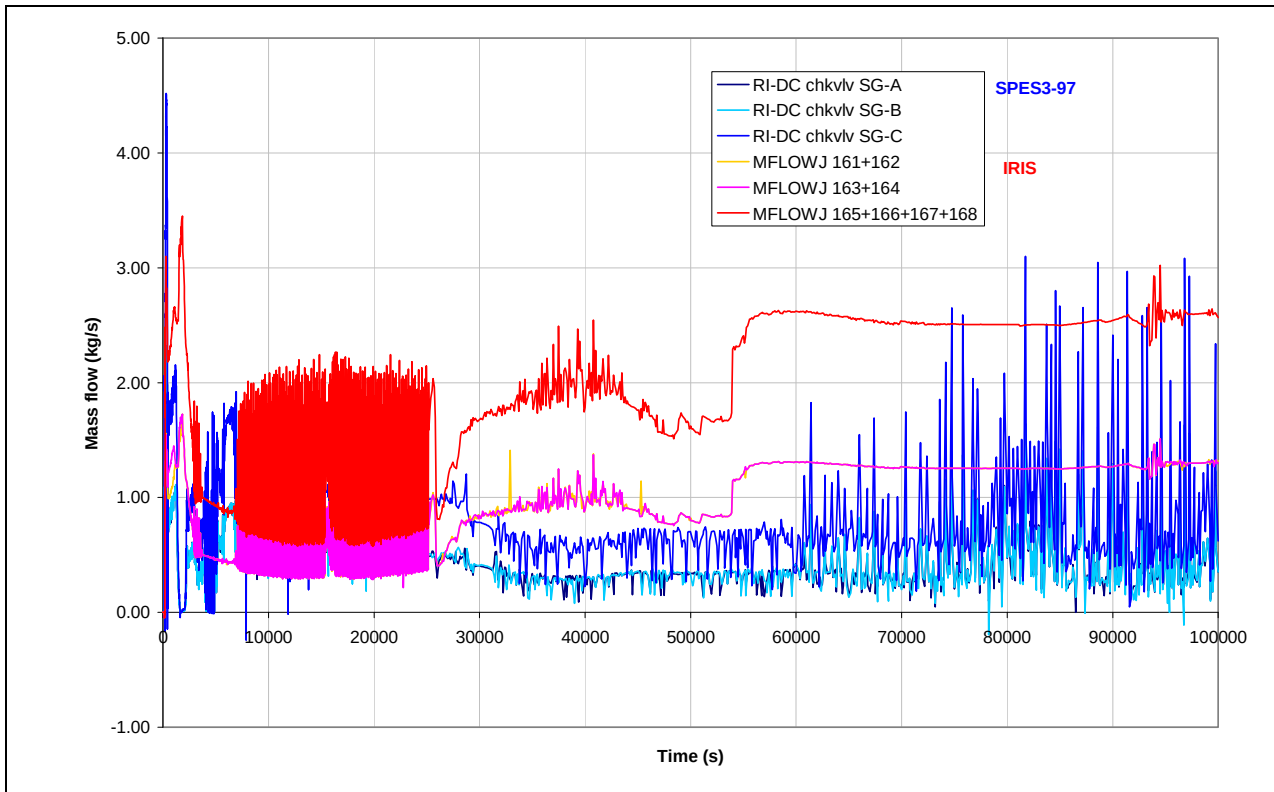
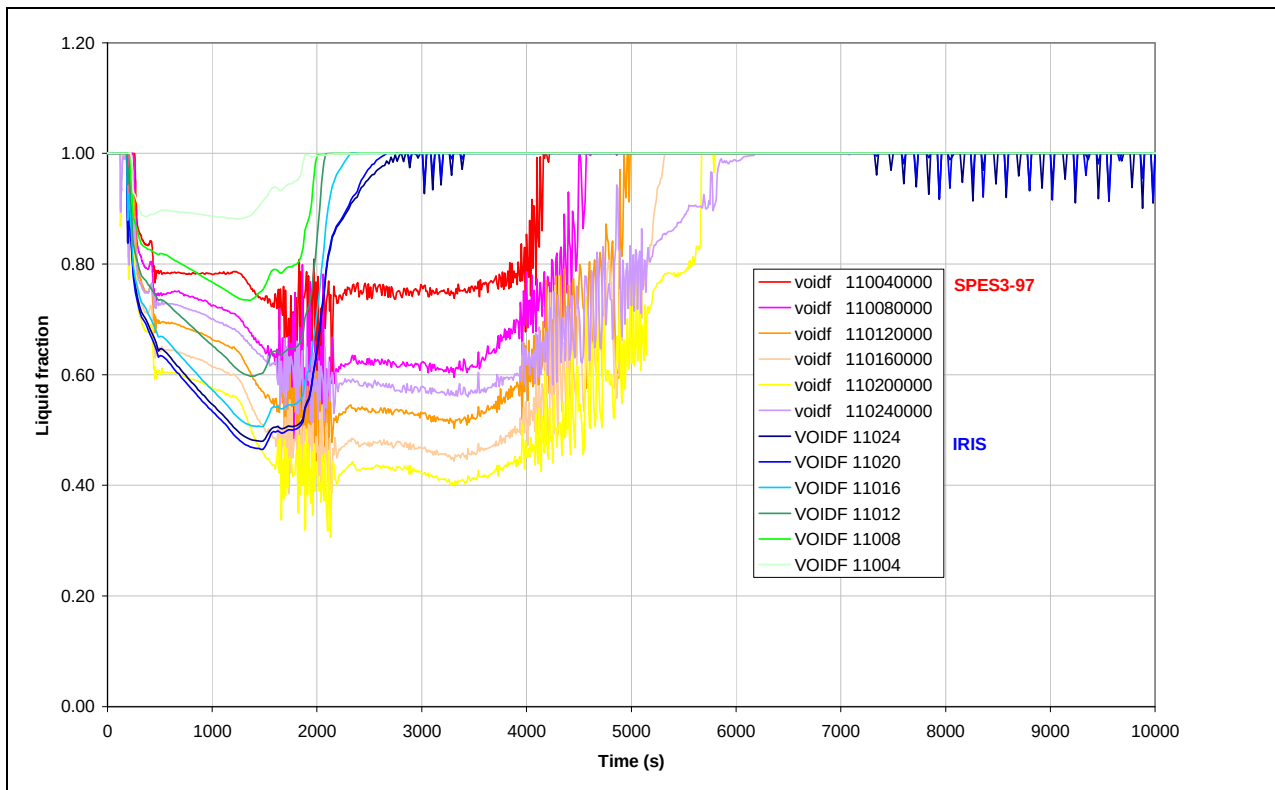
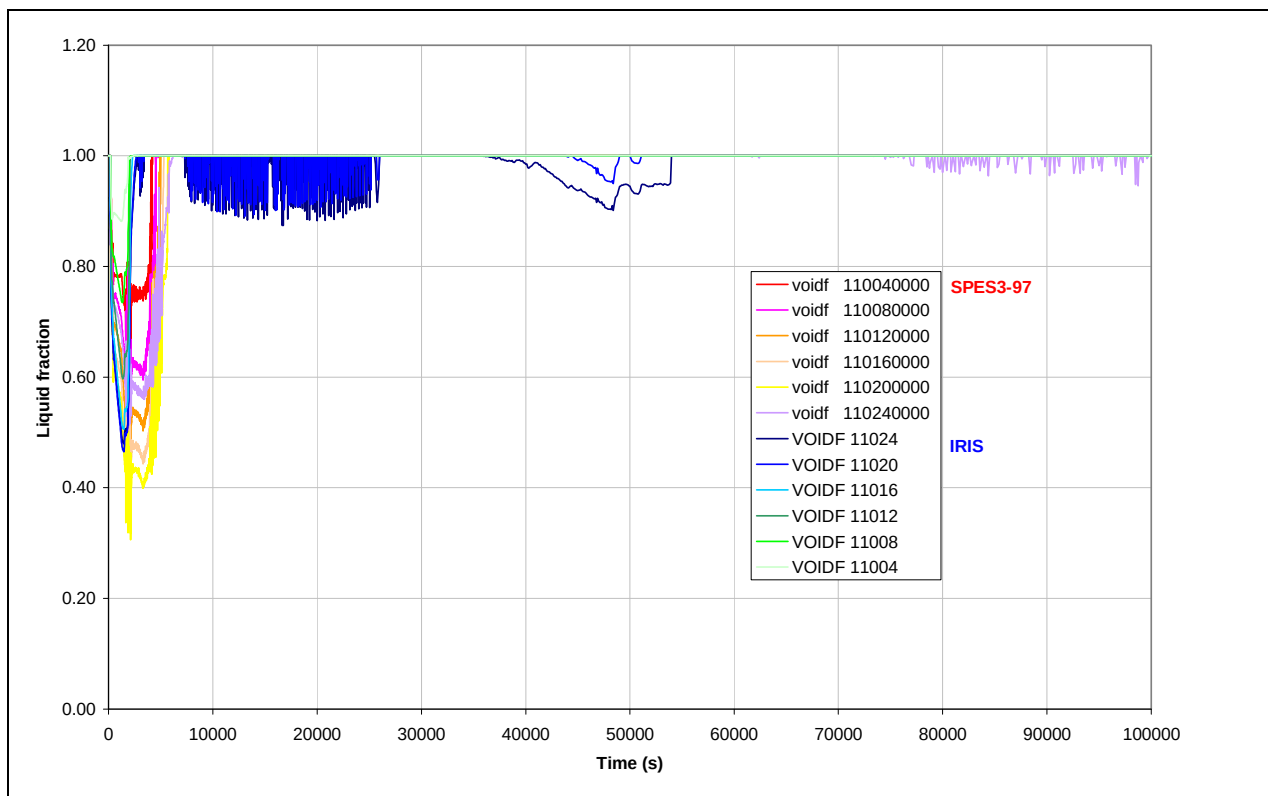


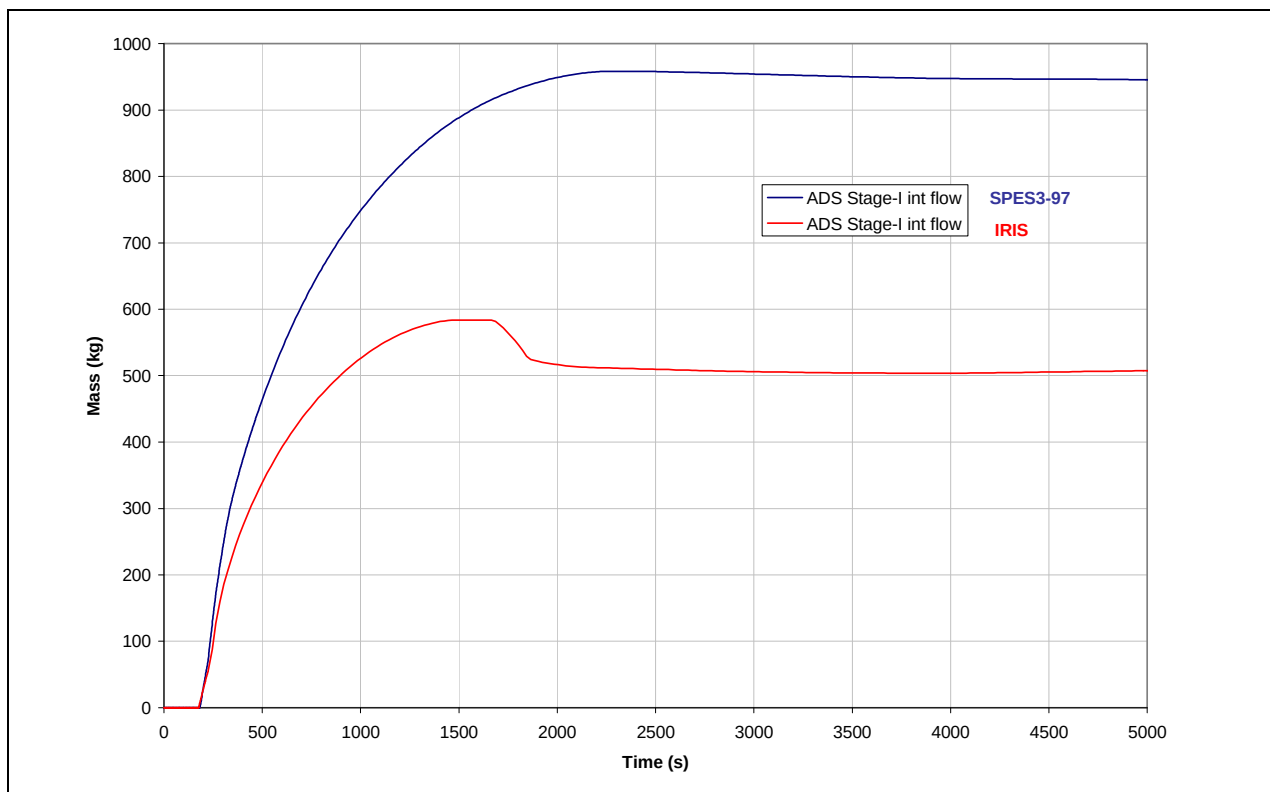
Fig.4.52 – SPES3-97 and IRIS HT1 core liquid void fraction (window)



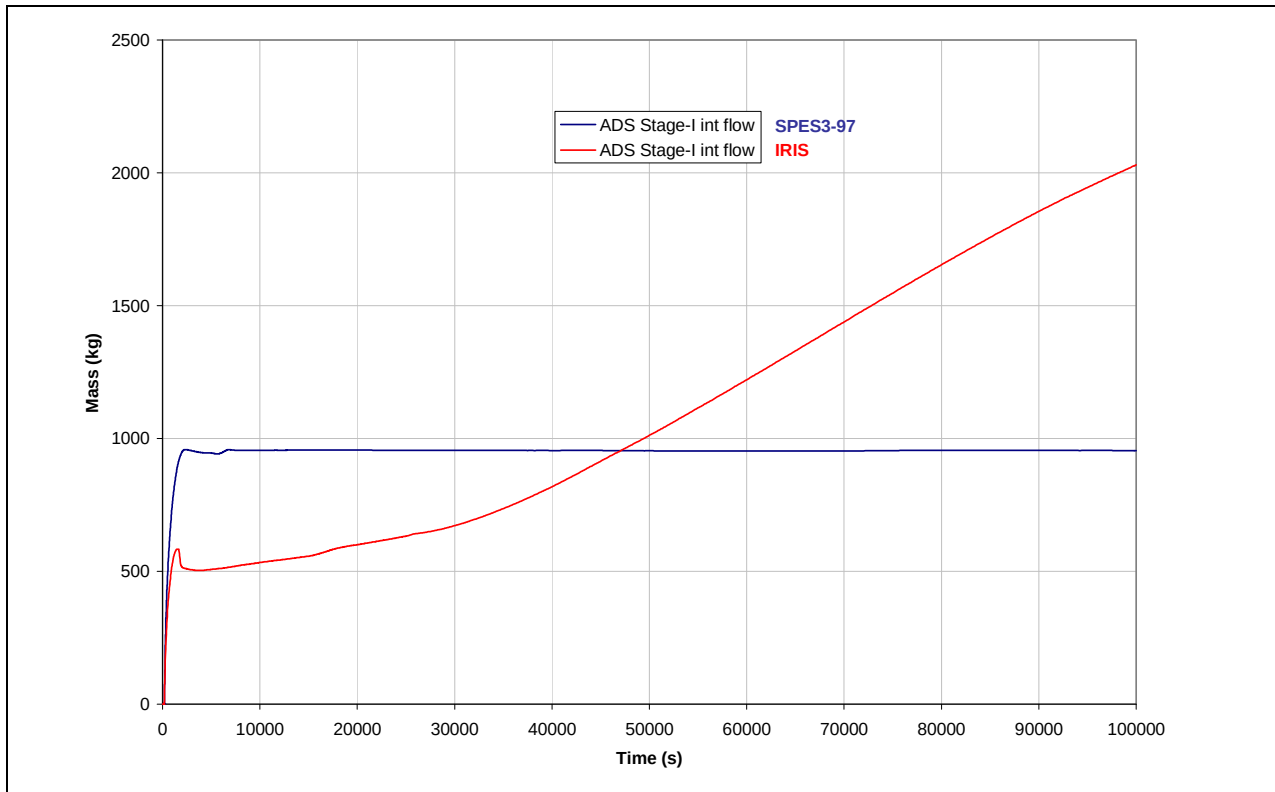
**Fig.4.53 – SPES3-97 and IRIS HT1 core liquid void fraction**



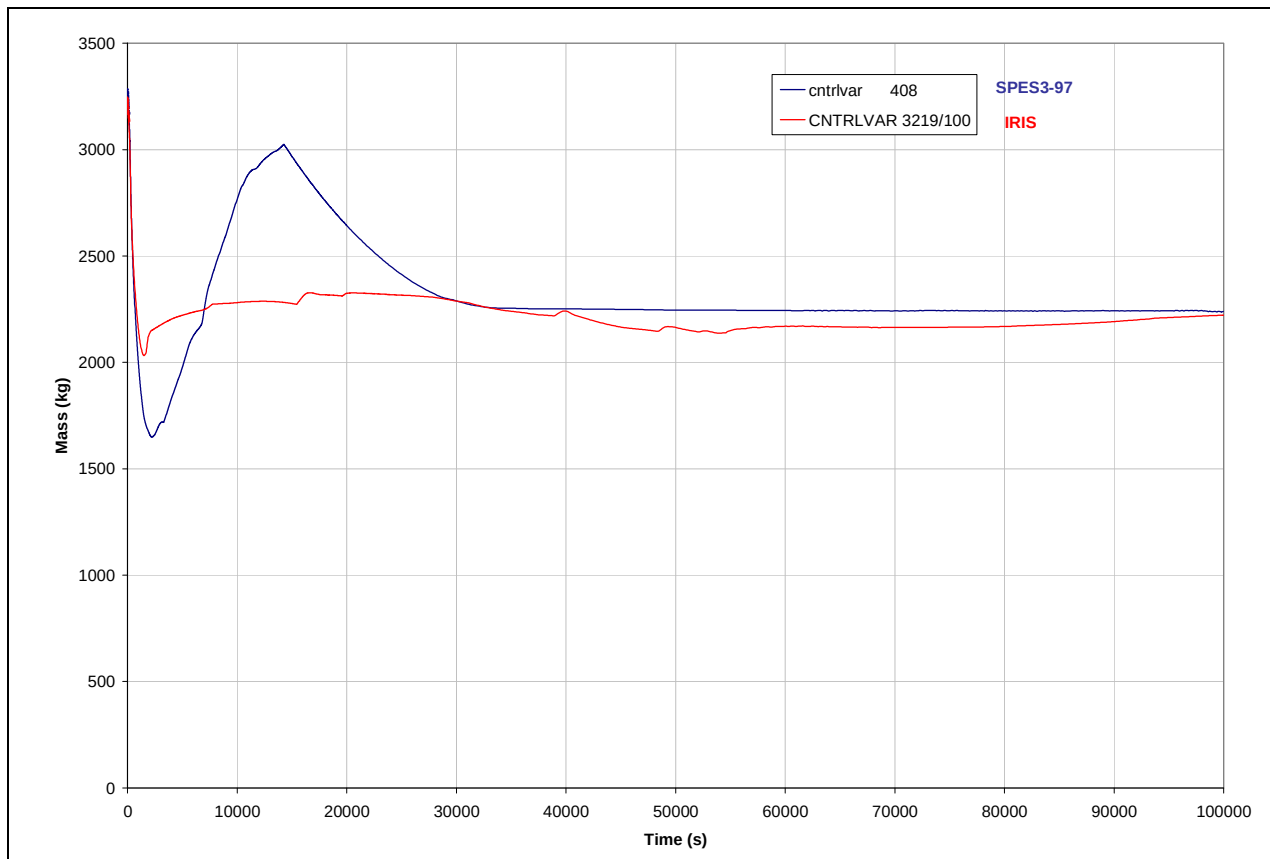
**Fig.4.54 – SPES3-97 and IRIS HT1 ADS Stage-I integral flow (window)**



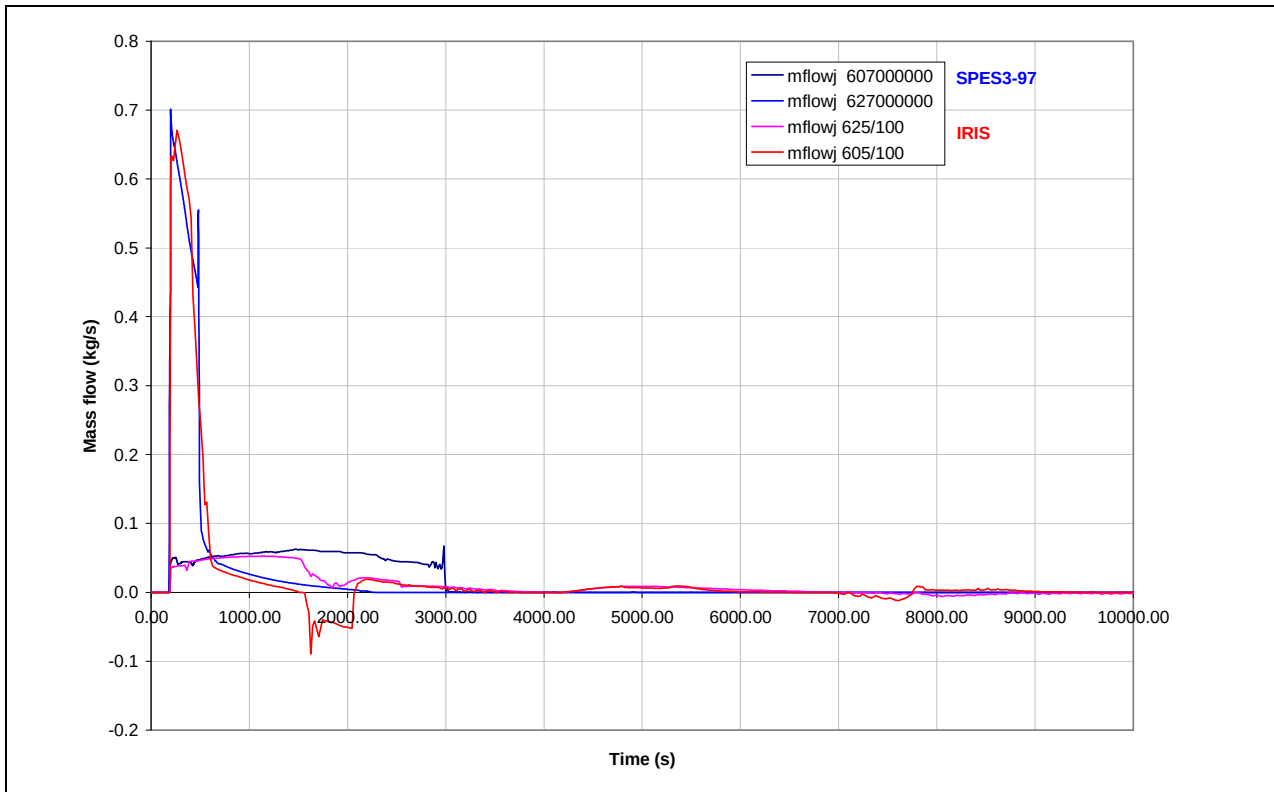
**Fig.4.55 – SPES3-97 and IRIS HT1 ADS Stage-I integral flow**



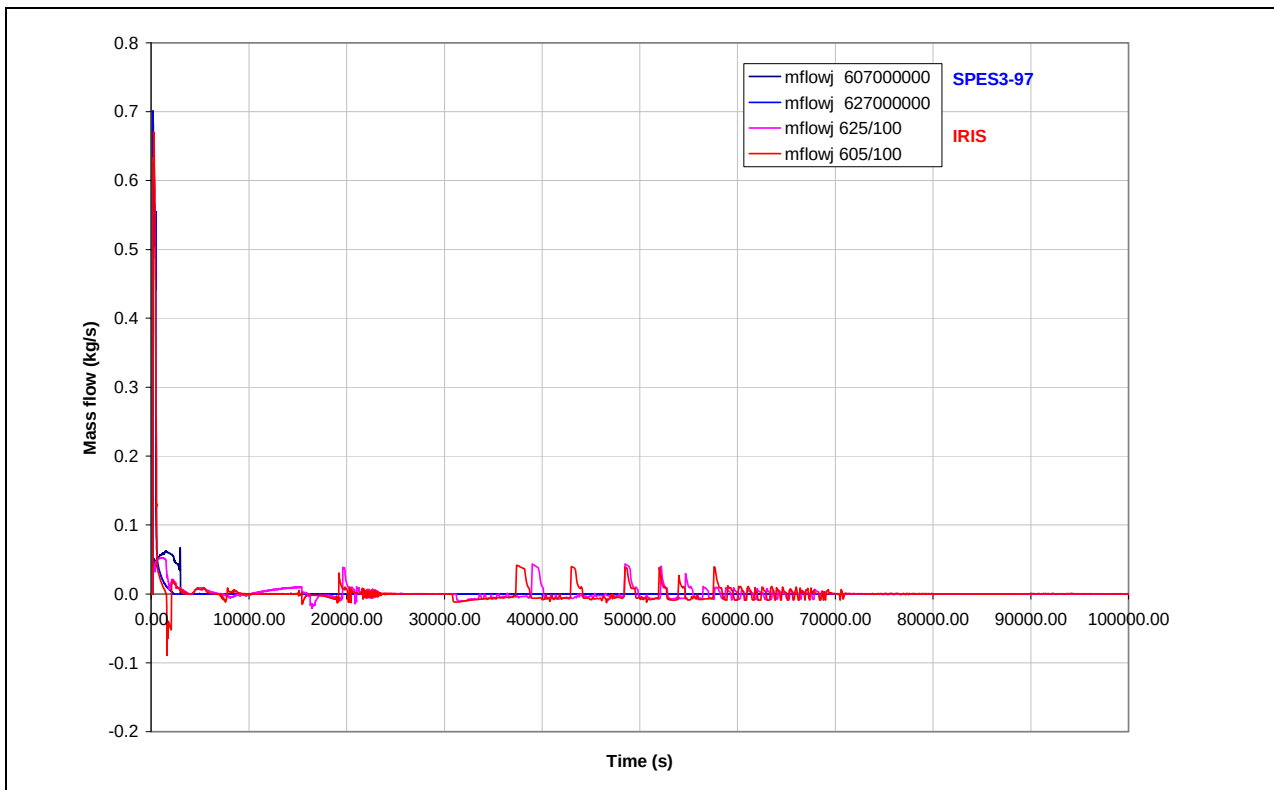
**Fig.4.56 – SPES3-97 and IRIS HT1 RV mass**



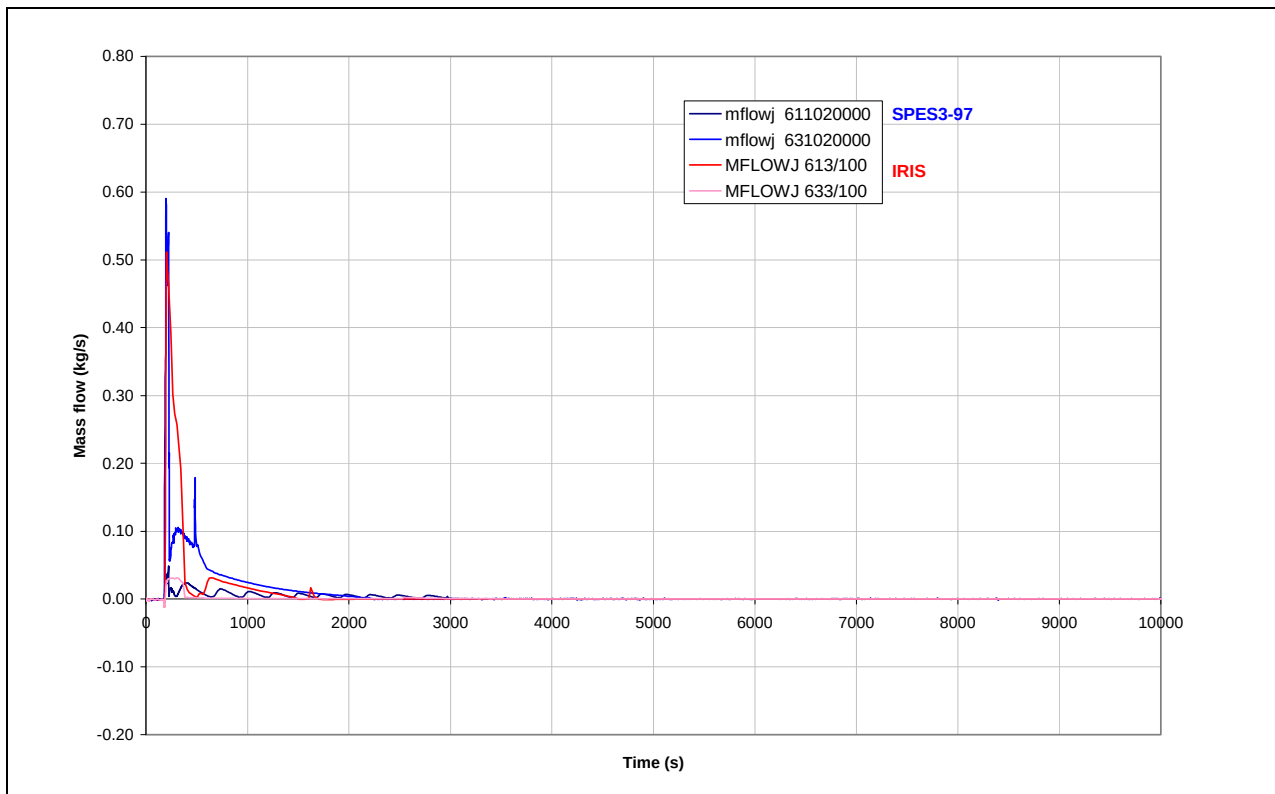
**Fig.4.57 – SPES3-97 and IRIS HT1 EBT injection mass flow (window)**



**Fig.4.58 – SPES3-97 and IRIS HT1 EBT injection mass flow**



**Fig.4.59 – SPES3-97 and IRIS HT1 EBT balance line to RV mass flow (window)**



**Fig.4.60 – SPES3-97 and IRIS HT1 EBT level (window)**

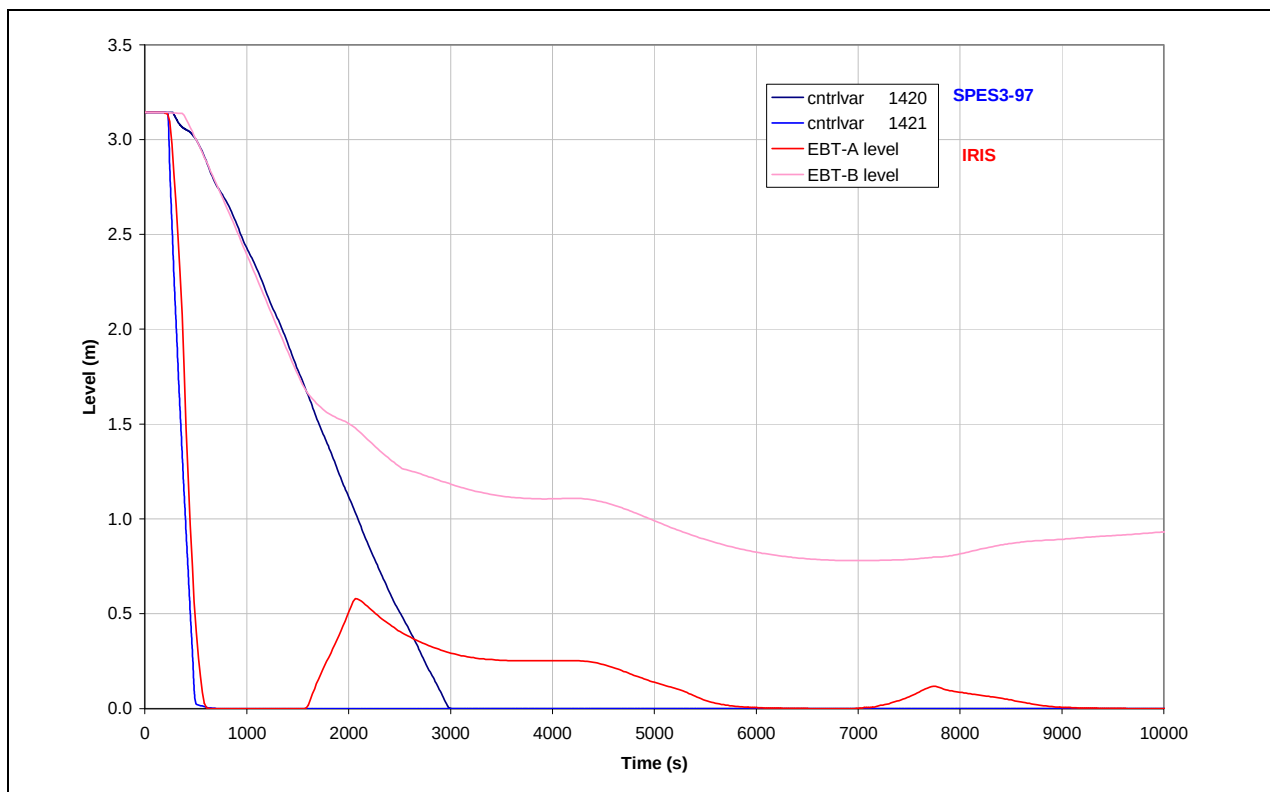




Fig.4.61 – SPES3-97 and IRIS HT1 EBT level

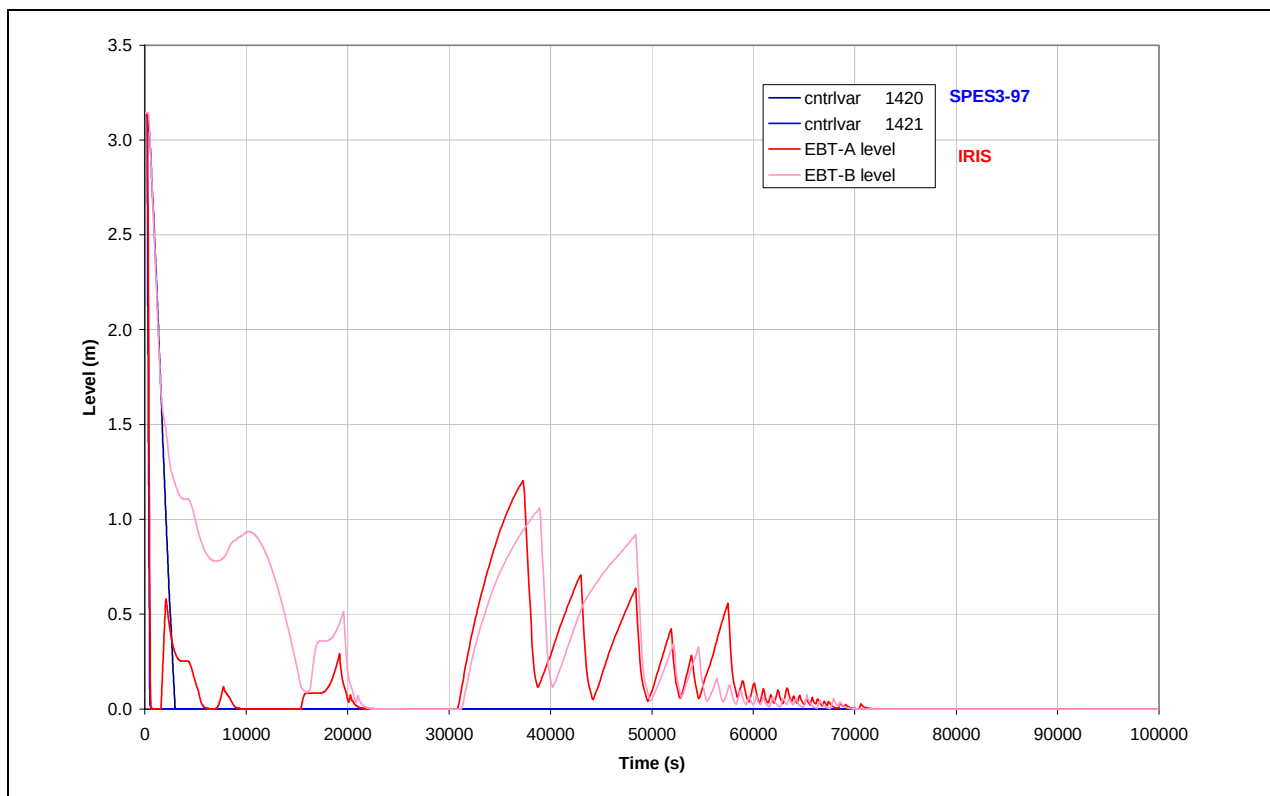
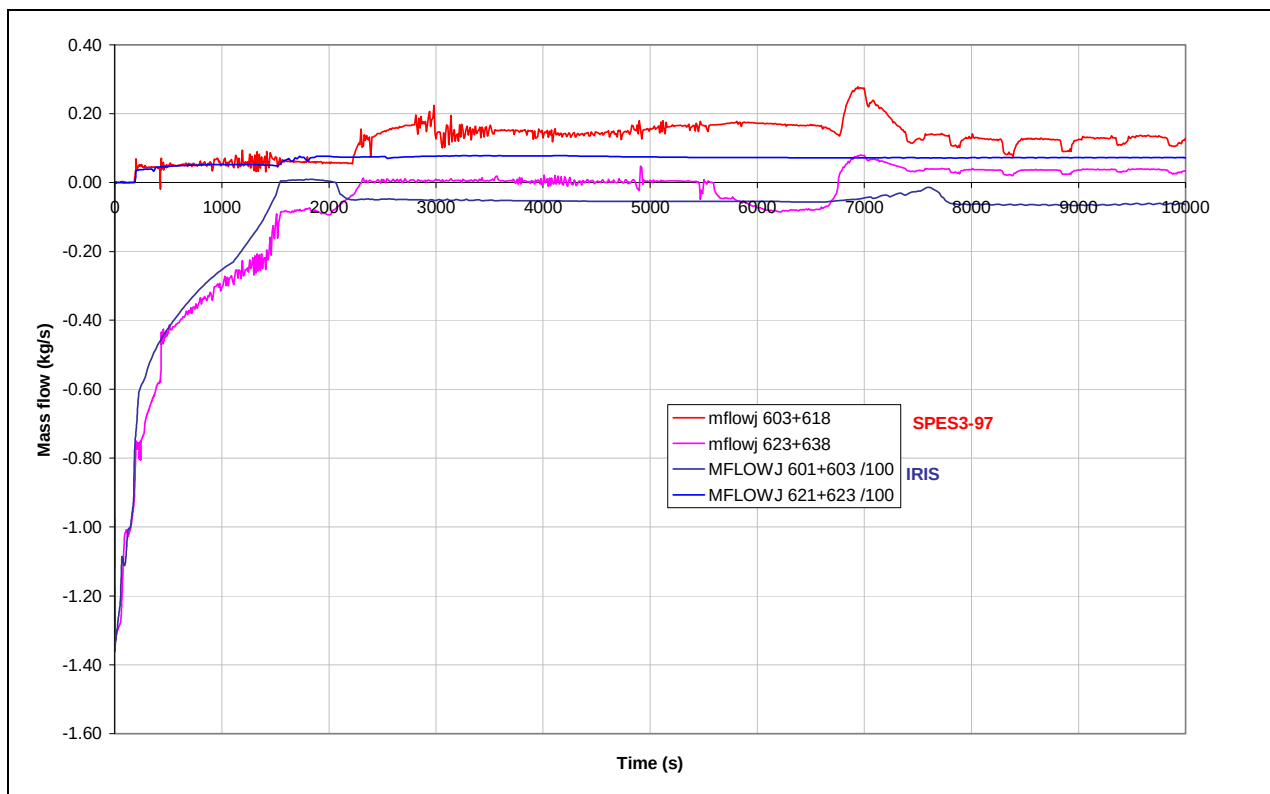
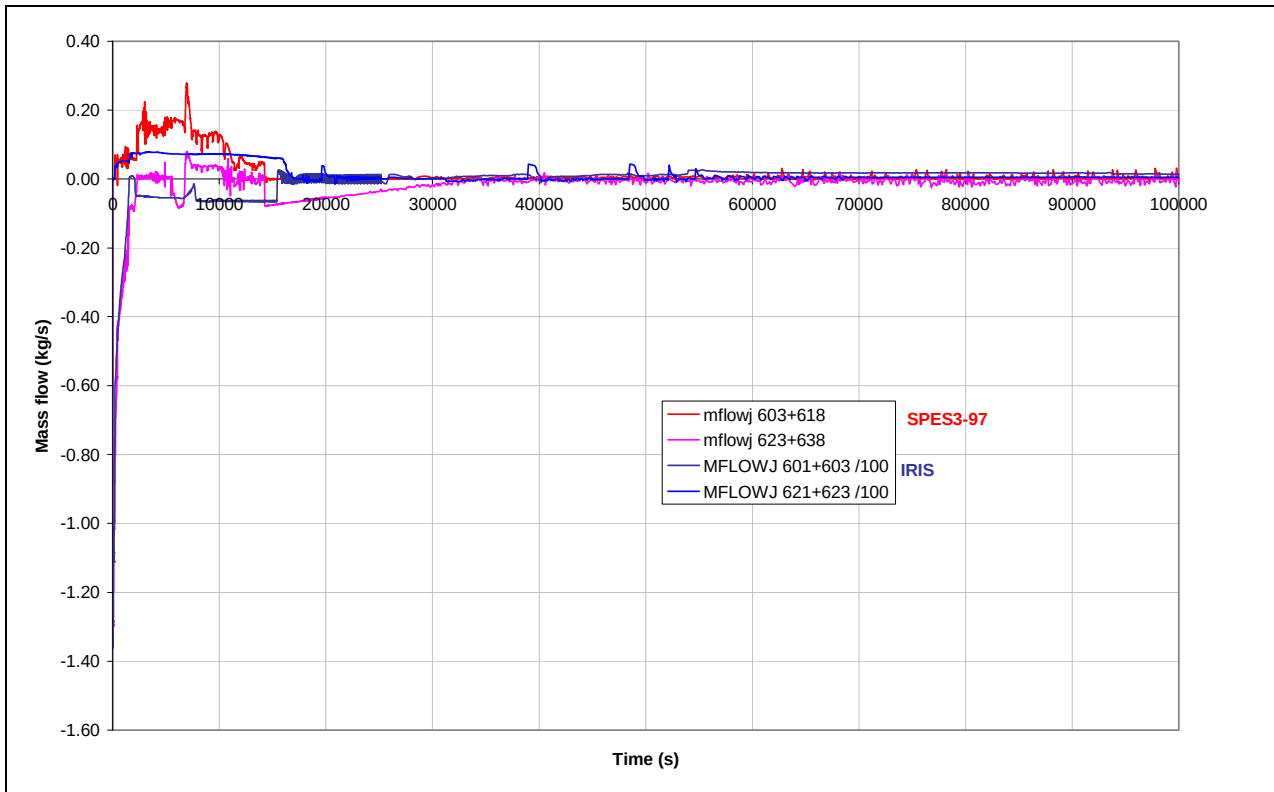


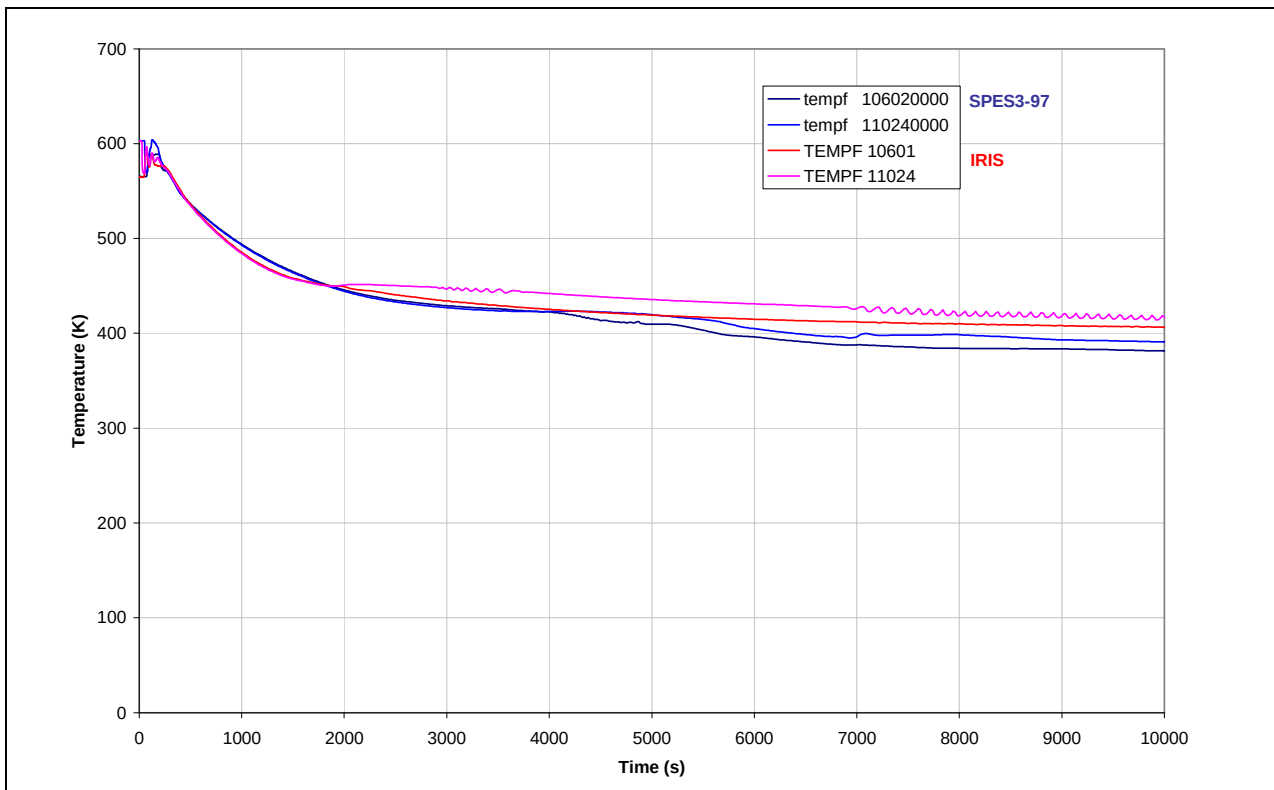
Fig.4.62 – SPES3-97 and IRIS HT1 DVI mass flow (window)



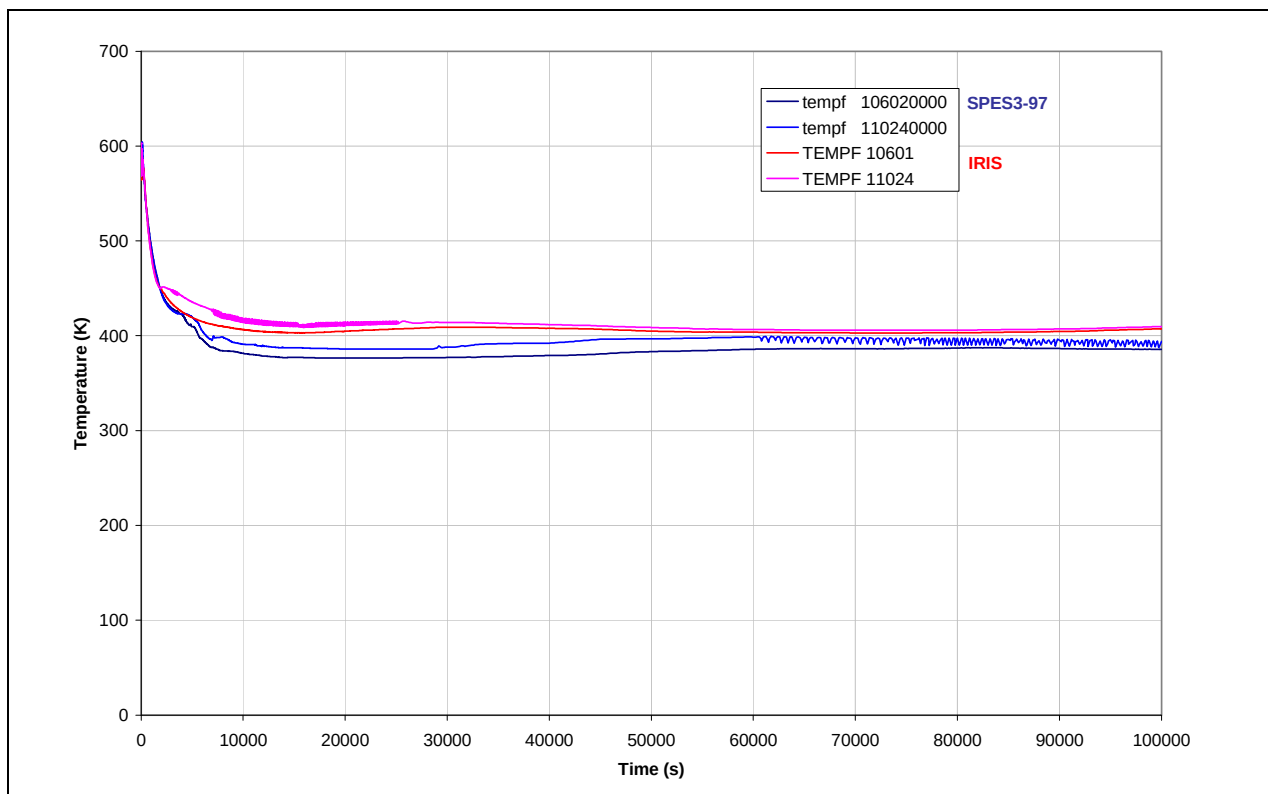
**Fig.4.63 – SPES3-97 and IRIS HT1 DVI mass flow**



**Fig.4.64 – SPES3-97 and IRIS HT1 Core inlet and outlet temperatures (window)**



**Fig.4.65 – SPES3-97 and IRIS HT1 Core inlet and outlet temperatures**



**Fig.4.66 – SPES3-97 and IRIS HT1 core heater rod outer surface temperature (window)**

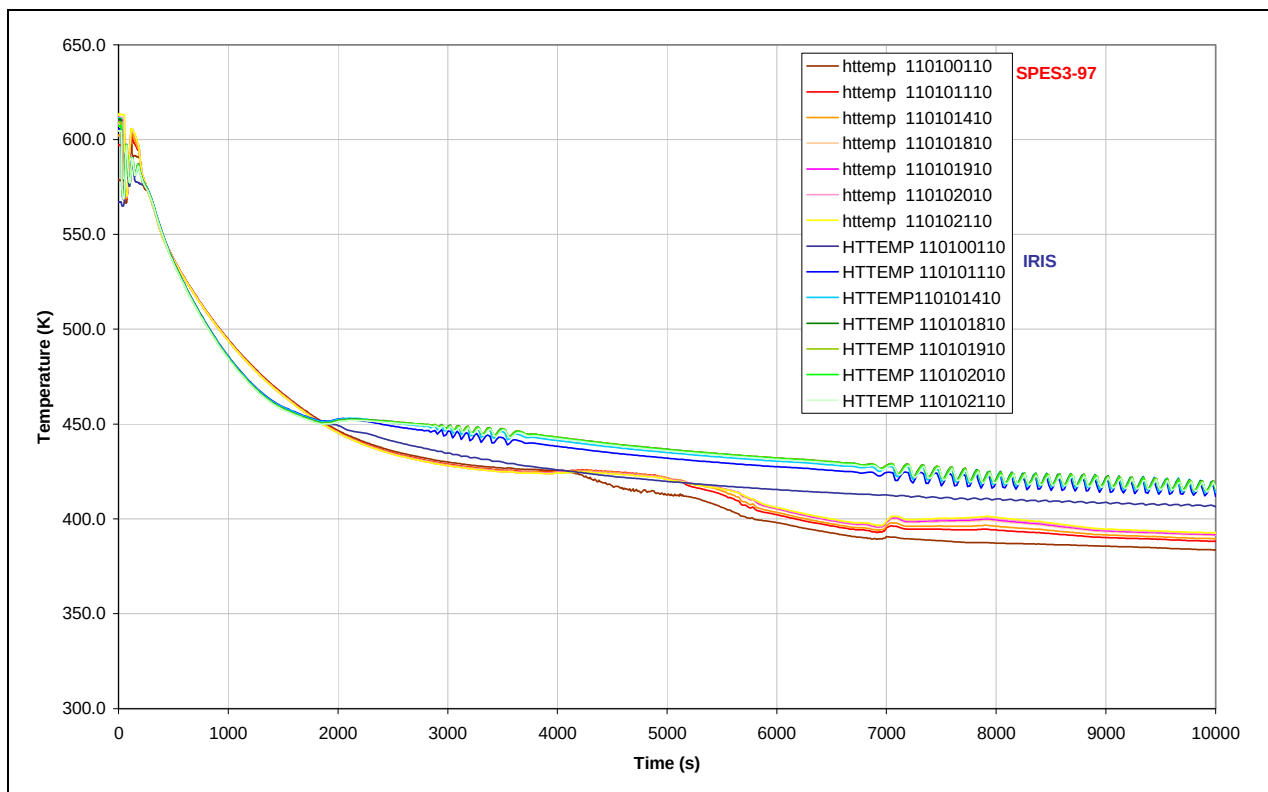


Fig.4.67 – SPES3-97 and IRIS HT1 core heater rod outer surface temperature

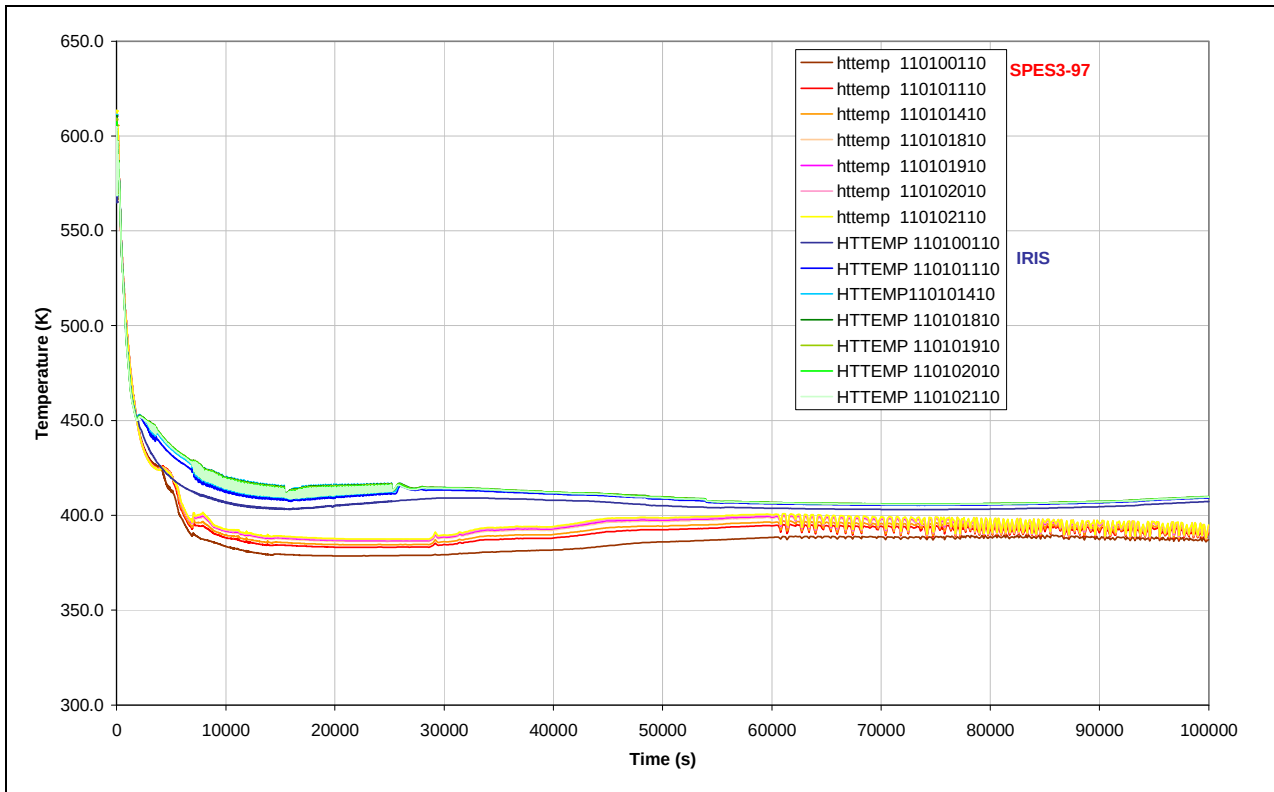
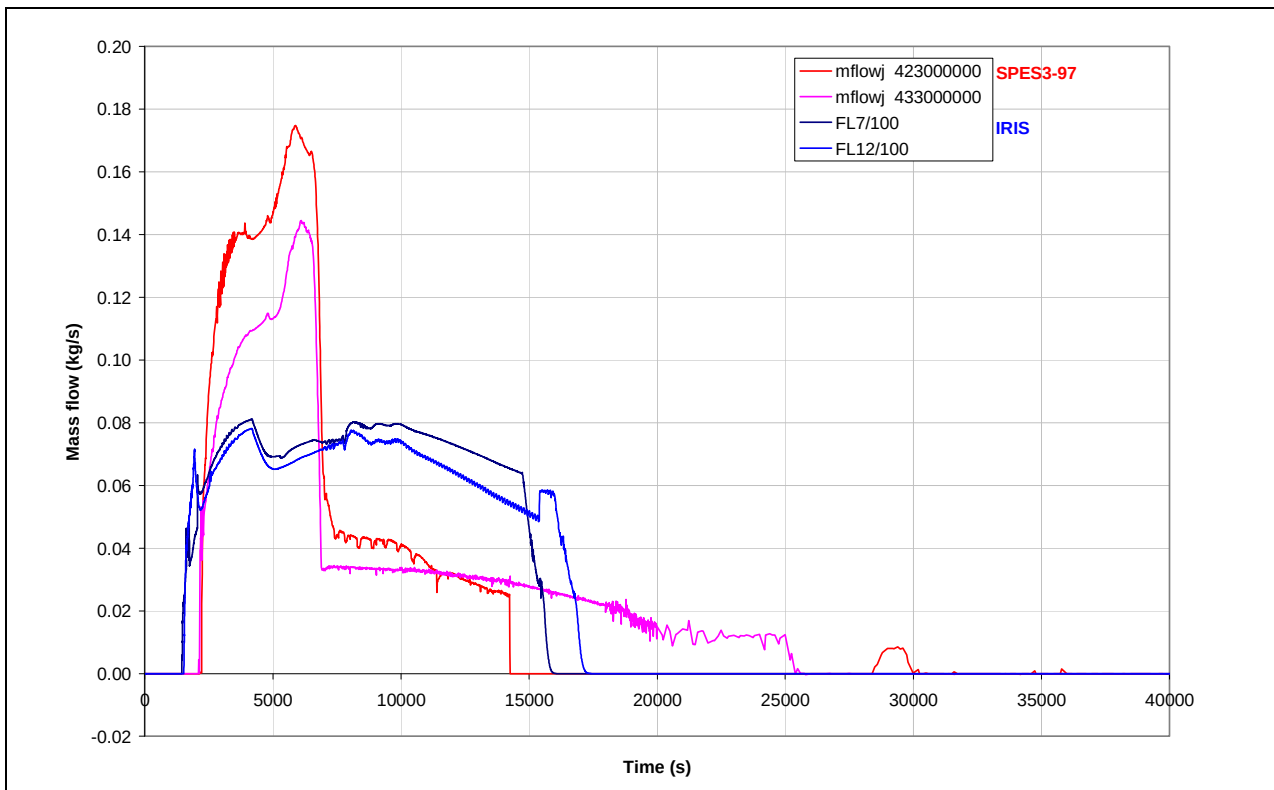
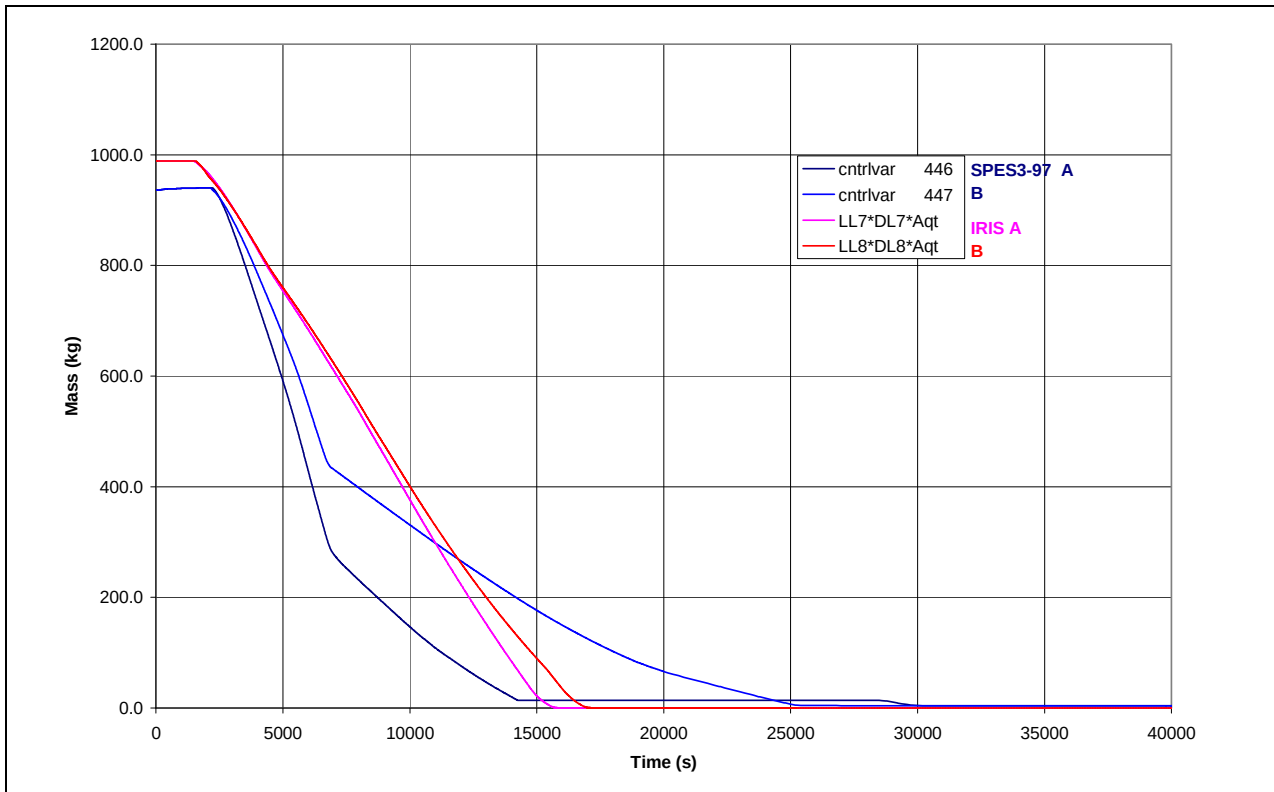


Fig.4.68 – SPES3-97 and IRIS HT1 LGMS injection mass flow (window)



**Fig.4.69 – SPES3-97 and IRIS HT1 LGMS mass (window)**



**Fig.4.70 – SPES3-97 and IRIS HT1 LGMS and DVI pressure (window)**

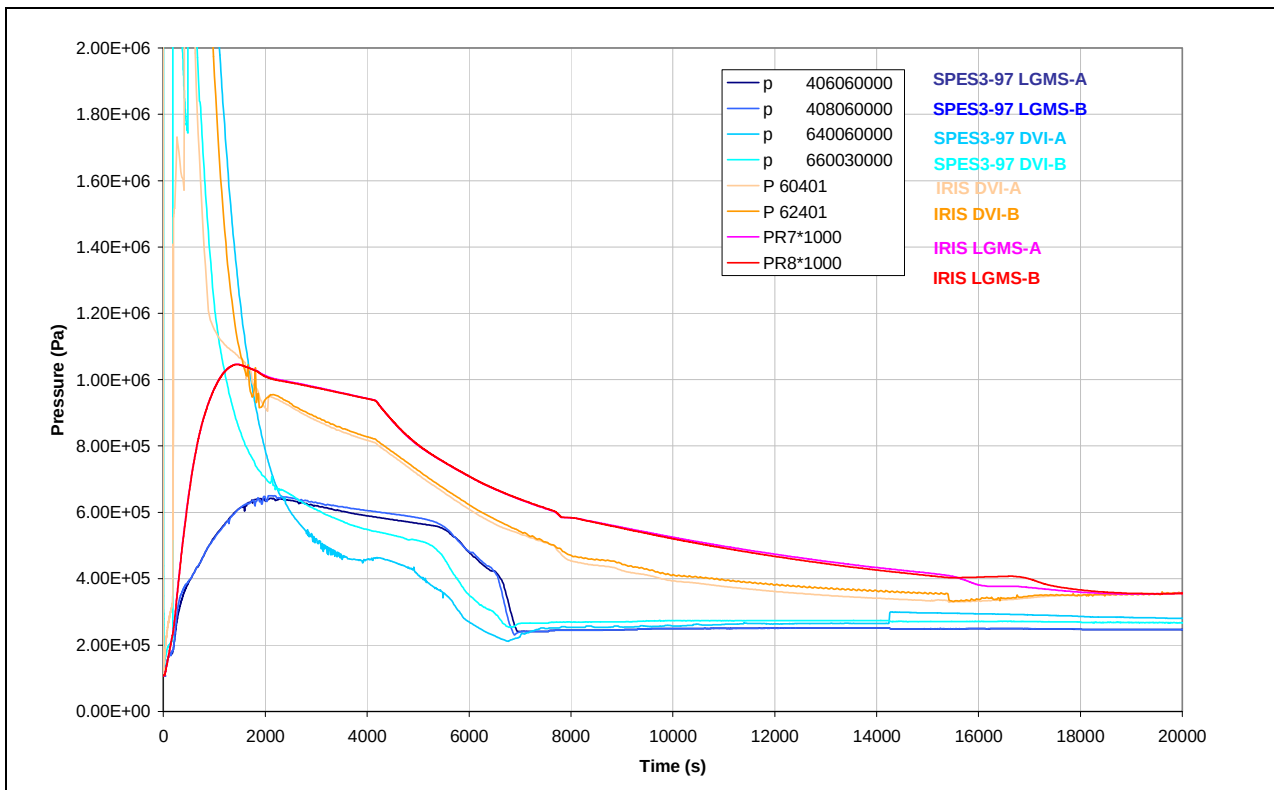


Fig.4.71 – SPES3-97 and IRIS HT1 LGMS and DVI pressure

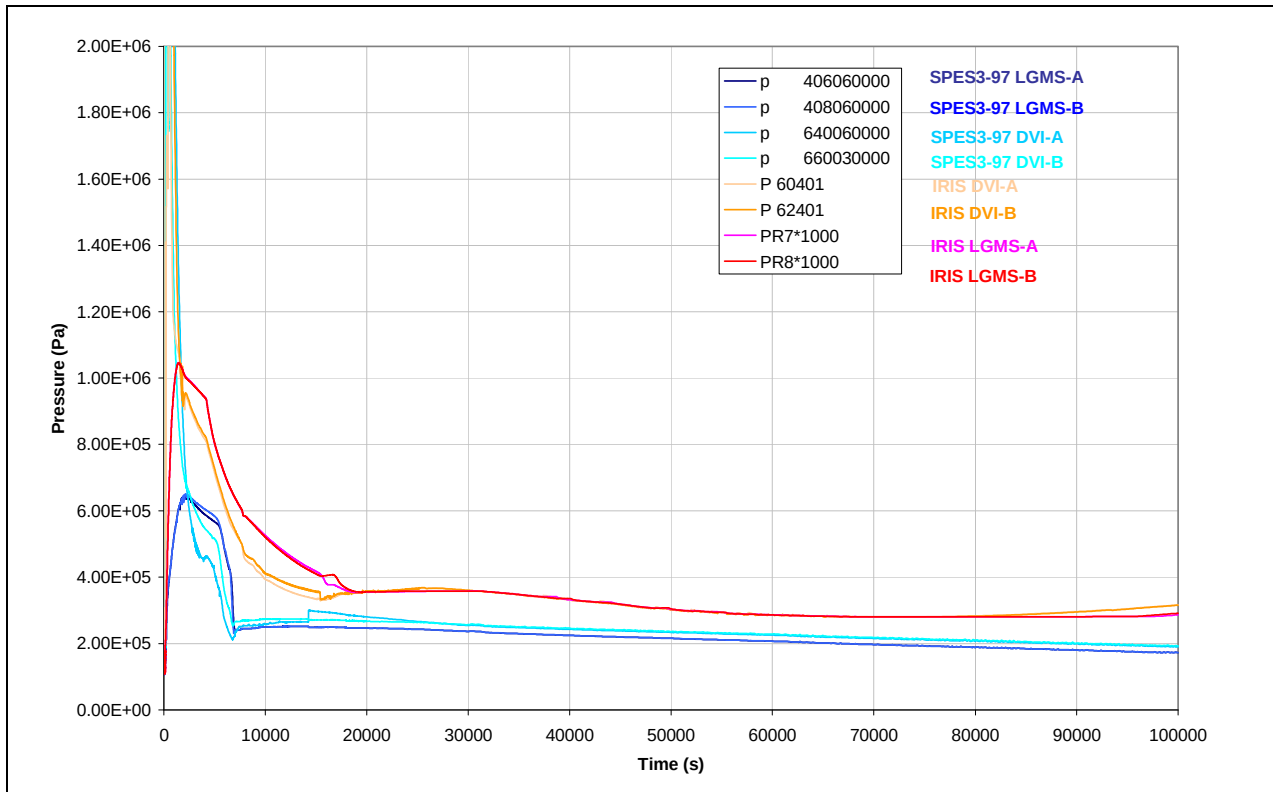
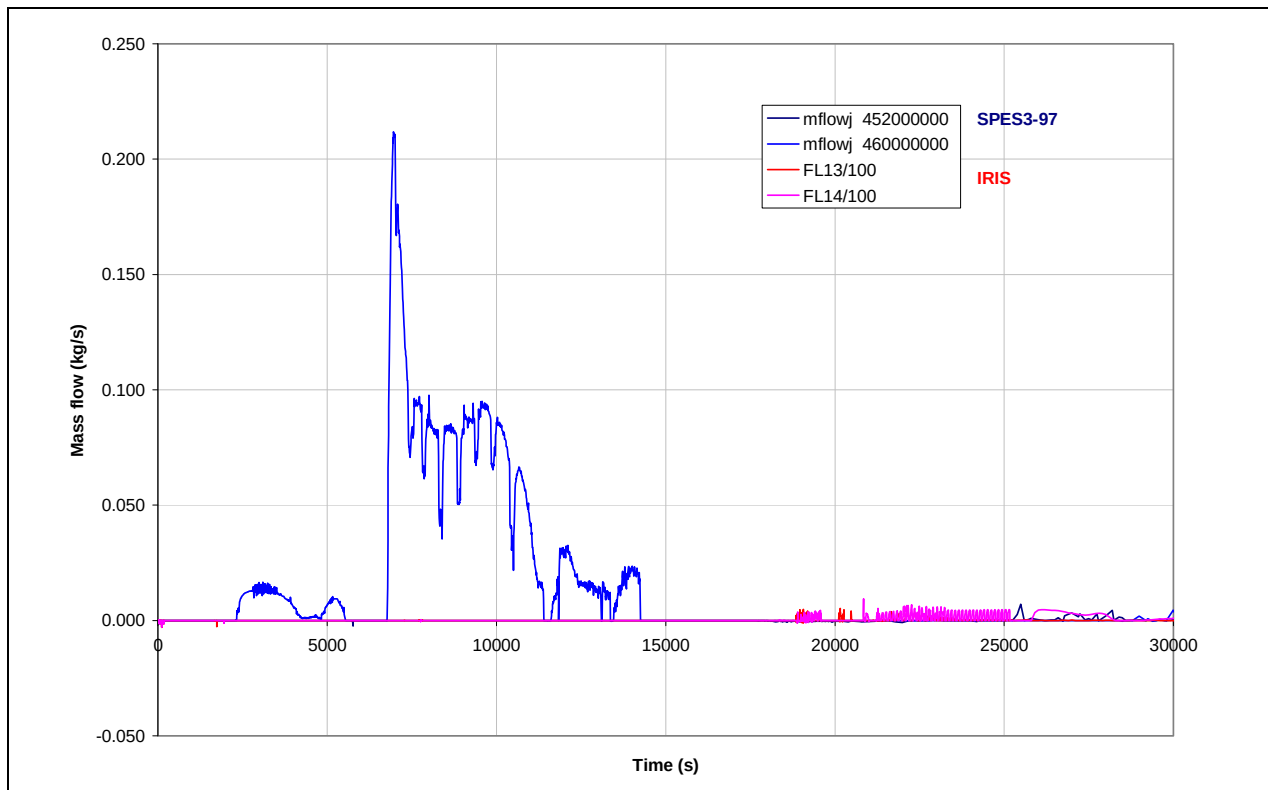
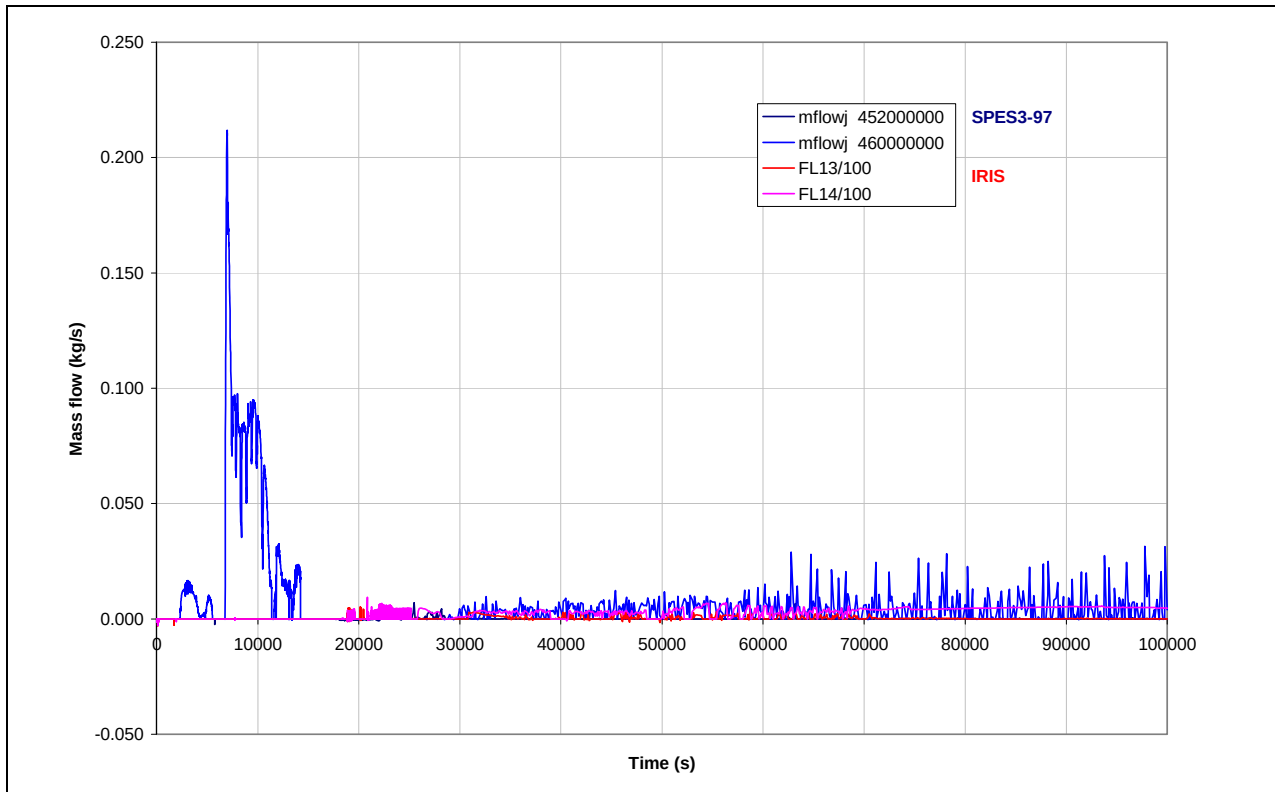


Fig.4.72 – SPES3-97 and IRIS HT1 RC to DVI mass flow (window)



**Fig.4.73 – SPES3-97 and IRIS HT1 RC to DVI mass flow**



**Fig.4.74 – SPES3-97 and IRIS HT1 RC to DVI integral mass flow**

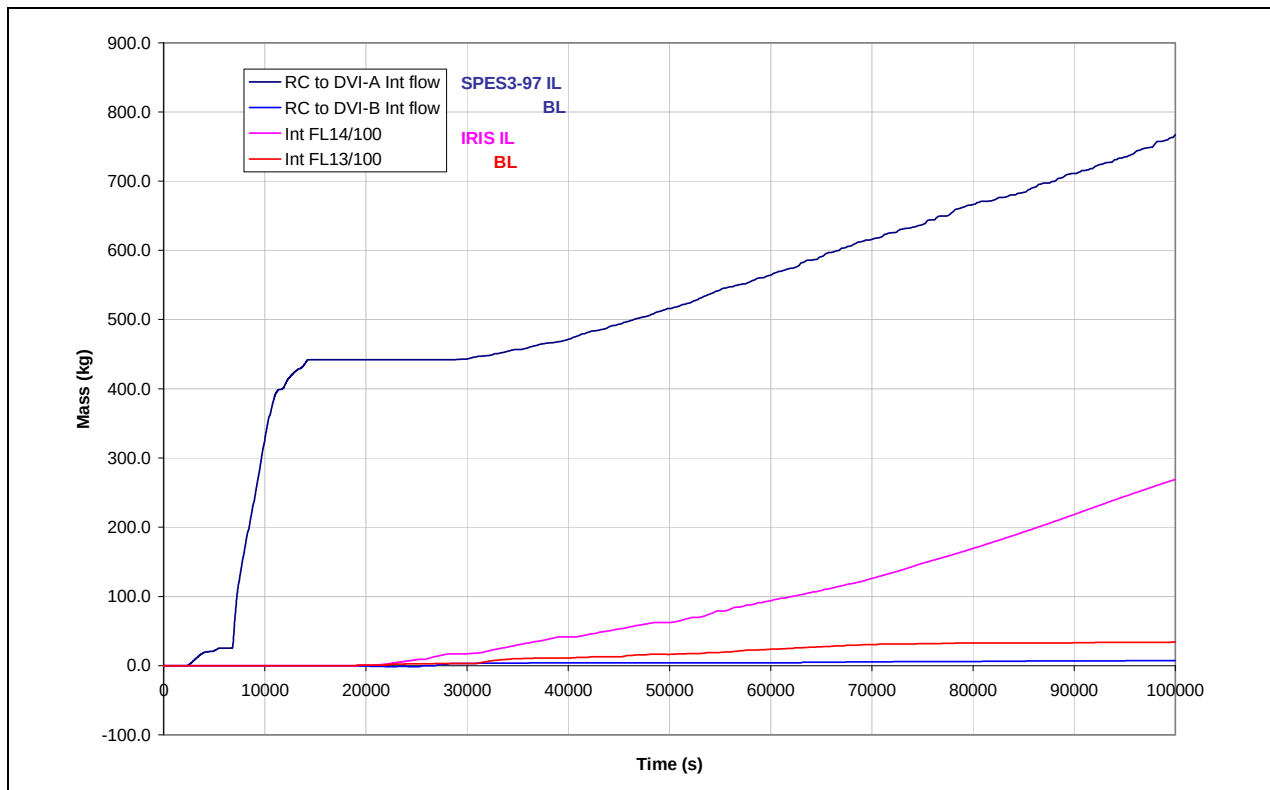


Fig.4.75 – SPES3-97 and IRIS HT1 QT level

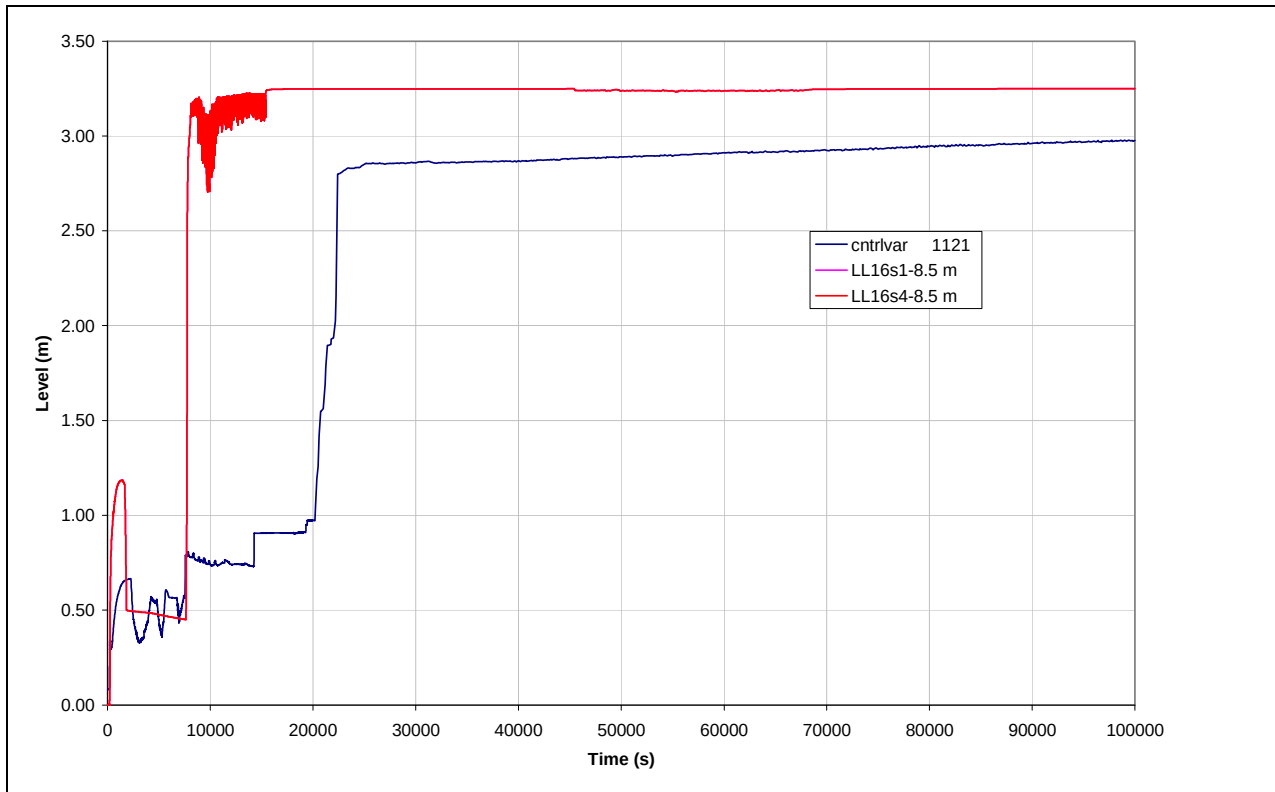


Fig.4.76 – SPES3-97 and IRIS HT1 ADS Stage-II mass flow (window)

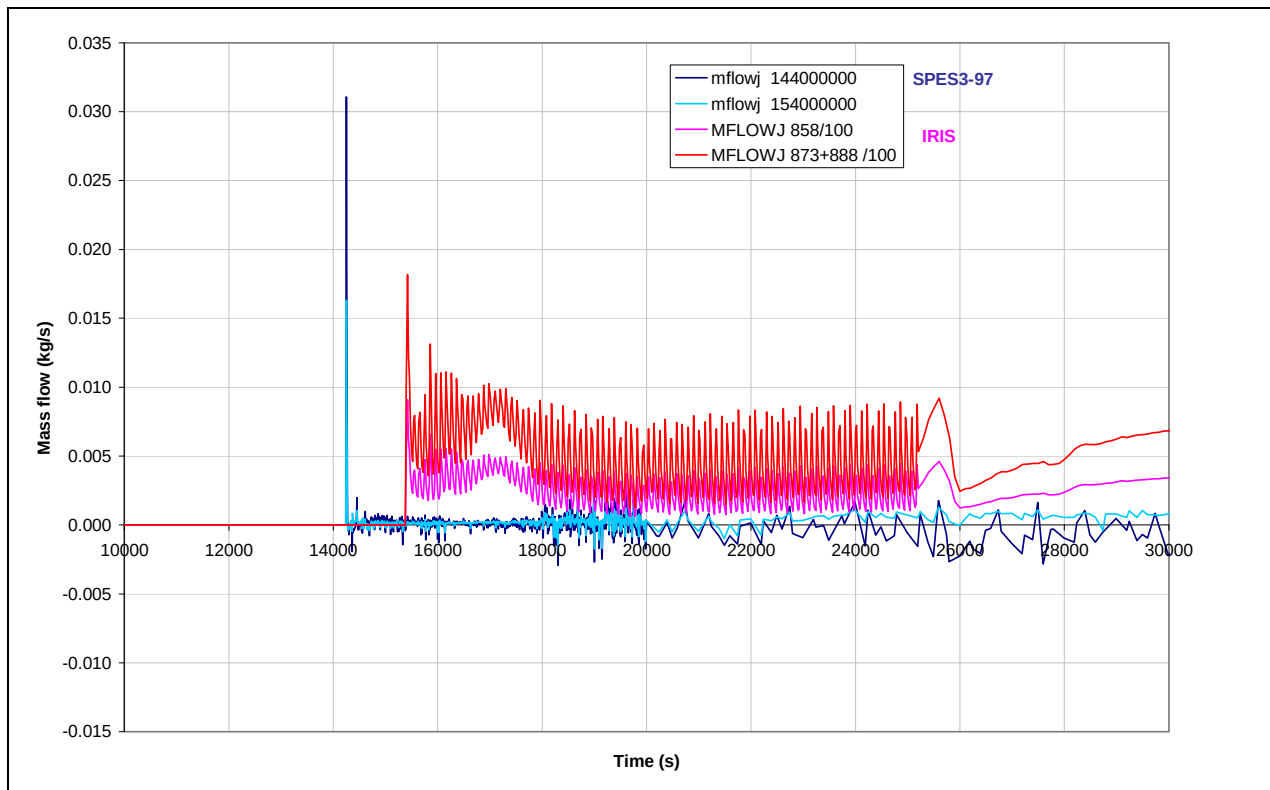




Fig.4.77 – SPES3-97 and IRIS HT1 ADS Stage-II mass flow

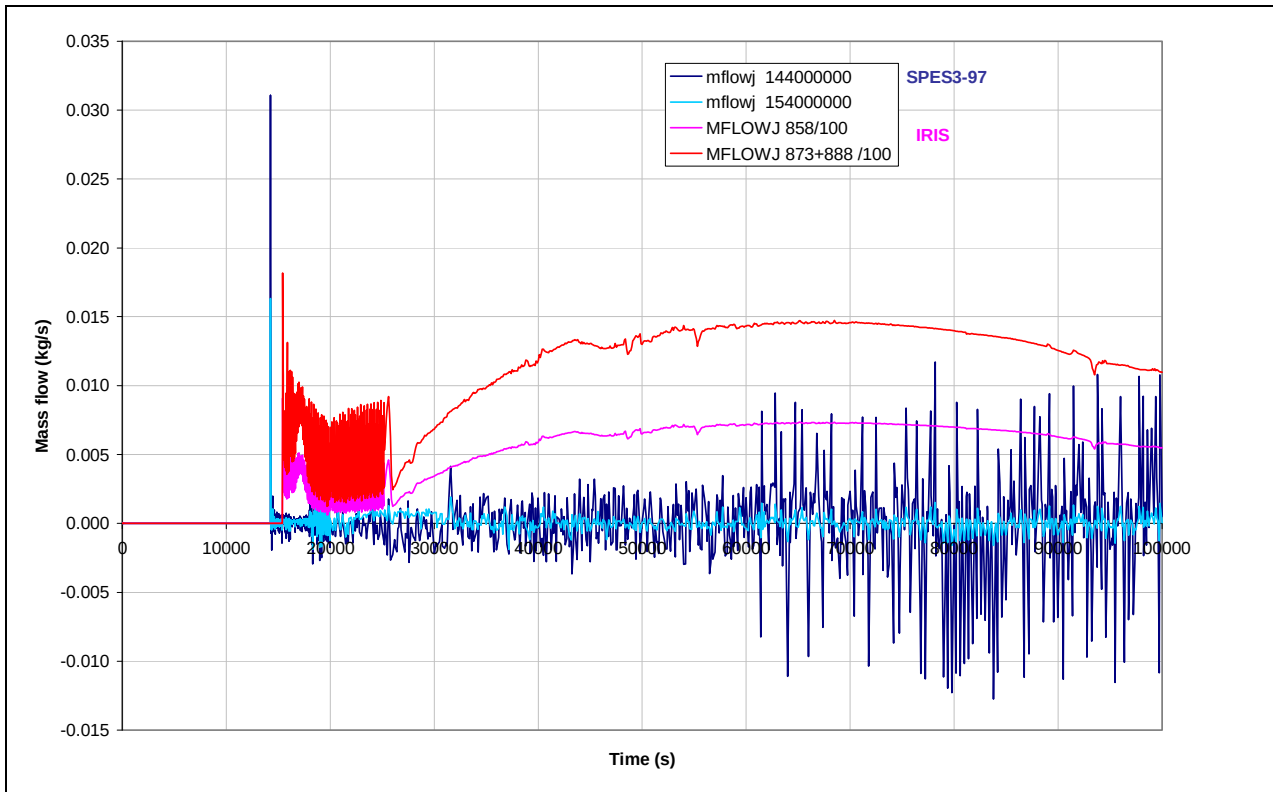


Fig.4.78 – SPES3-97 and IRIS HT1 RWST temperature

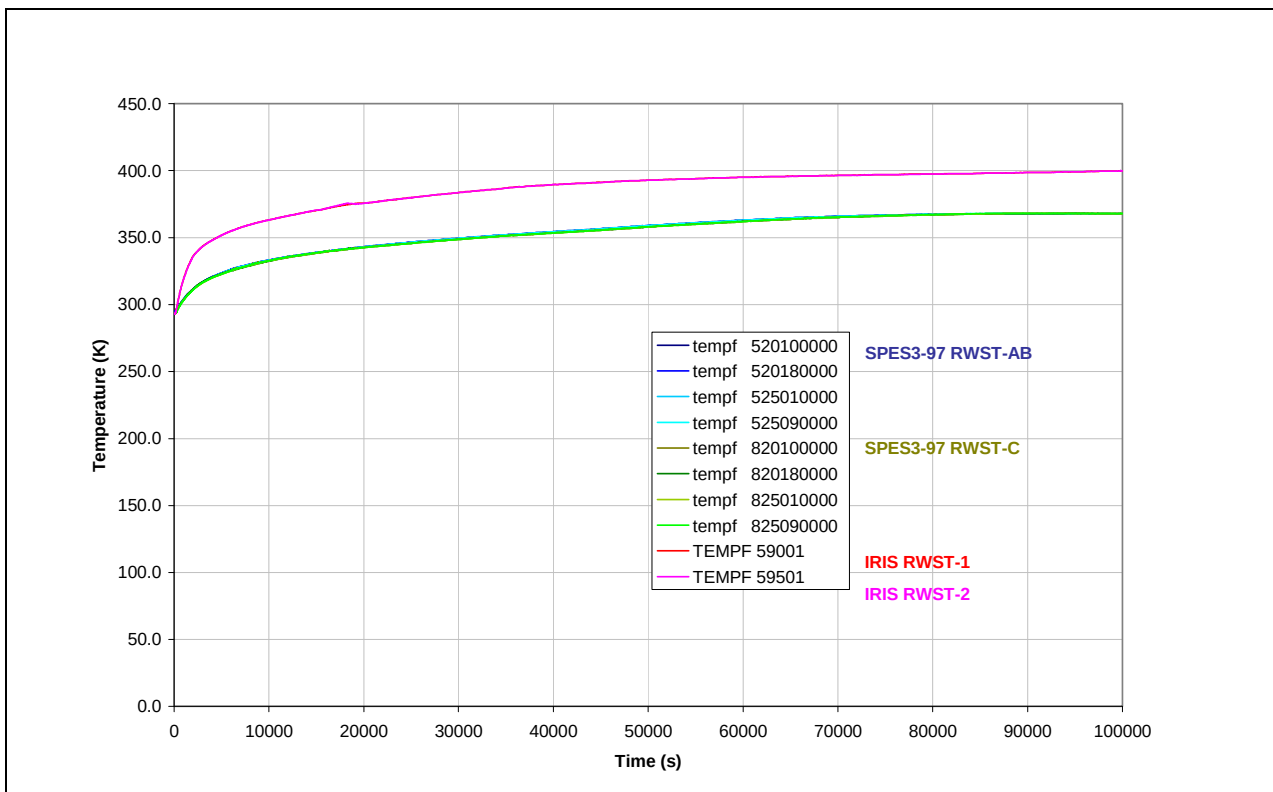


Fig.4.79 – SPES3-97 and IRIS HT1 RWST mass

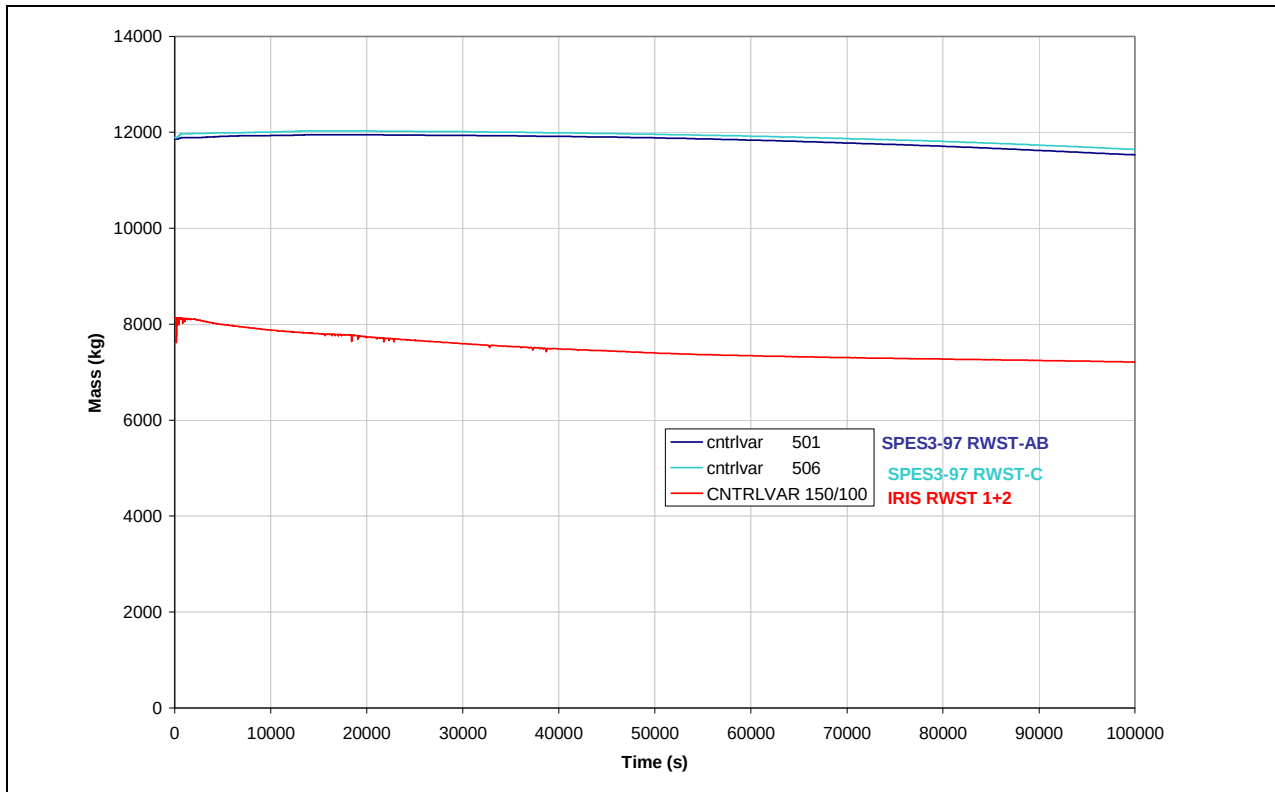
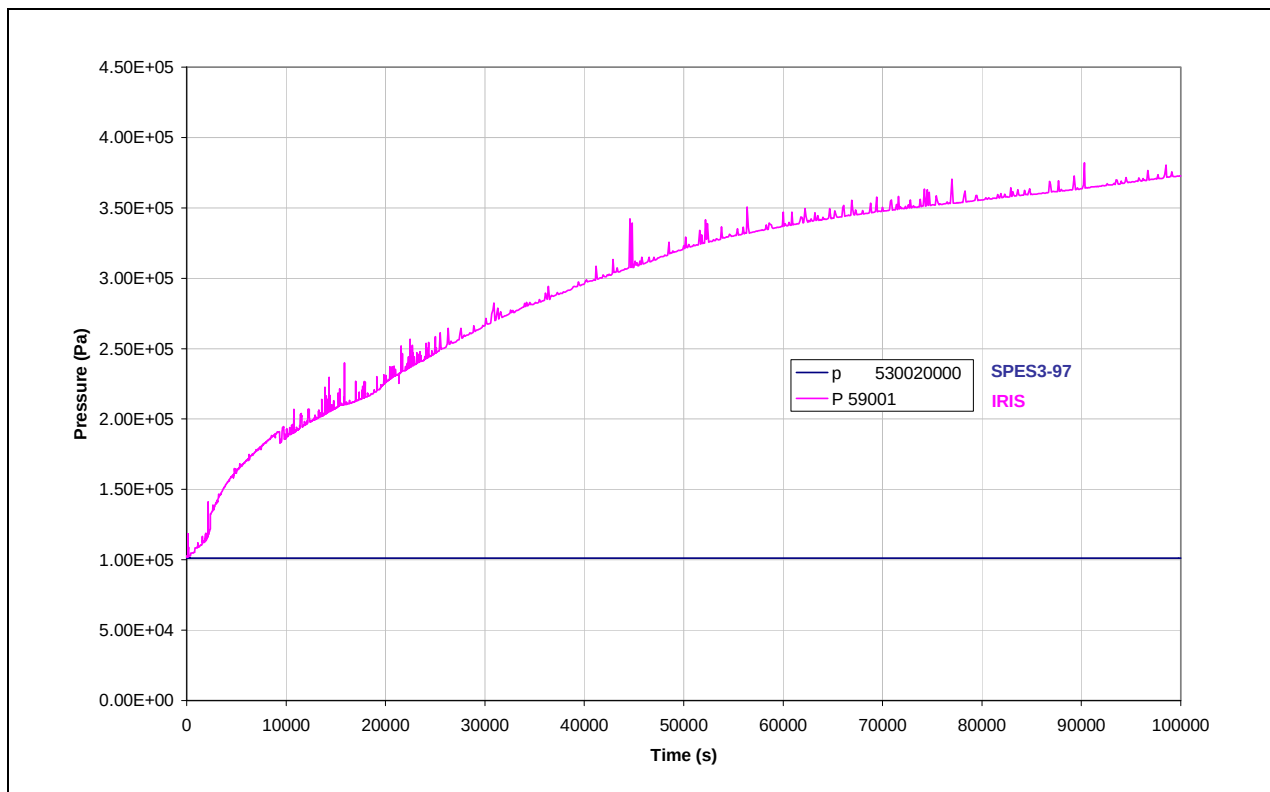
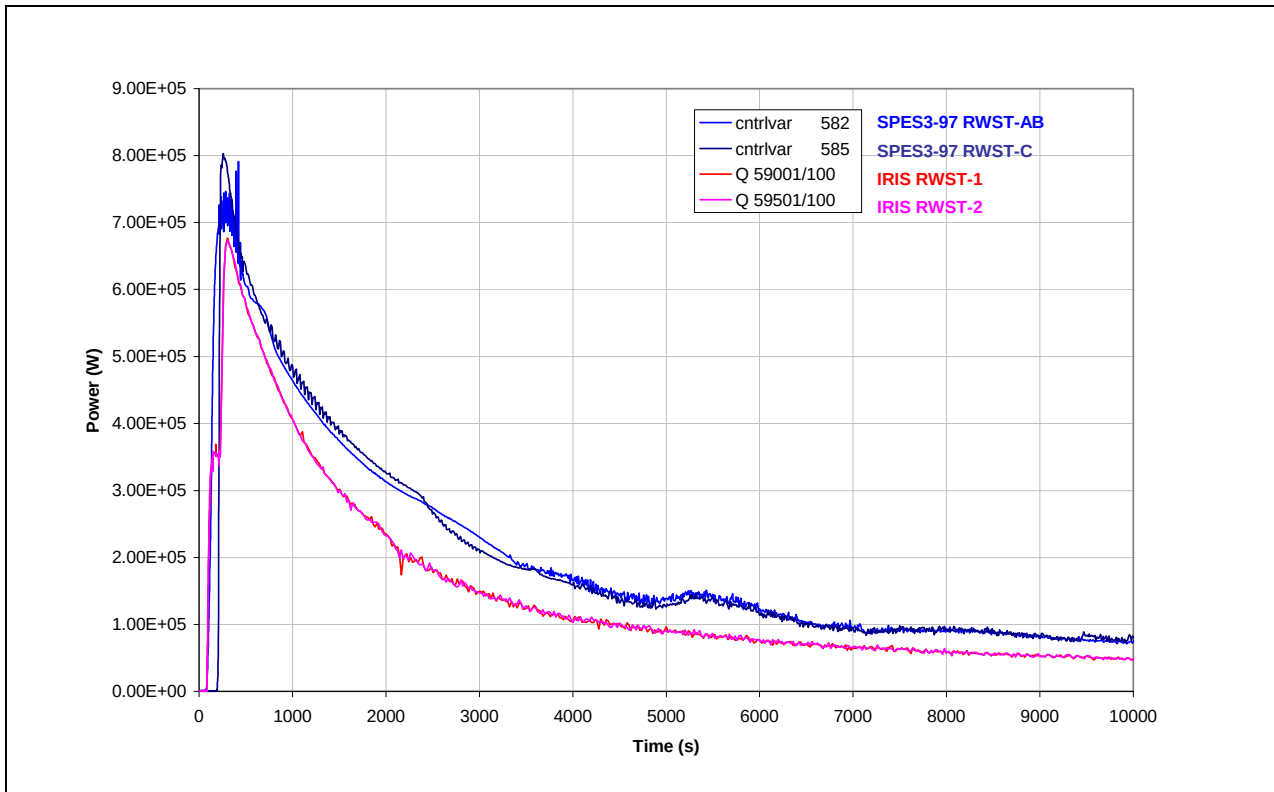


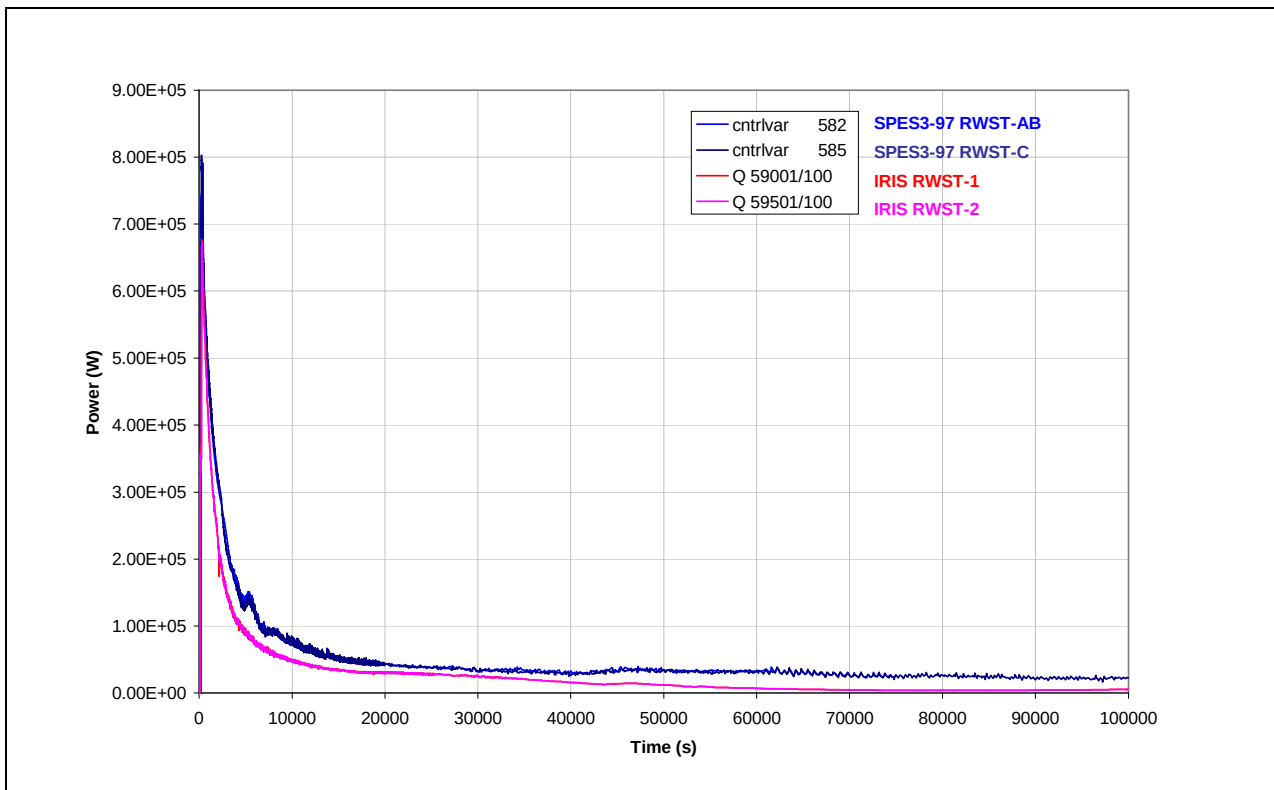
Fig.4.80 – SPES3-97 and IRIS HT1 RWST pressure



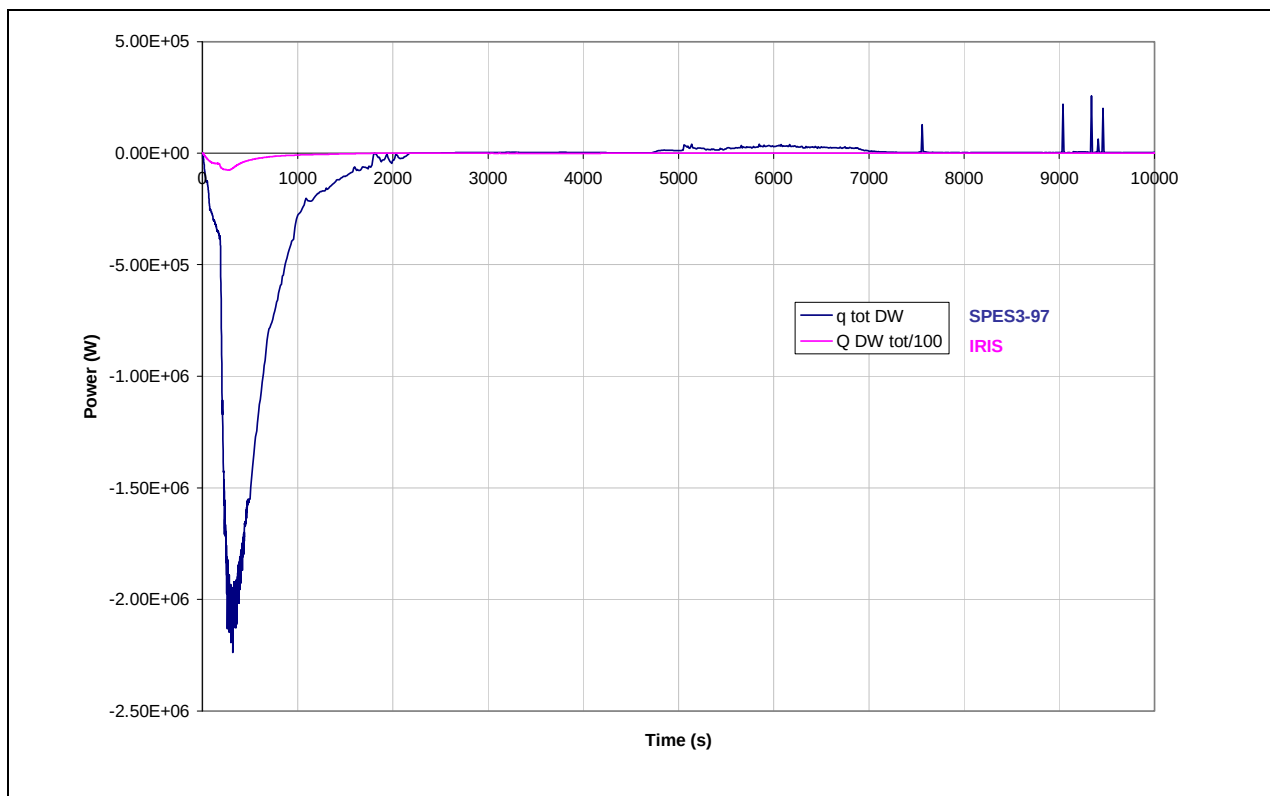
**Fig.4.81 – SPES3-97 and IRIS HT1 RWST power (window)**



**Fig.4.82 – SPES3-97 and IRIS HT1 RWST power**



**Fig.4.83 – SPES3-97 and IRIS HT1 DW power (window)**



**Fig.4.84 – SPES3-97 and IRIS HT1 DW power**

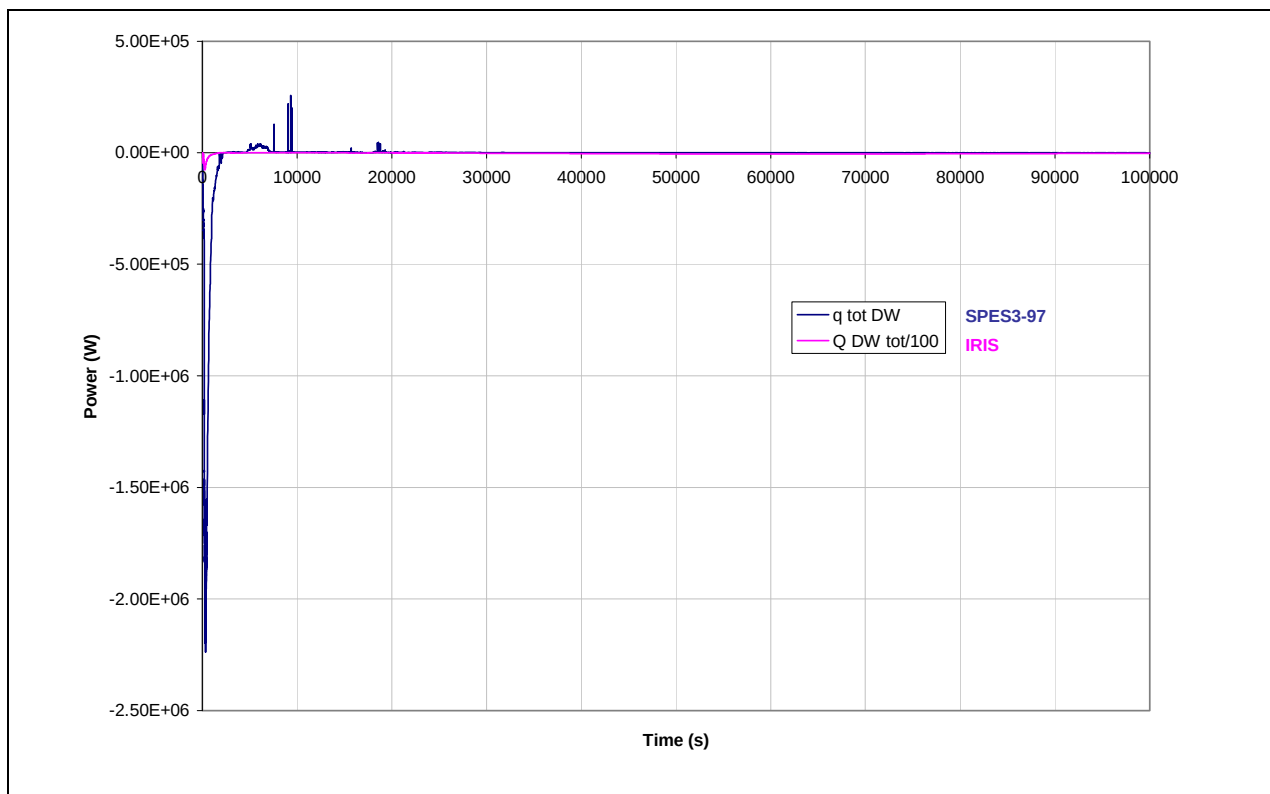


Fig.4.85 – SPES3-97 and IRIS HT1 DW inner and outer wall temperature (window)

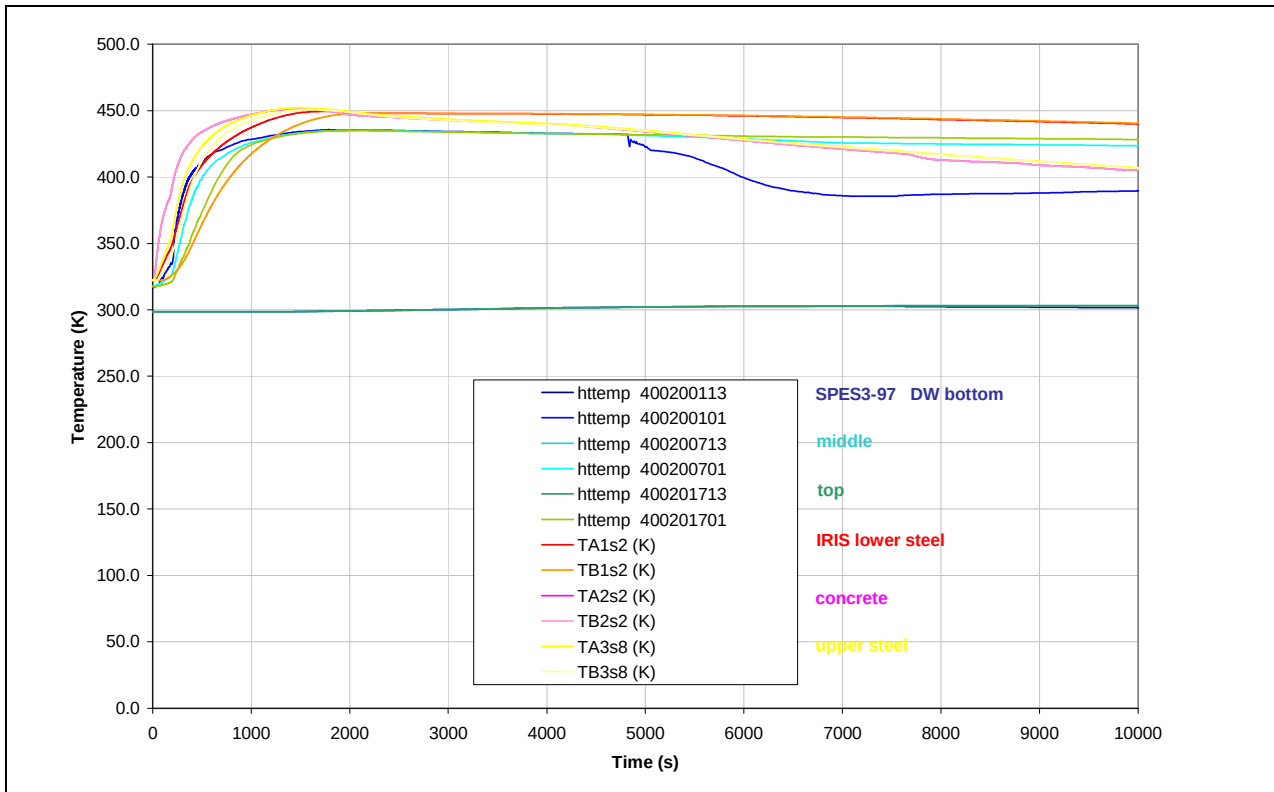
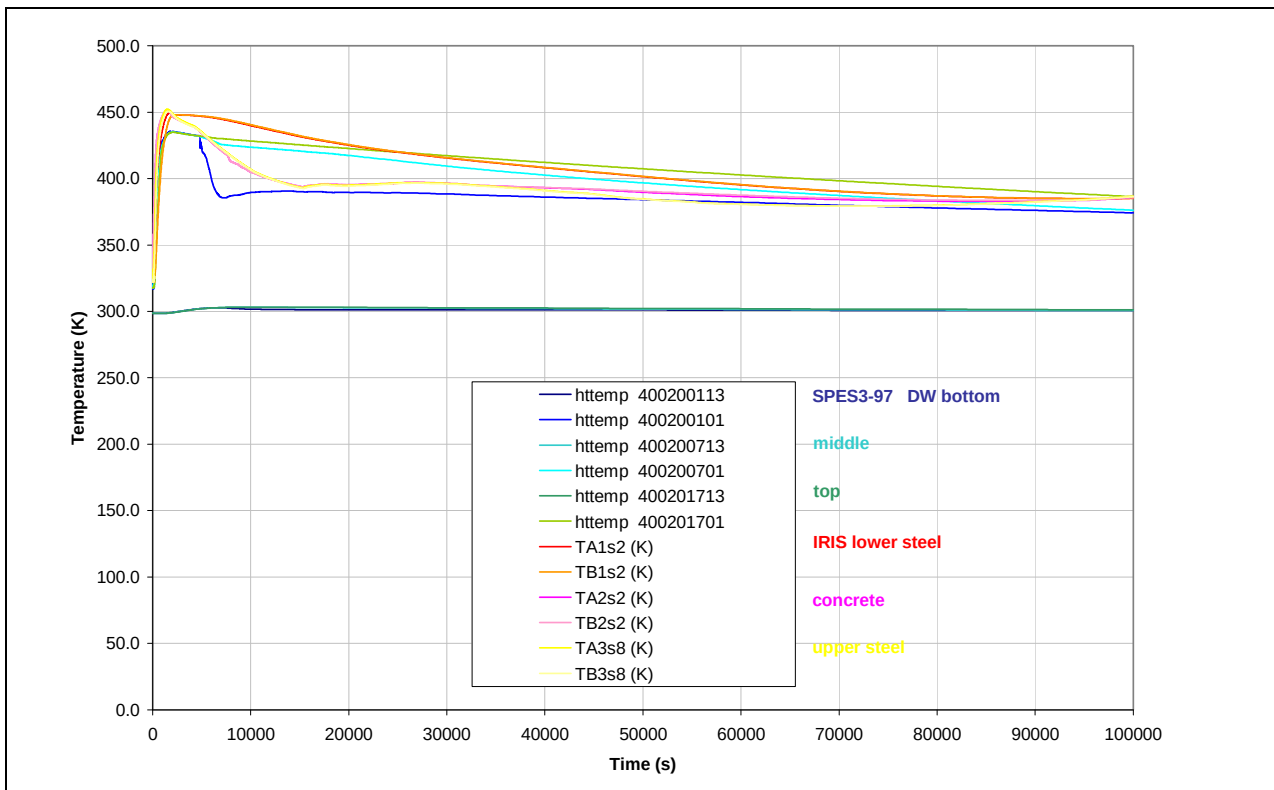


Fig.4.86 – SPES3-97 and IRIS DW inner and outer wall temperature



## 5. DVI DEG BREAK: SENSITIVITY CASES ON THE CONTAINMENT SYSTEM

On the basis of the outcomes of the direct comparison between SPES3-97 and IRIS-HT1, described in Chapter 4, and the preliminary Fractional Scaling Analysis application [6] [7], some sensitivity cases on the containment have been run to investigate the main causes of the differences between SPES3 and IRIS, Tab.5. 1.

The largest observed discrepancy between the plants is the containment pressure. Given its importance and influence on the sequence of events and transient evolution, a deeper analyses focused on the containment system is required to identify how to intervene on the SPES3 facility design and reduce the differences from IRIS.

The following paragraphs describe the results of the additional sensitivity cases on the containment, all simulating the same DVI DEG break and starting from the same initial conditions. In order to track the modifications between a case and the other, the main containment data are reported in sequence here below.

### *SPES3-94: sensitivity on the DW inner surface thermal insulation*

Reference [8] reports the results of a sensitivity case where 1 mm Teflon layer was applied on the DW inner surface to limit the steam condensation on the wall.

For completeness, the SPES3-94 case characteristics, described in [8], are reported here together with a meaningful summary of the results:

- As in case SPES3-89 [5]:

DW volume 35.36 m<sup>3</sup> (Di = 1.7 m);

DW thickness 25 mm;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

1 mm Teflon layer on the DW inner surface;

### *SPES3-99: sensitivity on the DW volume*

- As in case SPES3-97:

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

DW volume  $32.27 \text{ m}^3$ ; (for a 1:100 IRIS DW volume scaling)

DW thickness 25 mm;

#### *SPES3-100: sensitivity on the DW inner surface thermal insulation*

- As in case SPES3-99:

DW volume  $32.27 \text{ m}^3$ ;

DW thickness 25 mm;

RC volume  $5 \text{ m}^3$  (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume  $0.336 \text{ m}^3$  (Di = 0.37 m);

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

1.5 mm Rescor 902 Aluminium Silicate layer on the DW inner surface;

#### *SPES3-103: sensitivity on the DW inner surface thermal insulation*

- As in case SPES3-100:

DW volume  $32.27 \text{ m}^3$ ;

DW thickness 25 mm;

RC volume  $5 \text{ m}^3$  (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume  $0.336 \text{ m}^3$  (Di = 0.37 m);

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

3 mm Rescor 902 Aluminium Silicate layer on the DW inner surface;

#### *SPES3-104: sensitivity on the DW thickness*

- As in case SPES3-103:

DW volume  $32.27 \text{ m}^3$  (Di = 1.62 m);

RC volume  $5 \text{ m}^3$  (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume  $0.336 \text{ m}^3$  (Di = 0.37 m);

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

No DW inner surface thermal insulation;

DW thickness 15 mm (for a containment design pressure reduced to 1.5 MPa).

#### *SPES3-105: sensitivity on the DW thickness with IRIS heat structure mass scaled 1:100 and distributed on the SPES3 DW surface*

- As in case SPES3-104:

DW volume  $32.27 \text{ m}^3$  (Di = 1.62 m);

RC volume  $5 \text{ m}^3$  (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume  $0.336 \text{ m}^3$  (Di = 0.37 m);

QT thickness 6 mm;

PSS volume  $5.01 \text{ m}^3$  (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume  $1.66 \text{ m}^3$  (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New



DW thickness 10 mm (equivalent thickness by transforming concrete in equivalent steel);

*SPES3-106: sensitivity on the DW volume*

- As in case SPES3-104:

DW thickness 15 mm;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

DW volume 21.51 m<sup>3</sup>; (for a 1:150 IRIS DW volume scaling)

*SPES3-107: SG hydraulic diameter correction*

- As in case SPES3-99:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 25 mm;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

Corrected SG tube hydraulic diameter 14.084 mm (original wrong value 11.361 mm);

Corrected heater rod power curve at 7847 s (for a digit mistake the curve was not continuously decreasing);

Corrected DW bottom heat structure 401-2 to exchange with volume 401 (it exchanged with volume 400).

*SPES3-108: sensitivity on the DW heat structure mass and surface*

- As in case SPES3-107:

DW volume 32.27 m<sup>3</sup>;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

DW heat structures directly scaled 1:100 from IRIS in terms of mass and surface (a one-hundredth slice of IRIS structure is attributed to SPES3);

DW wall material properties as in IRIS;

Atmospheric temperature 35 °C (for DW boundary condition).

*SPES3-109: sensitivity on the PSS to DW vent pipe pressure drops*

- As in case SPES3-107:

DW volume 32.27 m<sup>3</sup>;

DW thickness 25 mm

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm) (original size 2 ½" Sch. 40) to match IRIS30H\_LB\_HT1 mass flow;

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm) (original size ¾" Sch. 40) to match IRIS30H\_LB\_HT1 mass flow;

*SPES3-110: sensitivity on the PSS to DW main vent pipe pressure drops*

- As in case SPES3-109:

DW volume 32.27 m<sup>3</sup>;

DW thickness 25 mm

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm) (original size 2 ½" Sch. 40) to match IRIS30H\_LB\_HT1 mass flow;

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm) (original size ¾" Sch. 40) to match IRIS30H\_LB\_HT1 mass flow;

- New

Main PSS vent pipe additional restriction at the check valve (Dorifice = 14.19 mm).

#### *SPES3-111: sensitivity on the DW heat structure initial temperature*

- As in case SPES3-104:

DW volume 32.27 m<sup>3</sup>;

DW thickness 15 mm;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m);

LGMS thickness top and bot 10 mm, middle 14 mm;

RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

- New

DW Heat structure initial temperature 84 °C.

#### *SPES3-112: sensitivity on the DW heat structure mass and surface and PSS heat structure mass*

- As in case SPES3-108:

DW volume 32.27 m<sup>3</sup>;

DW heat structures directly scaled 1:100 from IRIS in terms of mass and surface (a hundredth slice of IRIS structure is attributed to SPES3);

DW wall material properties as in IRIS;

RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);

RC thickness top 10 mm, middle 14 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);

PSS thickness bot 12 mm, top 18 mm;

LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)

LGMS thickness top and bot 10 mm, middle 14 mm;

DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.

Atmospheric temperature 35 °C (for DW boundary cond ition).

- New

PSS heat structures eliminated.

*SPES3-115: sensitivity on the containment compartment volumes, heat structure mass and temperature, piping pressure drops*

- As in case SPES3-110:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm;

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm);

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm);

QT heat structure initial temperature 48.9 °C.

- New

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m) (IRIS RC 1:100 volume scaling);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m) (IRIS PSS 1:100 volume scaling);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m) (IRIS LGMS 1:100 volume scaling);

LGMS height 4 m (original height 4.2 m);

LGMS thickness top and bot 8 mm, middle part 10 mm;

Main PSS vent pipe: No restriction on the check valve.

LGMS to DVI line calibrated orifice diameter 3.2 mm (original diameter 4 mm) to match IRIS30H\_LB\_HT1 mass flow;

ADS ST Stage-I calibrated orifice diameter 5.637 mm (original diameter 7.019 mm) to match IRIS30H\_LB\_HT1 mass flow;

ADS DT Stage-I calibrated orifice diameter 7.973 mm (original diameter 9.927 mm) to match IRIS30H\_LB\_HT1 mass flow;

EHR-A and B cold leg calibrated orifice diameter 5 mm (original diameter 6 mm) to match IRIS30H\_LB\_HT1 mass flow;

EHR-C cold leg calibrated orifice diameter 8.5 mm (original diameter 12 mm) to match IRIS30H\_LB\_HT1 mass flow;

DW Heat structure initial temperature 84 °C.

RC Heat structure initial temperature 84 °C.

PSS and LGMS Heat structure (air space) initial temperature 84 °C; (water space 48.9 °C).

#### *SPES3-118: sensitivity on the containment heat structure temperature and piping pressure drops*

- As in case SPES3-115:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm;

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle part 10 mm;

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm);

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm);

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHR-A and B cold leg calibrated orifice diameter 5 mm;

- New for this case

LGMS to DVI line calibrated orifice diameter 2.3 mm (from diameter 3.2 mm);

EHR-C cold leg calibrated orifice diameter 6.5 mm (from diameter 8.5 mm);

Extension PSS vent pipe calibrated orifice diameter 5.2 mm (no orifice originally).

DW, RC, PSS, LGMS, QT Heat structure initial temperature 48.9 °C.

*SPES3-119: sensitivity on the containment heat structure mass and piping pressure drops*

- As in case SPES3-118:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm);

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm);

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHRS-A and B cold leg calibrated orifice diameter 5 mm;

DW, QT, RC, PSS and LGMS Heat structure initial temperature 48.9 °C.

- New for this case

DW heat structures directly scaled 1:100 from IRIS in terms of mass and surface;

DW wall material properties as in IRIS;

PSS, LGMS, RC thickness 1 mm (to get closer to IRIS non-simulated structures);

LGMS to DVI line calibrated orifice diameter 2.5 mm (from diameter 2.3 mm) to match IRIS30H\_LB\_HT1 mass flow;

Extension PSS vent pipe calibrated orifice diameter 7.3 mm (from diameter 5.2 mm) to match IRIS30H\_LB\_HT1 mass flow;

RC to DVI line calibrated orifice diameter 1 mm (original valve diameter 10.7 mm) to match IRIS30H\_LB\_HT1 mass flow;

EHRS-C cold leg calibrated orifice diameter 7 mm (from diameter 6.5 mm) to match IRIS30H\_LB\_HT1 mass flow.

*SPES3-120: sensitivity on piping pressure drops and heat structure temperature*

- As in case SPES3-115:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm;

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle part 10 mm;

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm);

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm);

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHR-A and B cold leg calibrated orifice diameter 5 mm;

DW and RC Heat structure initial temperature 84 °C.

PSS and LGMS Heat structure (air space) initial temperature 84 °C; (water space 48.9 °C).

QT heat structure initial temperature 48.9 °C.

- New for this case (calibrated orifices as in SPES3-119):

LGMS to DVI line calibrated orifice diameter 2.5 mm;

EHR-C cold leg calibrated orifice diameter 7 mm;

Extension PSS vent pipe calibrated orifice diameter 7.3 mm;

RC to DVI line calibrated orifice diameter 1 mm.

#### *SPES3-122: sensitivity on the containment heat structure temperature*

- As in case SPES3-120:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm;

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle part 10 mm;

Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm);

Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm);

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHR-A and B cold leg calibrated orifice diameter 5 mm;

LGMS to DVI line calibrated orifice diameter 2.5 mm;  
EHRS-C cold leg calibrated orifice diameter 7 mm;  
Extension PSS vent pipe calibrated orifice diameter 7.3 mm;  
RC to DVI line calibrated orifice diameter 1 mm.

- New for this case

DW, RC, PSS, LGMS, QT heat structure initial temperature 48.9 °C.

*SPES3-124: sensitivity on piping pressure drops, PSS vent pipe geometry, PSS model and sparger elevation*

- As in case SPES3-122:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);  
DW thickness 15 mm; (corresponding to design pressure to 1.5 MPa);  
RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);  
RC thickness top 10 mm, bot 8 mm;  
QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);  
QT thickness 6 mm;  
PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);  
PSS thickness top 12 mm, bot 8 mm;  
LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);  
LGMS height 4 m;  
LGMS thickness top and bot 8 mm, middle part 10 mm;  
ADS ST Stage-I calibrated orifice diameter 5.637 mm;  
ADS DT Stage-I calibrated orifice diameter 7.973 mm;  
EHRS-A and B cold leg calibrated orifice diameter 5 mm;  
EHRS-C cold leg calibrated orifice diameter 7 mm;  
RC to DVI line calibrated orifice diameter 1 mm;

- New for this case

Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);  
Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);  
LGMS to DVI line calibrated orifice diameter 3.6 mm (from 2.5 mm);  
Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);  
Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);  
PSS sparger set at 0.75 m from PSS bottom to get closer to IRIS (original position 1 m from bottom)  
PSS bottom modeled with a branch.  
DW, RC and QT Heat structure initial temperature 84 °C.  
PSS and LGMS Heat structure (air space) initial temperature 84 °C; (water space 48.9 °C).



### 5.1 Sensitivity case: SPES3-94

Starting from the base case SPES3-89 [5], SPES3-94 was run to investigate the influence of a thermal insulation on the DW inner surface. In particular, 1 mm Teflon layer was simulated.

Fig.5. 1 and Fig.5. 2 show that the presence of an insulating layer on the inner wall of the DW does not change significantly the results. The containment pressure increases more rapidly in the early phases of the transient, due to the reduced steam condensation on the metal walls, but later, when Teflon is in thermal equilibrium with the metal wall, it has a very similar behavior to the base case. The containment pressure peak value and time of occurrence are very similar in SPES3-94 and 89 demonstrating that the thermal inertia of the metal wall is more effective in dumping pressure than how Teflon is in avoiding condensation.

One millimeter Teflon layer is not suitable to compensate for the differences between SPES3 and IRIS DW pressure. Moreover, considering the manufacturability complications related to the introduction of an insulation in the DW, compared to the limited advantages in pressure similarities, alternative solutions must be investigated, e.g. the DW volume influence.

### 5.2 Sensitivity case: SPES3-99

Starting from the base case SPES3-97, Chapter 4, SPES3-99 was run to investigate the influence of the DW volume reduction on the DW pressure response. According to [1], the IRIS DW volume is 3227 m<sup>3</sup> and the SPES3-97 one is 35.36 m<sup>3</sup>, not respecting the perfect 1:100 volume scaling criterion.

In SPES3-99, the DW volume is reduced to 32.27 m<sup>3</sup>.

Fig.5. 3 and Fig.5. 4 show that DW volume reduction to the correctly scaled one has no meaningful effect on the DW pressure response in the rising phase and for the peak value. The SPES3-99 DW slighter pressure decrease in the late phase of the transient, with respect to SPES3-97, can be explained with the lower heat losses to the environment due to the DW surface reduction.

The correction of DW volume scaling alone does not improve the SPES3 and IRIS similarities.

### 5.3 Sensitivity cases: SPES3-100 and SPES3-103

Starting from the case SPES3-99, a new insulating material, proposed by WEC (Aluminium Silicate Rescor 902) [15], is tested on the DW inner surface: in particular 1.5 mm thickness in SPES3-100 and 3 mm thickness in SPES3-103.

As shown in Fig.5. 5, the introduction of an increasing thickness of thermal insulation increases pressure between 200 s and 800 s, but the additional mass reduces the peak pressure.

These cases with different thickness of Rescor 902 in the DW show that trying to compensate the DW surface with an insulating material is effective only in the early phases of the transient, while the increase of mass affects and reduces the peak pressure.

The SPES-3 DW thermal insulation with Rescor 902 leads to worse effects on pressure than with non-insulated DW, showing that masses have larger effects than surfaces.

### 5.4 Sensitivity case: SPES3-104

The SPES3-104 case wants to investigate the influence of the DW heat structure mass on the containment pressure response. No thermal insulation is simulated on the DW inner surface, but the metal wall thickness is reduced from 25 mm to 15 mm (approximately corresponding to a design pressure of 1.5 MPa instead of the original 2 MPa [1]).

As shown in Fig.5. 6, the pressure increase in the early phases of the transient is steeper in SPES3-104 than SPES3-99 and the pressure peak results about 0.1 MPa higher. Anyway, the containment pressure is still below the IRIS HT1 pressure, showing that such DW metal mass reduction is not enough to have the desired pressure response.

### 5.5 Sensitivity case: SPES3-105

SPES3-105 is a further sensitivity case on the DW metal mass. It is a theoretical case where the DW metal mass is obtained by estimating the IRIS DW structure mass [14] and distributing it on the SPES3 DW surface to obtain an equivalent thickness of 10 mm.

The IRIS DW heat structures consist of carbon steel and concrete. In order to have a single material in SPES3, concrete has been transformed in equivalent steel, by weighing it on the specific heat.

From data contained in [14], an estimation of the IRIS steel and concrete mass has been done:

IRIS steel/100 = 3932 kg

IRIS concrete/100 = 1588 kg

The equivalent steel mass, by concrete, is obtained by:

$$M_{concrete} * c_{p_{concrete}} = M_{steel equiv.} * c_{p_{steel}}$$

$$M_{steel equiv.} = \frac{M_{concrete} * c_{p_{concrete}}}{c_{p_{steel}}} = 1588 * \frac{0.88}{0.46} = 3037 \text{ kg}$$

Total steel mass = 3932 + 3037 = 6969 kg

$$\text{Steel volume} = \frac{\text{Mass}}{\text{density}} = \frac{6969}{7850} = 0.887 \text{ m}^3$$

SPES3 DW surface ~84 m<sup>2</sup>

SPES3 equivalent thickness = 10.56 mm

10 mm thickness of AISI 304 (SPES3 material) is used in the calculation.

Fig.5. 7 shows the comparison among SPES3-105, 99 and IRIS HT1. The further DW metal mass reduction in SPES3-105 allows to get closer to IRIS with the pressure increase, in the early phases of the transient, and with the pressure peak. Anyway, the containment pressure is still below the IRIS HT1 pressure. This means that other parameters, other than the DW mass and surfaces, affect the results.

Fig.5. 8 shows power transferred to the heat structures in SPES3-99, SPES3-105 and IRIS HT1 during the blowdown phase. It is evident that reducing the metal thickness (SPS3-99 to SPES3-105), power decreases, but it is still larger in SPES3-105 than IRIS. Fig.5. 9 shows energy transferred to the DW metal structures. Around 2000 s, the energy transfer is over and in SPES3-105 it is about 13.5 times the IRIS one. This is partly explained by the SPES3 and IRIS DW surface ratio, around 10, and by a non-perfect scaling of IRIS structures mass on SPES3.

### 5.6 Sensitivity case: SPES3-106

SPES3-106 is a theoretical case where the DW volume is scaled 1:150 on the IRIS one.

As the DW volume reduction from 35.36 m<sup>3</sup> (SPES3-97) to 32.27 m<sup>3</sup> (SPES3-99) did not take any advantage on the containment pressure response, Fig.5. 3, it was made the attempt to scale the DW volume with 1:150 scaling factor in order to see how a large DW volume reduction affects pressure.

Fig.5. 10 compares the DW pressure for SPES3-106, SPES3-104 and IRIS HT1. Notwithstanding a faster pressure increase in the very early phases of the transient, the DW pressure reaches a lower peak and stays at lower values in the 1:150 volume case with respect to the 1:100 volume one. On the contrary, the PSS pressurize more due to a larger mass transfer from the DW through the PSS vent pipes, Fig.5. 11.

No improvement on the pressure trend is obtained by scaling the DW volume with a scaling factor different from 1:100. Moreover this would surely lead to introduce other distortions in the simulation with consequent disadvantages difficult to estimate.

### 5.7 Sensitivity case: SPES3-107

SPES3-107 case is an evolution of the SPES3-99 case with some minor modifications and corrections, in particular:

- the SG tube hydraulic diameter set at 14.084 mm (original wrong value 11.361 mm);
- heater rod power curve at 7847 s (for a digit mistake the curve was increasing at such time);
- DW bottom heat structure 401-2 set to exchange with volume 401 (it exchanged with volume 400).

Those variables, potentially affected by the SG tube hydraulic diameter modification, have been compared in SPES3-99 and SPES3-107, evidencing almost no differences in the SG exchanged power and core power, Fig.5. 12, Fig.5. 13, and a little difference in the SG tube collapsed level in the natural circulation transient phase, until about 30000 s, Fig.5. 14. The hydraulic diameter affects both the pressure drops and the heat transfer coefficient. The same primary side produced power is removed with a little lower SG level in SPES3-107.

### 5.8 Sensitivity case: SPES3-108

SPES3-108 case is a theoretical case where the DW heat structures are directly scaled 1:100 from IRIS in mass and surface. Based on the IRIS DW heat structures described in [14], a one-hundredth vertical slice of IRIS structures has been attributed to the SPES3 DW, maintaining the same thickness and material composition as in IRIS.

The cases SPES3-108 (IRIS mass and surface) and SPES3-105 (IRIS mass distributed on SPES3 DW surface) have the same DW structure mass, but different surface and materials. The DW pressure difference until about 250 s is related to the surface, then it is related to energy transfer to heat structures, Fig.5. 15, Fig.5. 16. Transferred energy is greater in SPES3-105 than SPES3-108, as the steel thermal conductivity is larger than concrete one, and consequently pressure is lower, Fig.5. 17, Fig.5. 18.

Fig.5. 15 and Fig.5. 16 report the DW pressure in SPES3-108 (IRIS mass and surface), SPES3-105 (IRIS mass distributed on SPES3 DW surface), SPES3-107 (reference case with 25 mm thick DW, equivalent to SPES3-99) and IRIS HT1. SPES3-108 DW pressure is similar to IRIS until 360 s, then the pressure increase is lower, probably due to factors different by the DW heat structures, e.g. heat transfer at the walls, other containment tank heat structures, volumes and non-condensable gas space. Anyway, focusing the attention to the early phases of the transient, some differences are evidenced that can be explained as follows.

As the SPES3-108 and IRIS HT1 are equivalent from the point of view of the DW heat structures and as the break mass flow is the same, Fig.5. 19, the pressure difference in the short term, until the ADS intervention (~190 s), can be justified only by a different heat transfer rate to the walls in RELAP5 and GOTHIC codes, with higher values in RELAP5. Fig.5. 17 and Fig.5. 18 show power transferred to the DW walls, while Fig.5. 22 and Fig.5. 23 show energy given to the same walls. Around 190 s, energy transferred to the DW walls in SPES3 is about 1.6 times the IRIS one. After the ADS intervention and hot fluid inlet into the DW, power and energy transfer to the DW walls increase in SPES3 more than IRIS. The ADS mass flow is greater in SPES3 than IRIS, Fig.5. 20 and Fig.5. 21, and this justify the faster pressure increase between 190 s and 360 s,

Fig.5. 16. On the other hand, power and energy transfer to the DW walls are greater in SPES3, so contributing to reduce pressure more in SPES3 than IRIS, Fig.5. 18.

Another cause of the DW pressure difference between SPES3 and IRIS is the SPES3 air space in PSS and LGMS, initially 13.9% larger than in IRIS. When, after the break, the steam-air mixture is transferred from the DW to the PSS, steam is condensed underwater and air accumulates in the PSS and LGMS top space. Fig.5. 24 shows the non-condensable quality in the DW. As the trend of non-condensable quality is quite similar in SPES3 and IRIS, similar quantities of air seem to be transferred from DW to PSS, so an eventual SPES3 gas volume reduction to the IRIS one could lead to a pressure peak increase from 0.88 MPa to 1 MPa in SPES3. Tab.5. 2 reports the containment liquid and gas volumes in IRIS and in SPES3-108 configuration.

Moreover, the presence of RC, PSS and LGMS heat structures in SPES3, not simulated in IRIS, surely affects the containment pressure contributing to steam condensation.

The DW depressurization phase, after the primary and containment pressure equalization and ADS Stage-I discharge stop (1950 s in SPES3 and 1490 s in IRIS), Fig.5. 20, is mainly related to the LGMS injection into the RC, through the broken DVI, and to the PSS back flow to the DW through the vent lines, Fig.5. 25, Fig.5. 26. After the LGMS actuation (1490 s in IRIS and 1950 s in SPES3), cold water enters the RC through the DVI-B split break line and condenses steam, dumping pressure. The LGMS injection mass flow in SPES3 is almost double than in IRIS, so fastening the containment depressurization between 2000 s and 3000 s, Fig.5. 15. The PSS injection into the DW starts around 3000 s in SPES3 and 4150 s in IRIS with a mass flow in SPES3 three times larger than in IRIS. This contributes to a further containment depressurization that speeds-up in SPES3 between 3000 s and 4500 s, while in IRIS it continues more slowly until about 7800 s when the PSS injection is over.

### 5.9 Sensitivity case: SPES3-109

SPES3-109 wants to investigate the influence of PSS to DW injection on the DW depressurization. As in SPES3-107 the PSS injection was three times larger than in IRIS, the SPES3-109 PSS vent pipes were reduced in size in order to increase the pressure drops and reduce the injection mass flow. In particular the main PSS vent pipe was reduced from 2 ½" to 2" Sch. 40 and the extension PSS vent pipe was reduced from ¾" to ½" Sch. 40.

Fig.5. 27 shows that the PSS injection mass flow decreases in SPES3-109 case with respect to SPES3-107 with consequent reduction of DW depressurization during the PSS injection phase, 4100 s to 7800 s in IRIS and 4700 s to 7500 s in SPES3-109, Fig.5. 28.

### 5.10 Sensitivity case: SPES3-110

SPES3-110 wants to investigate how the introduction of an additional pressure drop on the main PSS vent pipe connection to DW affects the DW pressure. For this, a calibrated orifice of 14.19 mm diameter is added at the check valves 473 and 483, suitable to introduce an estimated 0.05 MPa pressure drop with 0.1 kg/s flow at 4 kg/m<sup>3</sup> density.

Little differences between SPES3-110 and 109 are observed in the blowdown phase, when steam-air mixture is transferred from DW to PSS, Fig.5. 29. The additional restriction on the main PSS vent pipe causes a 6 kg mass transfer lower in SPES3-110 than SPES3-109, Fig.5. 30. Its influence on the DW pressure is quite low, Fig.5. 31, with a steeper pressure increase in the early phase and a pressure peak gain of 0.03 MPa.

### 5.11 Sensitivity case: SPES3-111

The impossibility to reduce the DW thickness under 15 mm, to resist to 1.5 MPa design pressure, leads necessarily to have an excess of mass with respect to IRIS 1:100 scaled mass. In SPES3-105 case, the IRIS scaled mass had been distributed on the SPES3 DW surface obtaining an equivalent thickness of 10 mm.

SPES3-111 investigates the possibility to compensate for the 5 mm extra mass by pre-heating the DW heat structures.

The preheating temperature has been obtained by an energy balance between the cases with DW 10 mm and 15 mm thickness, starting from an initial temperature of 48.9 °C and a wall temperature at regime of 172 °C for SPES3-105 (meaning for “regime” the time of 2000 s, after the heat-up transient).

The balance is:

$$(T_{FIN} - T_{IN(15)}) * M_{(15)} * c_p = (T_{FIN} - T_{IN(10)}) * M_{(10)} * c_p$$

where:

$T_{FIN}$  is the final temperature of the heat structures, equal for 15 mm and 10 mm cases;

$T_{IN(15)}$  is the unknown preheating temperature for the 15 mm case;

$M_{(15)}$  is the 15 mm DW mass;

$T_{IN(10)}$  is the initial temperature for the 10 mm case;

$M_{(10)}$  is the 10 mm DW mass;

$c_p$  is the stainless steel specific heat

Considering that  $M_{(15)}$  is 1.5 times  $M_{(10)}$ , the initial preheating temperature for the 15 mm case,  $T_{IN(15)}$ , results 84 °C.

Fig.5. 32 shows the DW pressure for the SPES3-111 case (15 mm pre-heated DW), SPES3-105 (10 mm DW), SPES3-104 (15 mm non-preheated DW) and IRIS. It is evident that the DW wall preheating at 84 °C, with respect to the specified initial temperature of 48.9 °C, compensates for the excess of mass in the 15 mm thick DW and allows to increase the DW pressure in SPES3 during the blowdown phase. Anyway, IRIS pressure is still higher than SPES3 one.

### 5.12 Sensitivity case: SPES3-112

SPES3-112 is a theoretical case with the IRIS DW structures scaled 1:100 in mass and surface on SPES3 (as in SPES3-108) and with the PSS heat structures removed.

SPES3-112 case wants to investigate the influence of the PSS heat structures on the SPES3 containment pressure response. The metal mass of the PSS, at the initial temperature of 48.9 °C, surely cools-down air when the air-steam mixture flows from the DW to the PSS, so limiting the pressure increase in the containment.

Fig.5. 33, at least for the initial transient phase until 900 s, shows a containment pressure gain without the PSS heat structures. Unfortunately, a code non-convergence error on the non-condensable gas properties stopped the run, but the result is anyhow evident.

### 5.13 Sensitivity case: SPES3-115

In order to reduce as much as possible distortions on the containment pressure related to scaling mismatching, in SPES3-115 the containment compartment volumes are scaled exactly 1:100 on IRIS volumes. Moreover, all tank thickness are reduced accordingly to a design pressure of 1.5 MPa, so limiting the thermal inertia of metal walls. An initial preheating of the containment heat structures is foreseen at 84 °C for the DW, RC and air space of PSS and LGMS while the liquid space of PSS and LGMS is at 48.9 °C.

In order to match the IRIS HT1 injection flowrates from the LGMS, the size of calibrated orifices has been reduced on the LGMS to DVI lines.

Moreover, the ADS ST and DT Stage-I orifices have been reduced to match the ADS mass flows.

Also the EHRS-CL orifices have been reduced on the three loops.

Fig.5. 34 compares the SPES3-115 DW pressure with SPES3-108 (IRIS DW 1:100 mass and surface), SPES3-107 (base case) and IRIS HT1. Notwithstanding a slower (about 250 s) DW pressure increase, the SPES3-115 case is similar to SPES3-108, showing that the containment volume resizing to the IRIS ones and the heat structure pre-heating are a good solution towards the IRIS containment pressure response. After the pressure peak, the SPES3 pressure decrease is still faster than in IRIS due to the larger LGMS injection, Fig.5. 35. The reduction of the orifice diameter leads to a reduction of the mass flow, that anyway remains higher than in IRIS. Around 6000 s, the SPES3 mass flow reduces to only a gravity driven flowrate, while IRIS one continues to be driven by the LGMS and PSS pressure higher than the DW and DVI one (for details on the phenomenon see Chapter 4).

The ADS Stage-I initial mass flow peak is very similar in SPES3 and IRIS after the ADS orifice size reduction. Difference is instead observed in the second peak due to water entrainment in the steam flow that is largely reduced in SPES3, Fig.5. 36.

The EHRS cold leg orifice resizing leads to similar mass flow in IRIS and SPES3-115 for EHRS-A and B, while EHRS-C cold leg flow is still overestimated in SPES3, Fig.5. 37.

### 5.14 Sensitivity case: SPES3-118

SPES3-118 is a sensitivity case on the containment heat structure temperatures (set at 48.9 °C) and on the piping pressure drops, in particular by resizing orifices on the LGMS to DVI lines and on the EHRS-C cold leg and by introducing an orifice on the PSS to DW vent line extension, all aimed at obtaining the IRIS mass flows.

The DW pressure is shown in Fig.5. 38. It is clear that the non-preheating of the containment heat structures in SPES3-118 lowers the DW pressure of about 0.07 MPa at the peak with respect to SPES3-115 case. After the peak, the pressure decrease in SPES3-118 is closer to IRIS than for SPES3-115, due to the lower injection of mass from LGMS and PSS, obtained by orifices.

Fig.5. 39 reports the LGMS injection in cases SPES3-118, SPES3-115 and IRIS HT1. SPES3-118 is close to IRIS, but slightly underestimated. This means the orifice is undersized. Notwithstanding the value of the mass flow, the trend is very similar in SPES3-118 and IRIS. This is due to the different behavior of PSS to DW injection that, delaying the PSS vent pipes emptying, maintains the LGMS and PSS pressurized with respect to the DW and DVI and sustains the LGMS injection flow.

Fig.5. 40 shows the PSS to DW injection mass flow. The introduction of an orifice at the PSS vent pipe extension limits the mass flow to values lower than IRIS ones, so delaying the PSS emptying. The orifice is undersized. Anyway, a limited cold water injection from PSS to DW leads to a similar DW depressurization between SPES3-118 and IRIS. This means that the condensation rate is larger in SPES3 (REALP5) than IRIS (GOTHIC).

The EHRS-C cold leg orifice resizing leads to similar mass flow in SPES3-118 and IRIS, anyway the new SPES3-118 mass flow is slightly underestimated, Fig.5. 41.



### 5.15 Sensitivity case: SPES3-119

SPES3-119 is a theoretical case to investigate the effect of the containment tank heat structures on the containment pressure response. In particular by setting the DW heat structures to IRIS ones, scaled 1:100 in mass and surface and reducing to 1 mm the RC, PSS and LGMS wall thickness.

Moreover SPES3-119 wants to investigate the piping pressure drop effect on the mass flow by re-calibrating the LGMS to DVI orifice, the EHRS-C cold leg orifice, the PSS vent pipe extension orifice and by introducing an orifice on the RC to DVI pipes to match the IRIS mass flow.

Fig.5. 42 compares the SPES3-119 and IRIS HT1 pressure. The rising phase is very similar until 400 s, later in SPES3-119 it increases a little slower, but up to reach a peak only 0.1 MPa lower than in IRIS. This results shows that the simulation of the containment tank heat structure is important in the pressure response and that they should be simulated in IRIS.

The depressurization phase is more rapid in SPES3-119 than IRIS, as the resized orifice on the PSS vent line extension determines a mass flow similar to IRIS one that produces a larger steam condensation in the DW, Fig.5. 43.

The LGMS injection mass flow maximum value is similar in SPES3-119 and IRIS HT1, but when the PSS empties and the containment compartment pressure equalize in SPES3-119, the LGMS injection is driven only by gravity, while it continues to be driven by over pressurized LGMS and PSS in IRIS, Fig.5. 44.

Fig.5. 45 shows the RC to DVI mass flow in SPES3-119 (with orifice), SPES3-107 (without orifice) and IRIS HT1. It is evident that SPES3-107 mass flow is much larger than IRIS one. The introduction of the orifice reduces the RC to DVI mass flow in SPES3-119 as shown in Fig.5. 46. The mass flow is in absolute very small and it is driven by the containment to primary side differential pressure.

The EHRS-C mass flow, after the orifice resizing is very similar in SPES3-119 and IRIS-HT1 at least until the EHRS heat transfer reduces in IRIS for the RWST heat-up (see Chapter 4), Fig.5. 47.

### 5.16 Sensitivity case: SPES3-120

SPES3-120 groups the solutions coming from the previous cases that led to a behavior close to IRIS HT1, in particular it has the containment tank volumes scaled 1:100 on IRIS, heat structures thickness designed for 1.5 MPa pressure, containment heat structures pre-heated at 84 °C, orifices optimized to reproduce the IRIS mass flows.

Fig.5. 48 compares the SPES3-120 and IRIS HT1 DW pressures. The pressure increase in the early phase of the transient follows the IRIS one with a certain delay due to the presence of heat structures and the heat transfer rate to the walls, different in GOTHIC and RELAP5 codes. The SPES3-120 DW pressure peak results 0.19 MPa lower than IRIS HT1 peak.

After the peak, the pressure decrease in the containment is mostly due to the LGMS injection into the DVI, Fig.5. 49 (and consequently into the RC through the broken loop) and to the PSS to DW injection through the vent pipes, Fig.5. 50.

In IRIS HT1, the LGMS injection into the DVI is always driven by the differential pressure between LGMS and DVI, until about 18700 s. Instead in SPES3, such differential pressure extinguishes earlier, around 9200 s and after that the LGMS injection is driven only by gravity with large reduction of the mass flow, Fig.5. 51, Fig.5. 49. The reason for early pressure equalization in SPES3 is related to the PSS injection stop, vent pipe emptying and gas flow from PSS to DW. This phenomenon does not occur in IRIS, where the vent pipes do not empty and do not allow air transfer from PSS to DW, so the PSS remain pressurized with respect to DW and DVI, Fig.5. 52. One of the possible reasons identified to explain the difference is the elevation of the main PSS vent pipe connection to DW. In IRIS HT1 it results only 0.2 m above the DW bottom, while in SPES3 it is 4.6 m above the DW bottom. When the LGMS and PSS inject water, it accumulates in the RC

which level increases up to flood the DW bottom, Fig.5. 53, Fig.5. 54, and cover the main vent pipe connection in IRIS forming a sort of siphon that prevents the pipe to empty.

The orifice size on the PSS vent pipe extension and on the LGMS to DVI lines allows to have the same IRIS mass flow, with different differential pressure values between PSS and DW and between LGMS and DVI. In particular, at 5000 s, the PSS-DW pressure in IRIS is 0.107 MPa and in SPES3 it is 0.316 MPa, both corresponding to 0.37 kg/s mass flow, Fig.5. 55, Fig.5. 50. Analogously, at 5000 s, the LGMS-DVI differential pressure is 0.078 MPa in IRIS and 0.317 MPa in SPES3, both corresponding to about 0.075 kg/s mass flow, Fig.5. 51, Fig.5. 49.

Even if reproducing the IRIS mass flow in SPES3 has allowed to make a direct comparison between the plants, the piping pressure drop scaling principle is not respected, i.e. piping designed to have the same pressure drops, should give the same mass flow under the same differential pressure. In practice, in SPES3-120, pressure drops in the lines are increased (by introducing small orifices) to reproduce the IRIS mass flow with larger differential pressures.

Fig.5. 56 shows the PSS collapsed level in SPES3-120 and IRIS HT1. Due to the different shape of PSS in IRIS and SPES3 and the same initial liquid mass, the initial value of level is different. Due to the PSS injection into the DW, the water level decreases down to the PSS sparger level in IRIS and below the sparger in SPES3. The IRIS sparger is located at 0.25 m from the PSS bottom, while the SPES3-120 sparger is at 1 m above the PSS bottom. The SPES3 PSS final level gets down to 0.33 m from the bottom showing a behavior non-properly reflecting the reality, related to the RELAP5 model for PSS [4].

#### 5.17 Sensitivity case: SPES3-122

SPES3-122 has the same geometrical characteristics as SPES3-120, but no initial containment metal structure pre-heating.

Fig.5. 57 shows IRIS HT1 DW pressure compared to SPES3-122 and SPES3-120. It is clear that the metal structures preheating at 84 °C allows to have a DW pressure response closer to IRIS one, 0.075 MPa higher in SPES3-120 than SPES3-122 at the peak. Such difference is maintained during the following transient phases.

#### 5.18 Sensitivity case: SPES3-124

On the basis of the comparison between the SPES3-120 and IRIS HT1 and the identifications of differences in the geometry and plant modeling, a review of both IRIS and SPES3 models was performed.

In IRIS, the containment heat structures were added together with the secondary side piping ones, the main PSS vent connection to DW was risen upwards of about 4 m and the PSS sparger was set at 0.75 m from the PSS bottom (the PSS tank was lowered of 0.25 m and the sparger vertical pipe shortened of 0.25 m), Fig.3. 17. The RWST model was corrected to have the proper mass and pressure boundary condition, Fig.3. 18.

SPES3-124 is a review of the model to match the IRIS HT5g new configuration.

The details of the SPES3 model changes are listed in the followings.

The PSS vent pipes and the LGMS to DVI pipes were dimensioned according to the pressure drop conservation criterion that maintains IRIS pressure drops without searching for the IRIS mass flow. This led to increase the main PSS vent pipe from 2" to 2 ½" Sch. 40 (as in SPES3-97) and the PSS vent extension from ½" to 1" Sch. 40. The orifice on the PSS extension pipe was enlarged.

In order to have the same gravity head of the PSS vent extension as in IRIS, the connection to DW was lowered of about 1.5 m to have a pipe 0.9 m longer than in IRIS to keep into account that the initial SPES3 PSS water level is 0.9 m higher than IRIS, due to the different tank shape, Fig.3. 8.



The PSS sparger elevation from PSS bottom was brought to 0.75 m (by lengthening the vent pipe).

The PSS model was modified to connect the sparger at a lower level and to join it to a bottom volume instead of to one of the vertical slices, Fig.3. 8.

The LGMS to DVI line orifice was enlarged to match IRIS pressure drops.

All the containment air space heat structure pre-heating at 84 °C was simulated.

The main variables related to the IRIS and SPES3 model modifications are compared to check the effectiveness of changes.

Fig.5. 58 and Fig.5. 59 report the DW pressure in the short and long term, respectively. The containment pressure response of the two plants is quite similar and also the value of the pressure peak, 0.05 MPa lower in SPES3 than IRIS. Instead, one of the most evident differences with respect to the previous cases is that, after the DW depressurization, pressure remains higher in SPES3 than IRIS and continues to decrease along all the rest of the transient. In IRIS, it decreases until about 50000 s and then it increases, probably due to an unbalance between core power and power rejected to RWST.

The PSS injection mass flow into the DW is compared in Fig.5. 60. It is anticipated in IRIS than in SPES3 for the faster DW depressurization after the peak, Fig.5. 58. Due to the larger differential pressure in SPES3 than IRIS, Fig.5. 61, the SPES3 injection reaches values double than IRIS and the PSS are emptied in a shorter time. The PSS water level and mass are shown in Fig.5. 62 and Fig.5. 63. Notwithstanding the PSS bottom model modification, even in SPES3-124, the PSS water level decreases below the sparger level and 277 kg of water (for each PSS) more than in IRIS are transferred from PSS to DW.

The LGMS injection into the DVI is shown in Fig.5. 64. The LGMS to DVI differential pressure is higher in SPES3 than IRIS and consequently the injection mass flow, Fig.5. 65, Fig.5. 66. As already explained for the previous cases, the injection mode is different in IRIS and SPES3 due to the longer LGMS pressurization in IRIS and the LGMS emptying is slower in SPES3 than IRIS, Fig.5. 67.

The DW level is shown in Fig.5. 68. In this case, the Main PSS vent connection to DW is not covered by water when the DW fills-up.

The PSS vent pipes in IRIS HT5g remain full of water after the PSS injection into the DW is over. In SPES3-124 they empty when the PSS sparger is uncovered, Fig.5. 69.

The correction of IRIS RWST model led to similar behavior of RWST temperature, mass, pressure and power, Fig.5. 70, Fig.5. 71, Fig.5. 72, Fig.5. 73. Temperature increases more rapidly in SPES3-124 RWST than IRIS, due to the larger transferred power from EHRS, Fig.5. 73. Such overestimated power is related to the higher and stable EHRS mass flow that lasts until about 20000 s in SPES3-124, Fig.5. 74, Fig.5. 75. The EHRS mass flow in IRIS shows strong oscillations starting around 1000 s.

Notwithstanding the persistence of some differences, it seems the IRIS and SPES3 models well agree to reproduce all the transient events with similar values of the main quantities. Only the modification of the SPES3 PSS bottom model is foreseen to avoid emptying below the sparger level.

The resulting case is SPES3-127 suitable for a detailed comparison with the IRIS HT5g case, deriving both of them from the design and model review described in this chapter.

**Tab.5. 1 – Summary of SPES3 sensitivity cases on the containment system**

| SPES3 run | Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | New for this case                                                                                                       |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| SPES3-94  | <ul style="list-style-type: none"> <li>As in case SPES3-89 [5]:<br/>DW volume 35.36 m<sup>3</sup> (Di = 1.7 m);<br/>DW thickness 25 mm;<br/>RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);<br/>RC thickness top 10 mm, middle 14 mm;<br/>QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);<br/>QT thickness 6 mm;<br/>PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);<br/>PSS thickness bot 12 mm, top 18 mm;<br/>LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)<br/>LGMS thickness top and bot 10 mm, middle 14 mm;<br/>DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.</li> </ul> | 1 mm Teflon layer on the DW inner surface                                                                               |
| SPES3-99  | <ul style="list-style-type: none"> <li>As in case SPES3-97 (directly deriving from SPES3-89):<br/>RC volume 5 m<sup>3</sup> (Di top = 1.022 m; Di bot = 0.5496 m);<br/>RC thickness top 10 mm, middle 14 mm;<br/>QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);<br/>QT thickness 6 mm;<br/>PSS volume 5.01 m<sup>3</sup> (Di top = 1.17 m; Di bot = 0.78 m);<br/>PSS thickness bot 12 mm, top 18 mm;<br/>LGMS volume 1.66 m<sup>3</sup> (Di top and bot = 0.57 m; Di mid = 0.855 m)<br/>LGMS thickness top and bot 10 mm, middle 14 mm;<br/>DW, RC, QT, PSS, LGMS heat structure initial temperature 48.9 °C.</li> </ul>                                           | DW volume 32.27 m <sup>3</sup> ; (for a 1:100 IRIS DW volume scaling)<br><br>DW thickness 25 mm;                        |
| SPES3-100 | <ul style="list-style-type: none"> <li>As SPES3-99</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 1.5 mm Rescor 902 Aluminium Silicate layer on the DW inner surface                                                      |
| SPES3-103 | <ul style="list-style-type: none"> <li>As SPES3-100</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 3 mm Rescor 902 Aluminium Silicate layer on the DW inner surface                                                        |
| SPES3-104 | <ul style="list-style-type: none"> <li>As SPES3-103</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | No DW inner surface thermal insulation<br><br>DW thickness 15 mm (for a containment design pressure reduced to 1.5 MPa) |
| SPES3-105 | <ul style="list-style-type: none"> <li>As SPES3-104</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | DW thickness 10 mm (equivalent thickness by transforming concrete in equivalent steel)                                  |
| SPES3-106 | <ul style="list-style-type: none"> <li>As SPES3-104</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | DW volume 21.51 m <sup>3</sup> ; (for a 1:150 IRIS DW volume scaling)                                                   |

to be continued...

...continued

|           |                                                                |                                                                                                                                                                                                                                                                                                                        |
|-----------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SPES3-107 | <ul style="list-style-type: none"> <li>As SPES3-99</li> </ul>  | <p>Corrected SG tube hydraulic diameter 14.084 mm (original wrong value 11.361 mm);</p> <p>Corrected heater rod power curve at 7847 s (for a digit mistake the curve was not continuously decreasing);</p> <p>Corrected DW bottom heat structure 401-2 to exchange with volume 401 (it exchanged with volume 400).</p> |
| SPES3-108 | <ul style="list-style-type: none"> <li>As SPES3-107</li> </ul> | <p>DW heat structures directly scaled 1:100 from IRIS in terms of mass and surface (a one-hundredth slice of IRIS structure is attributed to SPES3);</p> <p>DW wall material properties as in IRIS;</p> <p>Atmospheric temperature 35 °C (for DW boundary condition)</p>                                               |
| SPES3-109 | <ul style="list-style-type: none"> <li>As SPES3-107</li> </ul> | <p>Main PSS vent pipe diameter 2" Sch. 40 (Di = 52.5 mm) (original size 2 ½" Sch. 40) to match IRIS30H_LB_HT1 mass flow;</p> <p>Extension PSS vent pipe diameter ½" Sch. 40 (Di = 15.8 mm) (original size ¾" Sch. 40) to match IRIS30H_LB_HT1 mass flow;</p>                                                           |
| SPES3-110 | <ul style="list-style-type: none"> <li>As SPES3-107</li> </ul> | <p>Main PSS vent pipe additional restriction at the check valve (Dorifice = 14.19 mm).</p>                                                                                                                                                                                                                             |
| SPES3-111 | <ul style="list-style-type: none"> <li>As SPES3-104</li> </ul> | <p>DW Heat structure initial temperature 84 °C.</p>                                                                                                                                                                                                                                                                    |
| SPES3-112 | <ul style="list-style-type: none"> <li>As SPES3-108</li> </ul> | <p>PSS heat structures eliminated.</p>                                                                                                                                                                                                                                                                                 |

to be continued...

...continued

|           |                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SPES3-115 | <ul style="list-style-type: none"> <li>As SPES3-110</li> </ul> | <p>RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m) (IRIS RC 1:100 volume scaling);<br/> RC thickness top 10 mm, bot 8 mm;<br/> QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);<br/> QT thickness 6 mm;<br/> PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m) (IRIS PSS 1:100 volume scaling);<br/> PSS thickness top 12 mm, bot 8 mm;<br/> LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m) (IRIS LGMS 1:100 volume scaling);<br/> LGMS height 4 m (original height 4.2 m);<br/> LGMS thickness top and bot 8 mm, middle part 10 mm;<br/> Main PSS vent pipe: No restriction on the check valve.<br/> LGMS to DVI line calibrated orifice diameter 3.2 mm (original diameter 4 mm) to match IRIS30H_LB_HT1 mass flow;<br/> ADS ST Stage-I calibrated orifice diameter 5.637 mm (original diameter 7.019 mm) to match IRIS30H_LB_HT1 mass flow;<br/> ADS DT Stage-I calibrated orifice diameter 7.973 mm (original diameter 9.927 mm) to match IRIS30H_LB_HT1 mass flow;<br/> EHRS-A and B cold leg calibrated orifice diameter 5 mm (original diameter 6 mm) to match IRIS30H_LB_HT1 mass flow;<br/> EHRS-C cold leg calibrated orifice diameter 8.5 mm (original diameter 12 mm) to match IRIS30H_LB_HT1 mass flow;<br/> DW Heat structure initial temperature 84 °C.<br/> RC Heat structure initial temperature 84 °C.<br/> PSS and LGMS Heat structure (air space) initial temperature 84 °C;<br/> (water space 48.9 °C).</p> |
| SPES3-118 | <ul style="list-style-type: none"> <li>As SPES3-115</li> </ul> | <p>LGMS to DVI line calibrated orifice diameter 2.3 mm (from diameter 3.2 mm);<br/> EHRS-C cold leg calibrated orifice diameter 6.5 mm (from diameter 8.5 mm);<br/> Extension PSS vent pipe calibrated orifice diameter 5.2 mm (no orifice originally).<br/> DW, RC, PSS, LGMS, QT Heat structure initial temperature 48.9 °C.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

to be continued...

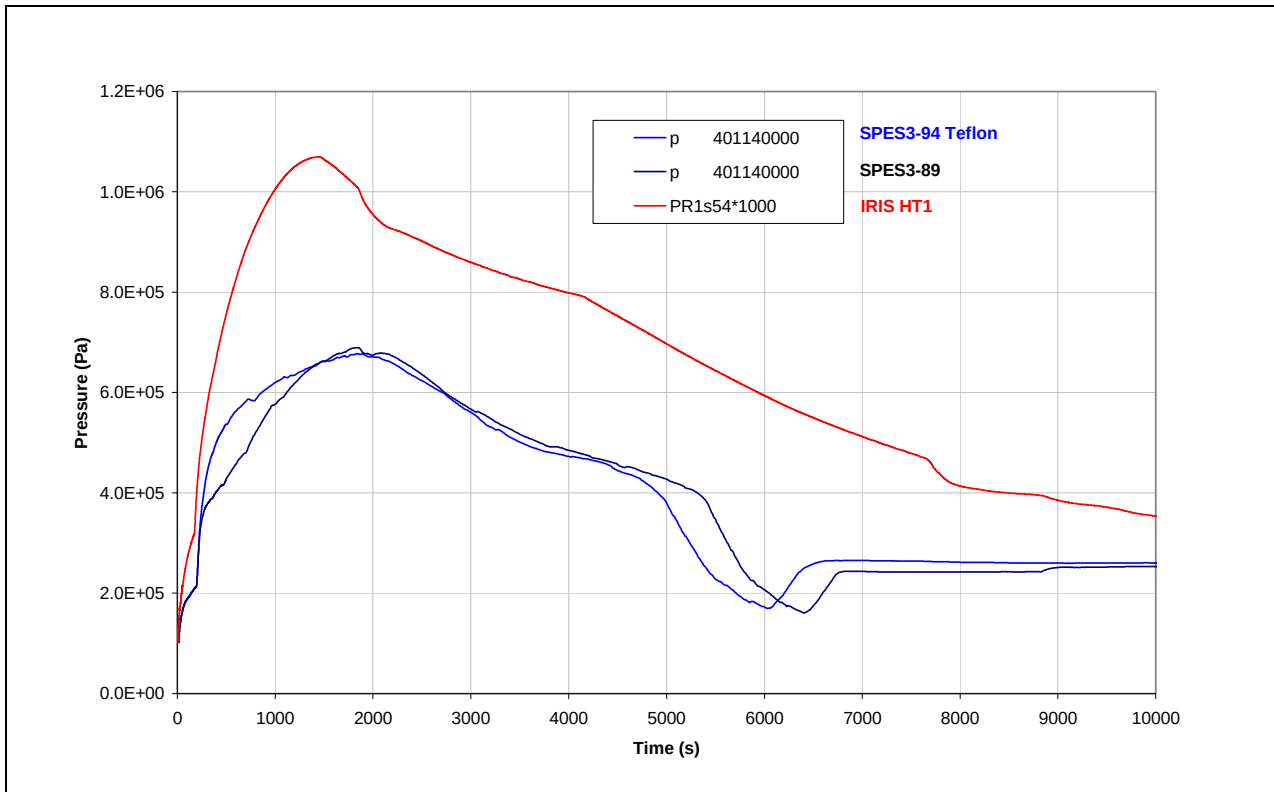
...continued

|           |                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SPES3-119 | <ul style="list-style-type: none"> <li>As SPES3-118</li> </ul> | DW heat structures directly scaled 1:100 from IRIS in terms of mass and surface;<br>DW wall material properties as in IRIS;<br>PSS, LGMS, RC thickness 1 mm (to get closer to IRIS non-simulated structures);<br>LGMS to DVI line calibrated orifice diameter 2.5 mm (from diameter 2.3 mm) to match IRIS30H_LB_HT1 mass flow;<br>Extension PSS vent pipe calibrated orifice diameter 7.3 mm (from diameter 5.2 mm) to match IRIS30H_LB_HT1 mass flow;<br>RC to DVI line calibrated orifice diameter 1 mm (original valve diameter 10.7 mm) to match IRIS30H_LB_HT1 mass flow;<br>EHRS-C cold leg calibrated orifice diameter 7 mm (from diameter 6.5 mm) to match IRIS30H_LB_HT1 mass flow.                                                                      |
| SPES3-120 | <ul style="list-style-type: none"> <li>As SPES3-115</li> </ul> | LGMS to DVI line calibrated orifice diameter 2.5 mm;<br>EHRS-C cold leg calibrated orifice diameter 7 mm;<br>Extension PSS vent pipe calibrated orifice diameter 7.3 mm;<br>RC to DVI line calibrated orifice diameter 1 mm.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| SPES3-122 | <ul style="list-style-type: none"> <li>As SPES3-120</li> </ul> | DW, RC, PSS, LGMS, QT heat structure initial temperature 48.9 °C.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| SPES3-124 | <ul style="list-style-type: none"> <li>As SPES3-122</li> </ul> | Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);<br>Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);<br>LGMS to DVI line calibrated orifice diameter 3.6 mm (from 2.5 mm);<br>Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);<br>Extension PSS vent pipe length decreased to match IRIS length.<br>Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);<br>PSS sparger set at 0.75 m from PSS bottom to get closer to IRIS (original position 1 m from bottom)<br>PSS bottom modeled with a branch.<br>DW, RC and QT Heat structure initial temperature 84 °C.<br>PSS and LGMS Heat structure (air space) initial temperature 84 °C;<br>(water space 48.9 °C). |

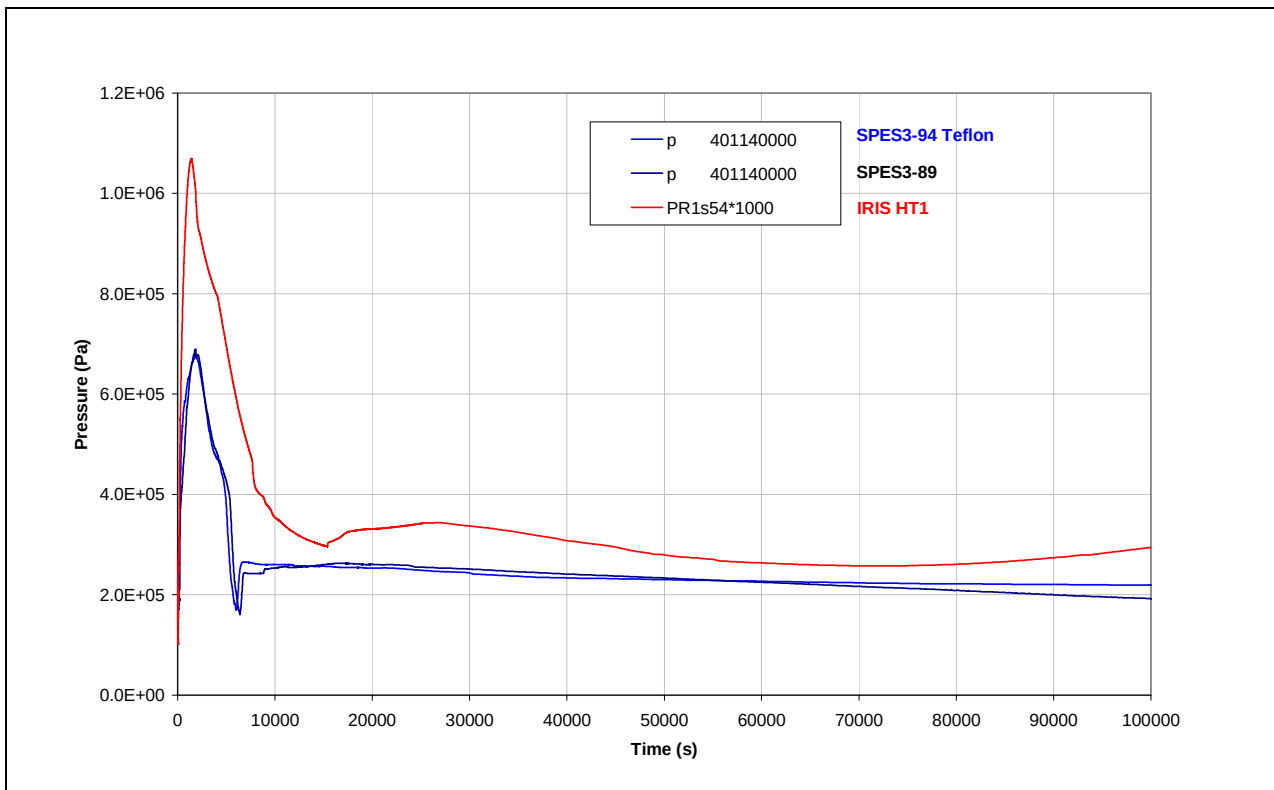
**Tab.5. 2 – IRIS and SPES3 containment gas and liquid volumes**

|          | <b>IRIS/100</b>                   |                                 |                                    | <b>SPES3</b>                      |                                 |                                    | <b>%</b> |
|----------|-----------------------------------|---------------------------------|------------------------------------|-----------------------------------|---------------------------------|------------------------------------|----------|
|          | Total<br>volume (m <sup>3</sup> ) | Gas volume<br>(m <sup>3</sup> ) | Liquid<br>volume (m <sup>3</sup> ) | Total<br>volume (m <sup>3</sup> ) | Gas volume<br>(m <sup>3</sup> ) | Liquid<br>volume (m <sup>3</sup> ) |          |
| DW       | 32.27                             | 32.27                           |                                    | 32.27                             | 32.27                           |                                    |          |
| RC       | 4.5                               | 4.5                             |                                    | 5                                 | 5                               |                                    |          |
| PSS-A    | 4.59                              | 3.09                            | 1.5                                | 5.01                              | 3.51                            | 1.5                                |          |
| PSS-B    | 4.59                              | 3.09                            | 1.5                                | 5.01                              | 3.51                            | 1.5                                |          |
| LGMS-A   | 1.5                               | 0.5                             | 1                                  | 1.66                              | 0.66                            | 1                                  |          |
| LGMS-B   | 1.5                               | 0.5                             | 1                                  | 1.66                              | 0.66                            | 1                                  |          |
| QT       | 0.336                             | 0.336                           |                                    | 0.336                             | 0.336                           |                                    |          |
|          |                                   |                                 |                                    |                                   |                                 |                                    |          |
| TOTAL    | 49.286                            | 44.286                          | 5                                  | 50.946                            | 45.946                          | 5                                  |          |
|          |                                   |                                 |                                    |                                   |                                 |                                    |          |
| PSS+LGMS |                                   | 7.18                            |                                    |                                   | 8.34                            |                                    | 13.9     |

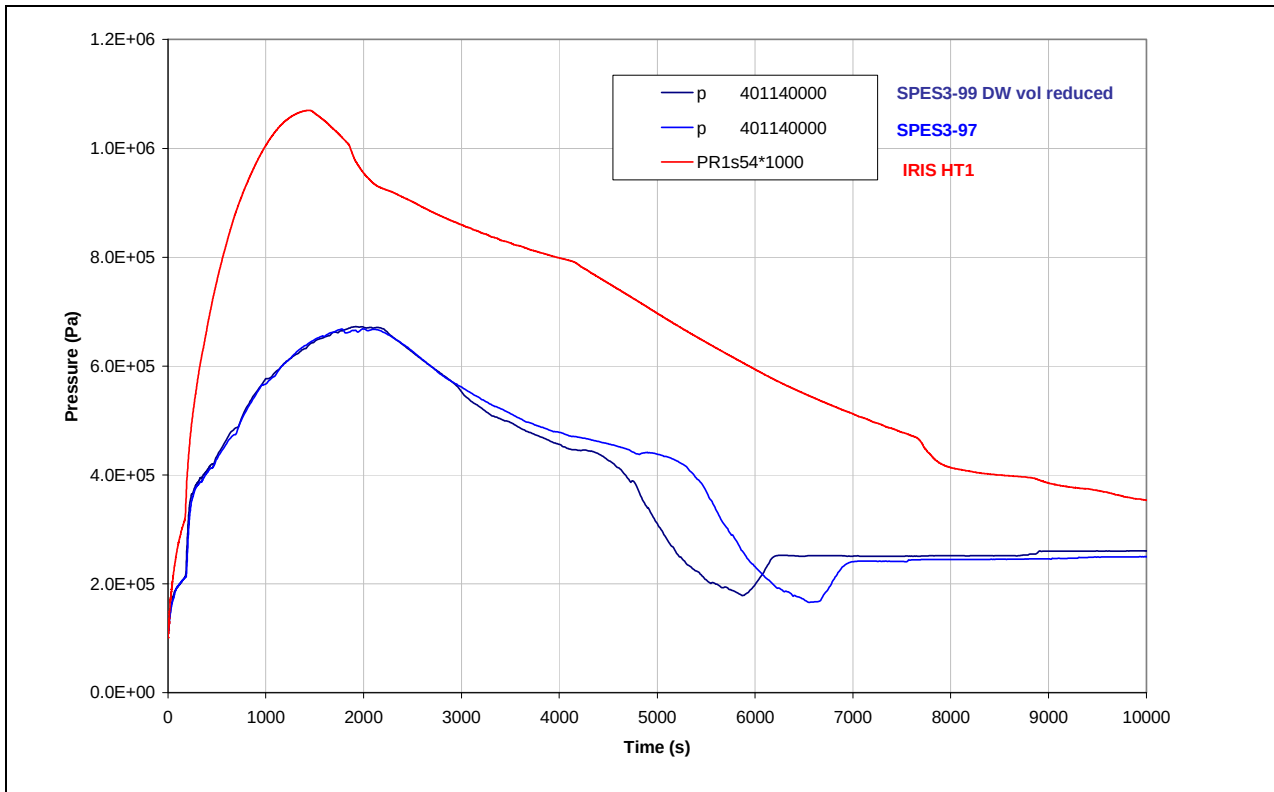
**Fig.5. 1 – SPES3-94, 89 and IRIS HT1: DW pressure (window)**



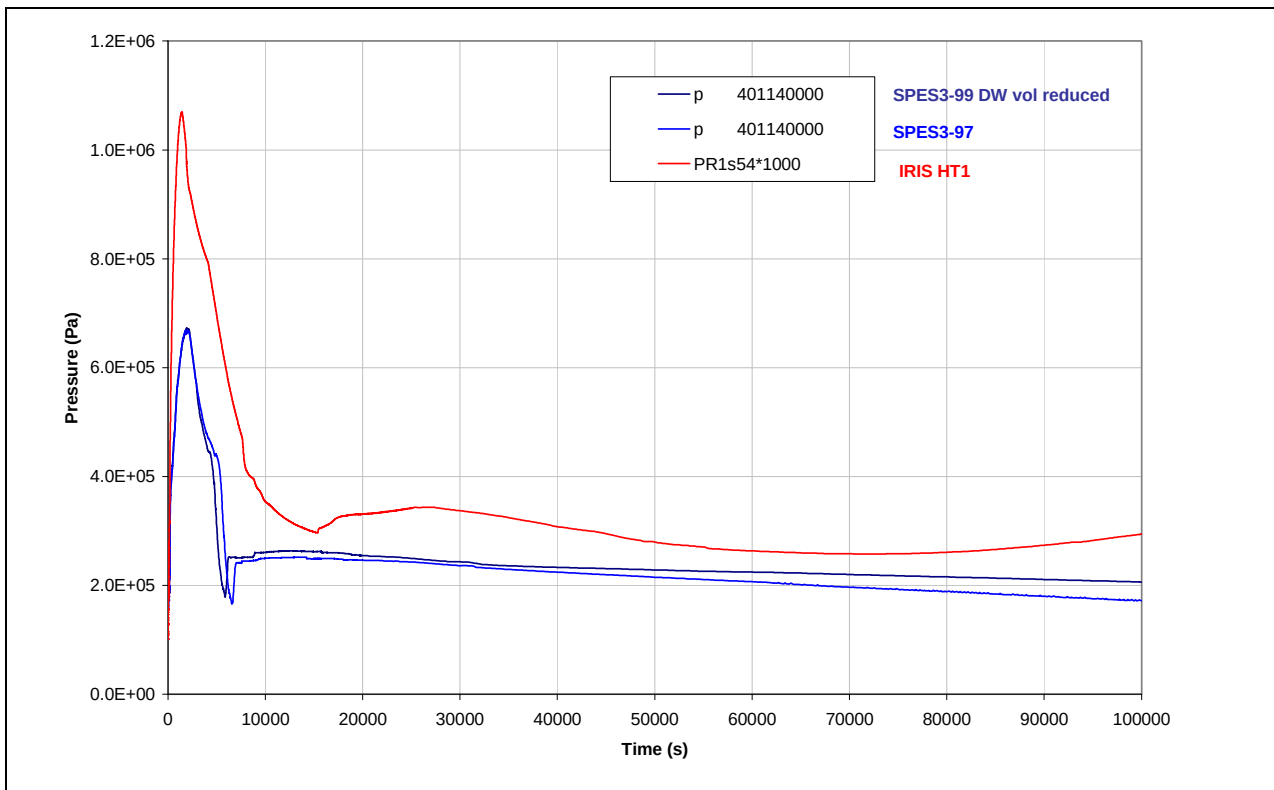
**Fig.5. 2 – SPES3-94, 89 and IRIS HT1: DW pressure**



**Fig.5. 3 – SPES3-99, 97 and IRIS HT1: DW pressure (window)**

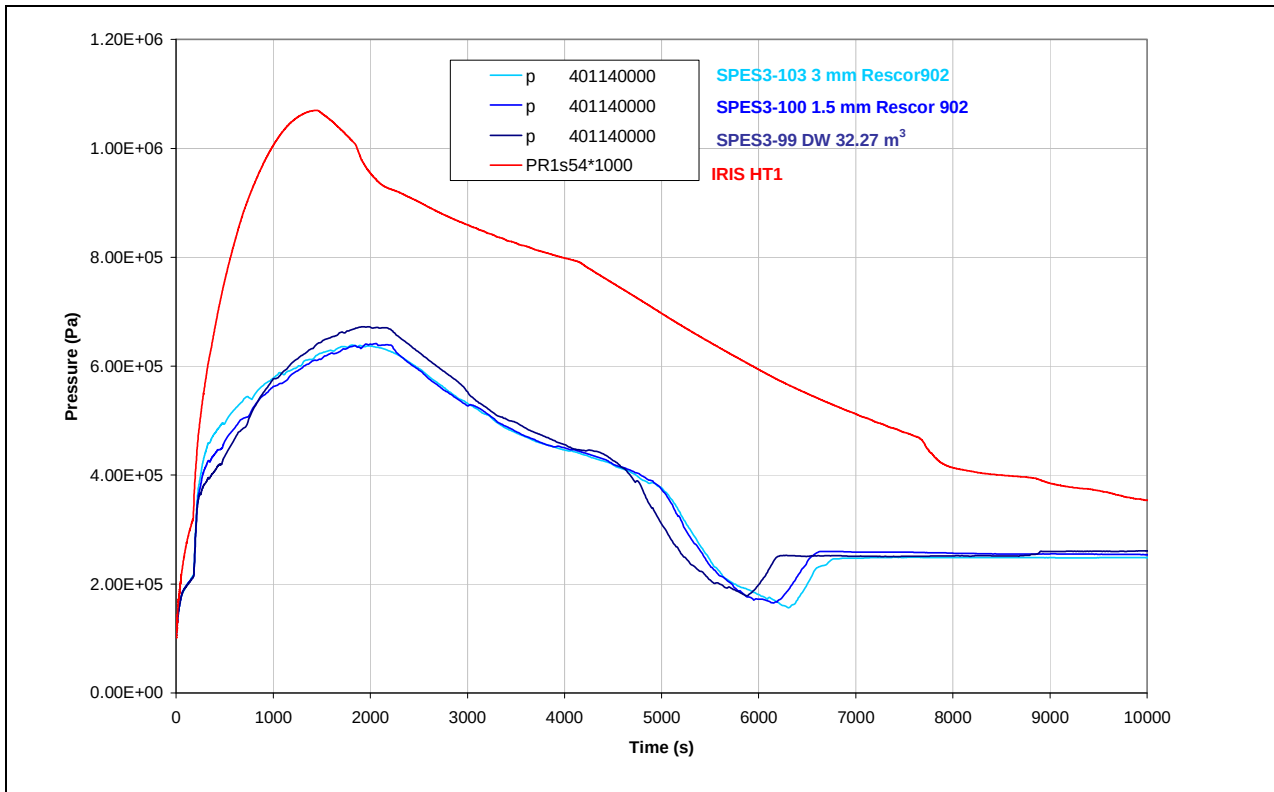


**Fig.5. 4 – SPES3-99, 97 and IRIS HT1: DW pressure**

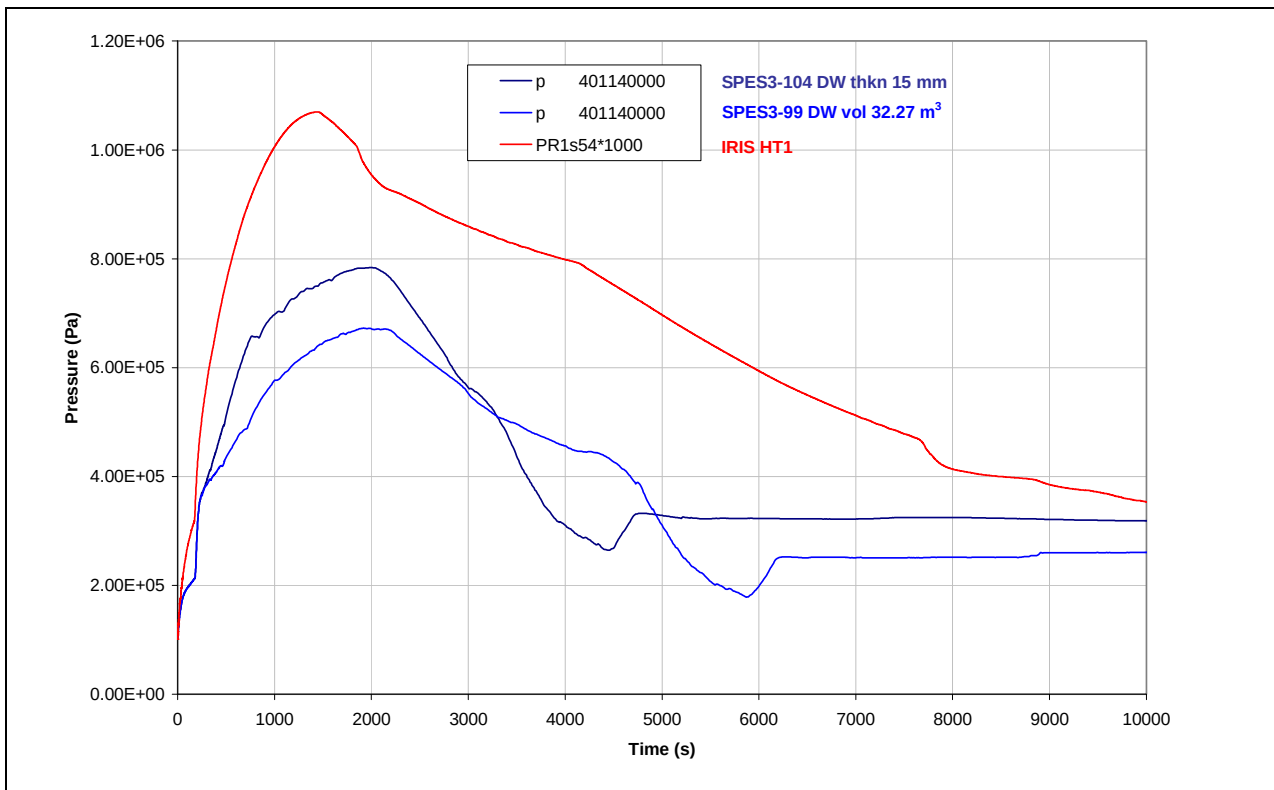




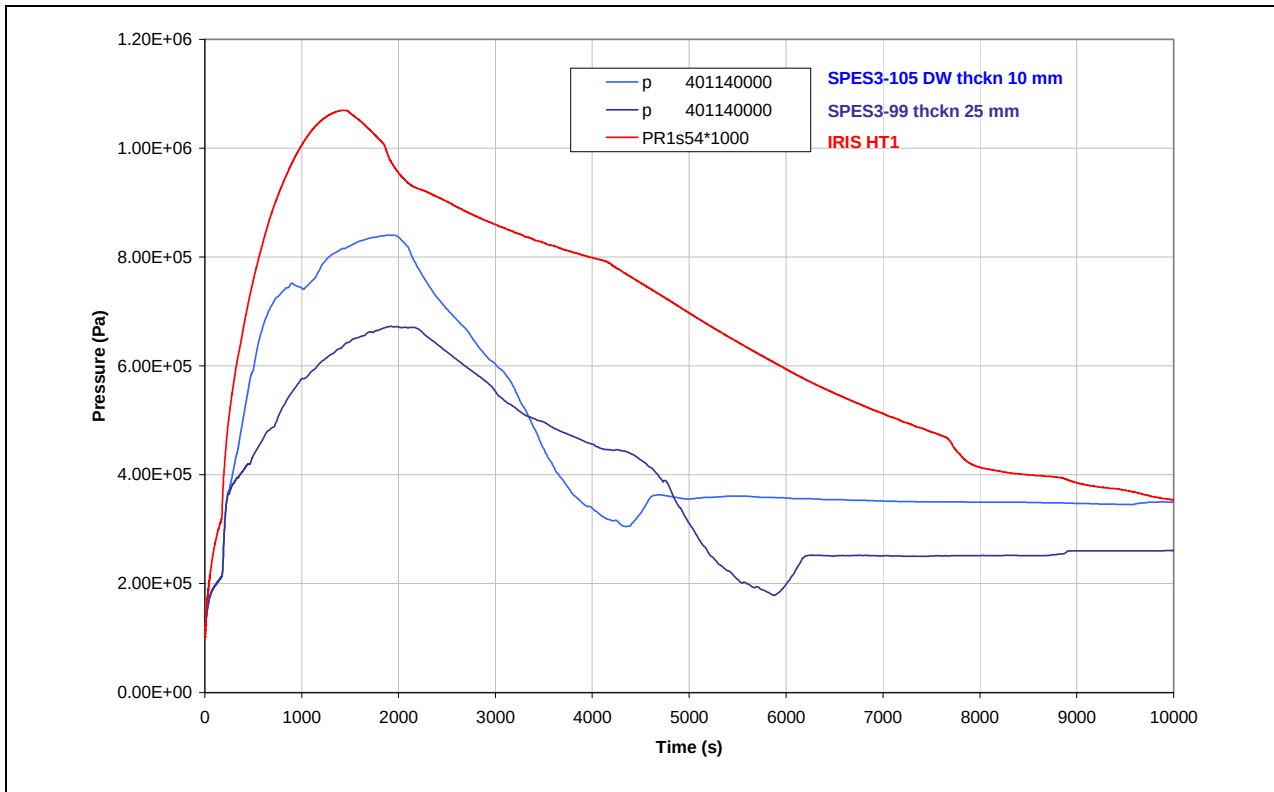
**Fig.5. 5 – SPES3-99, 100, 103 and IRIS HT1: DW pressure (window)**



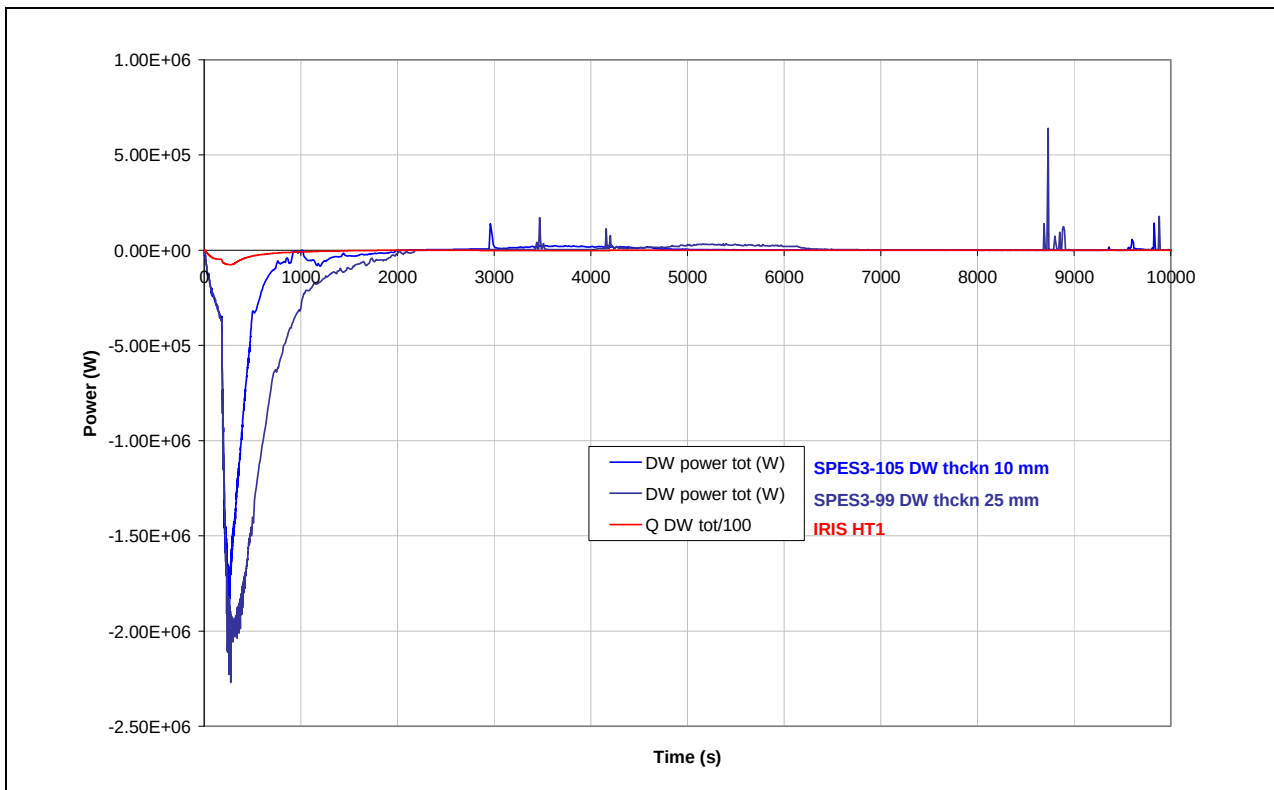
**Fig.5. 6 – SPES3-99, 104 and IRIS HT1: DW pressure (window)**



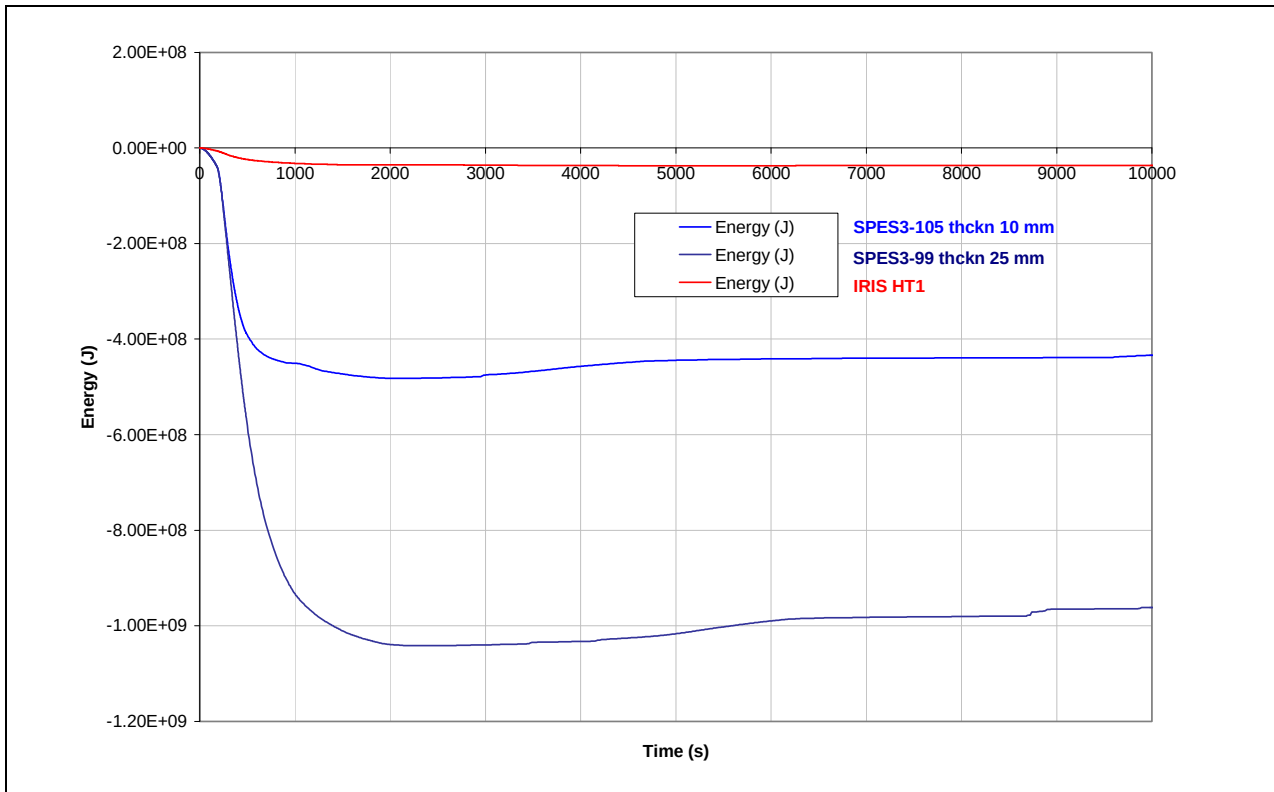
**Fig.5. 7 – SPES3-99, 105 and IRIS HT1: DW pressure (window)**



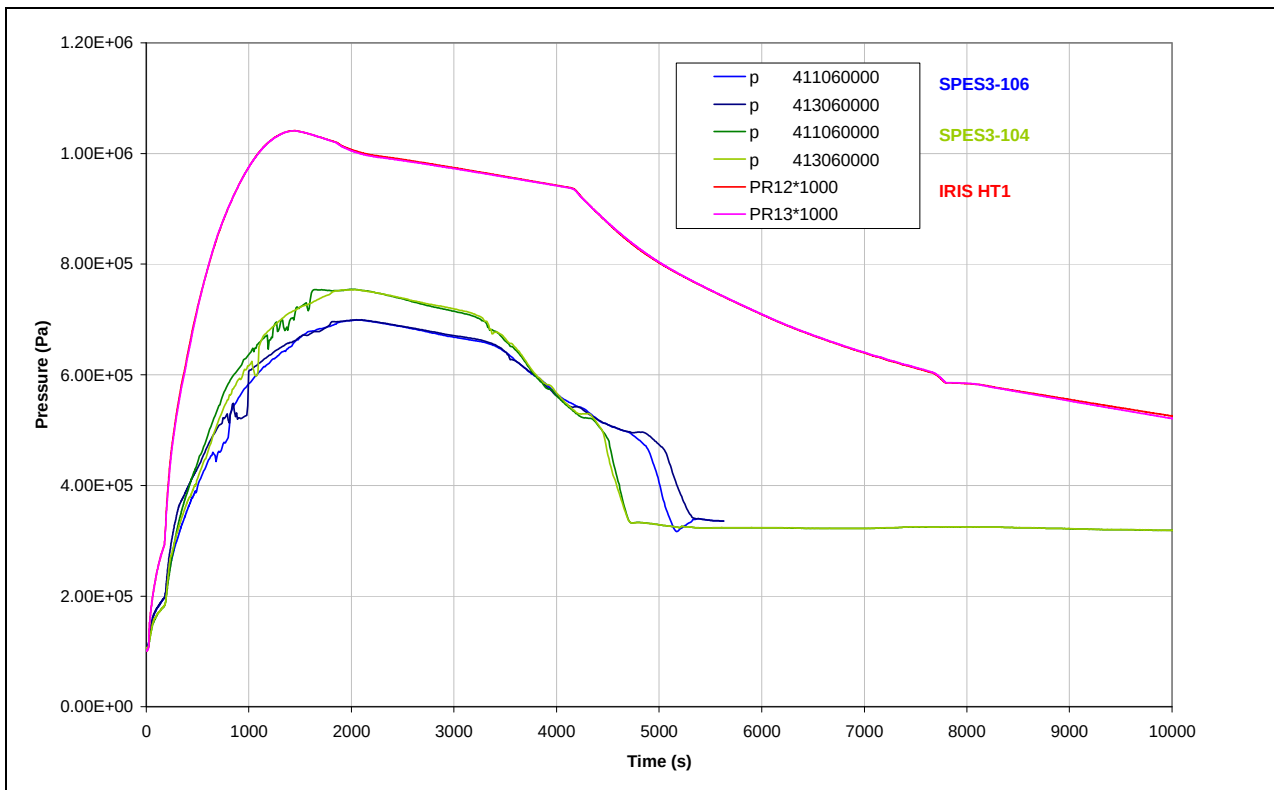
**Fig.5. 8 – SPES3-99, 105 and IRIS HT1: DW heat structure power (window)**



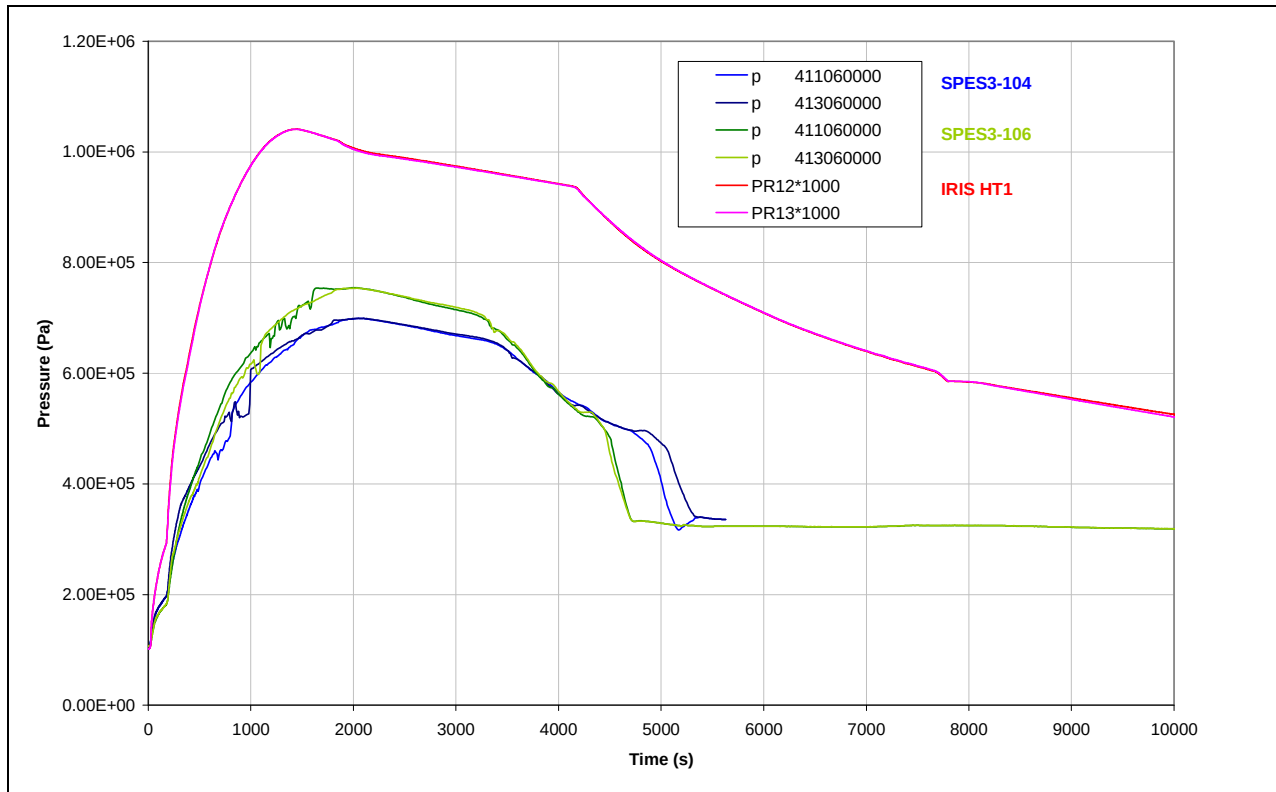
**Fig.5. 9 – SPES3-99, 105 and IRIS HT1: DW heat structure energy (window)**



**Fig.5. 10 – SPES3-104, 106 and IRIS HT1: DW pressure (window)**



**Fig.5. 11 – SPES3-104, 106 and IRIS HT1: PSS pressure (window)**



**Fig.5. 12 – SPES3-107 and 99: Core power (window)**

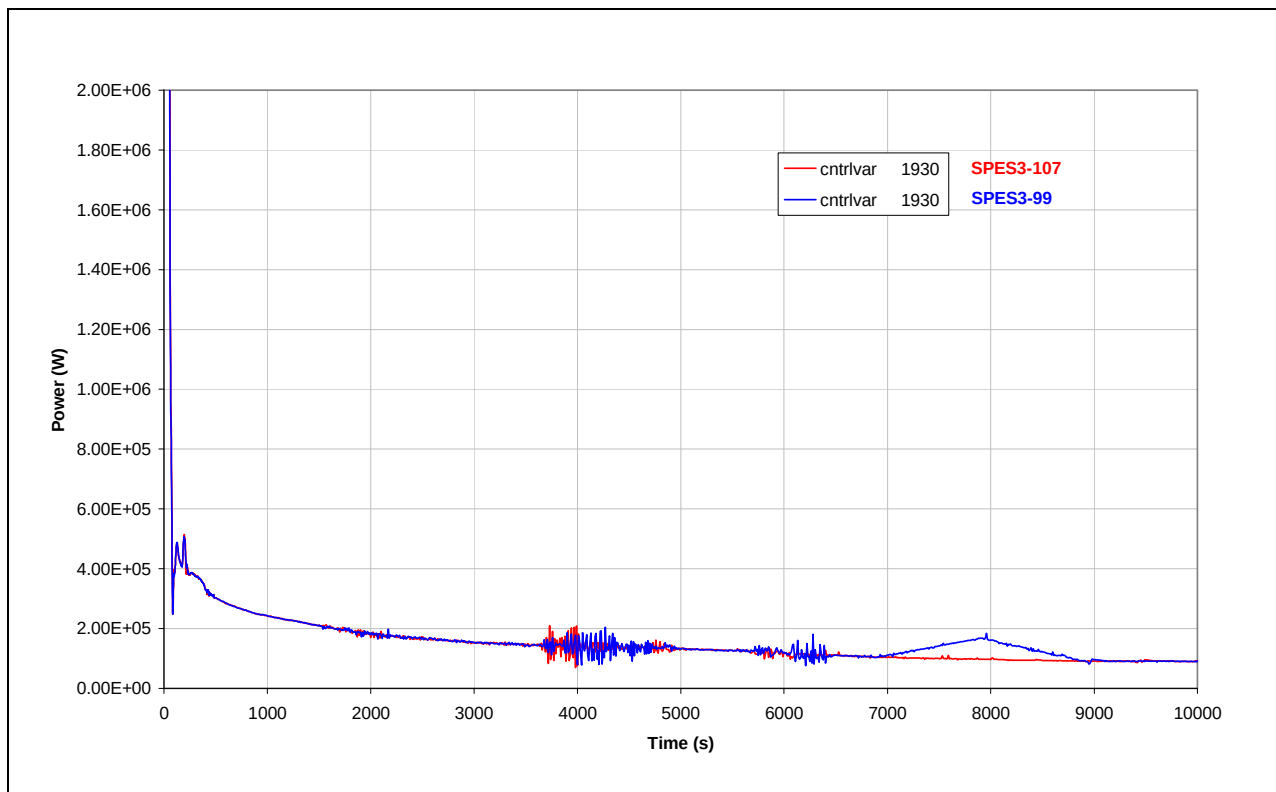


Fig.5. 13 – SPES3-107 and 99: SG total power (window)

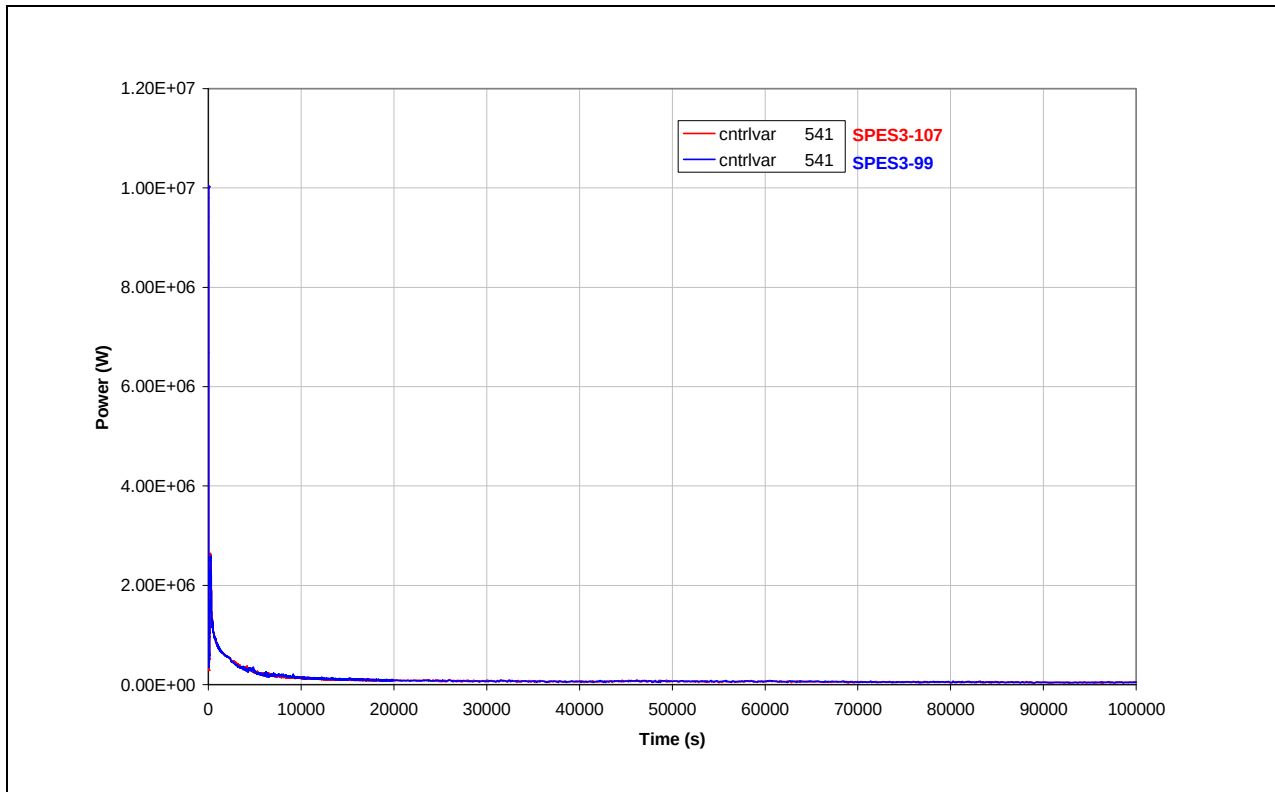
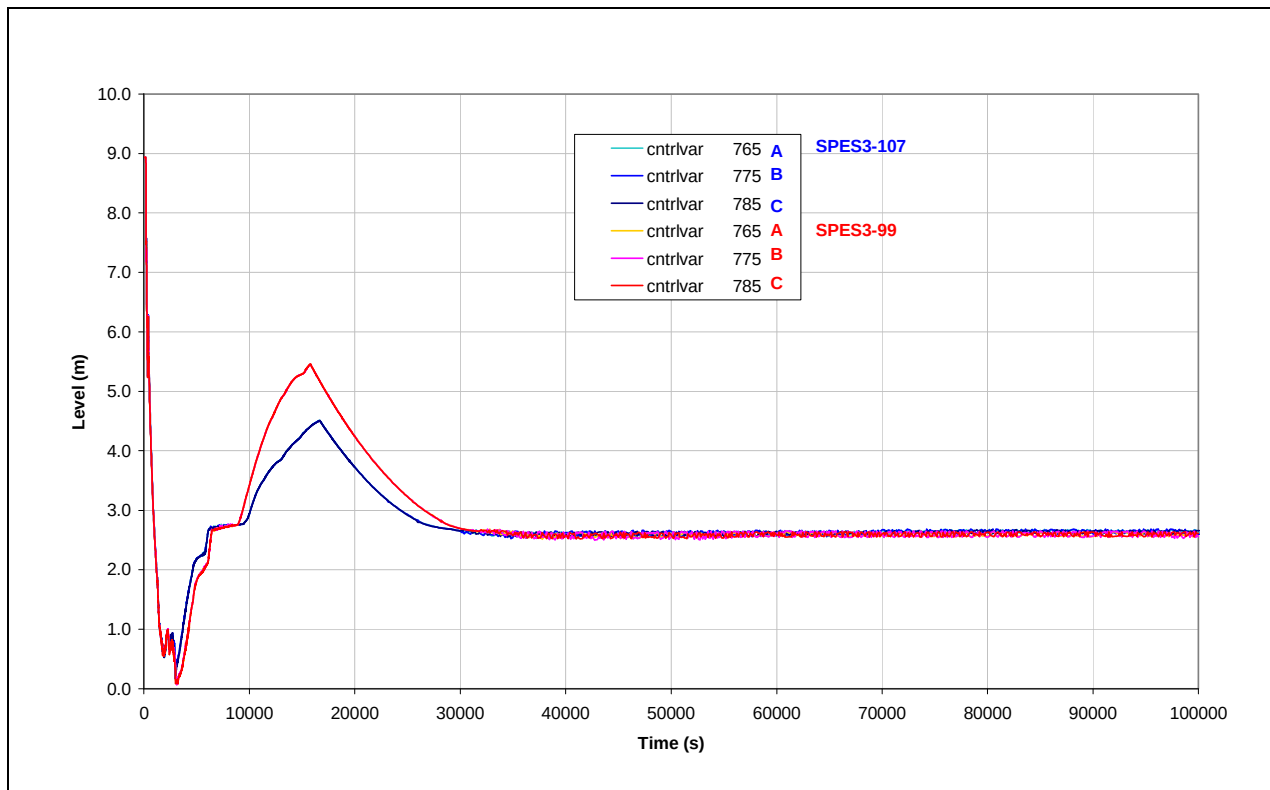
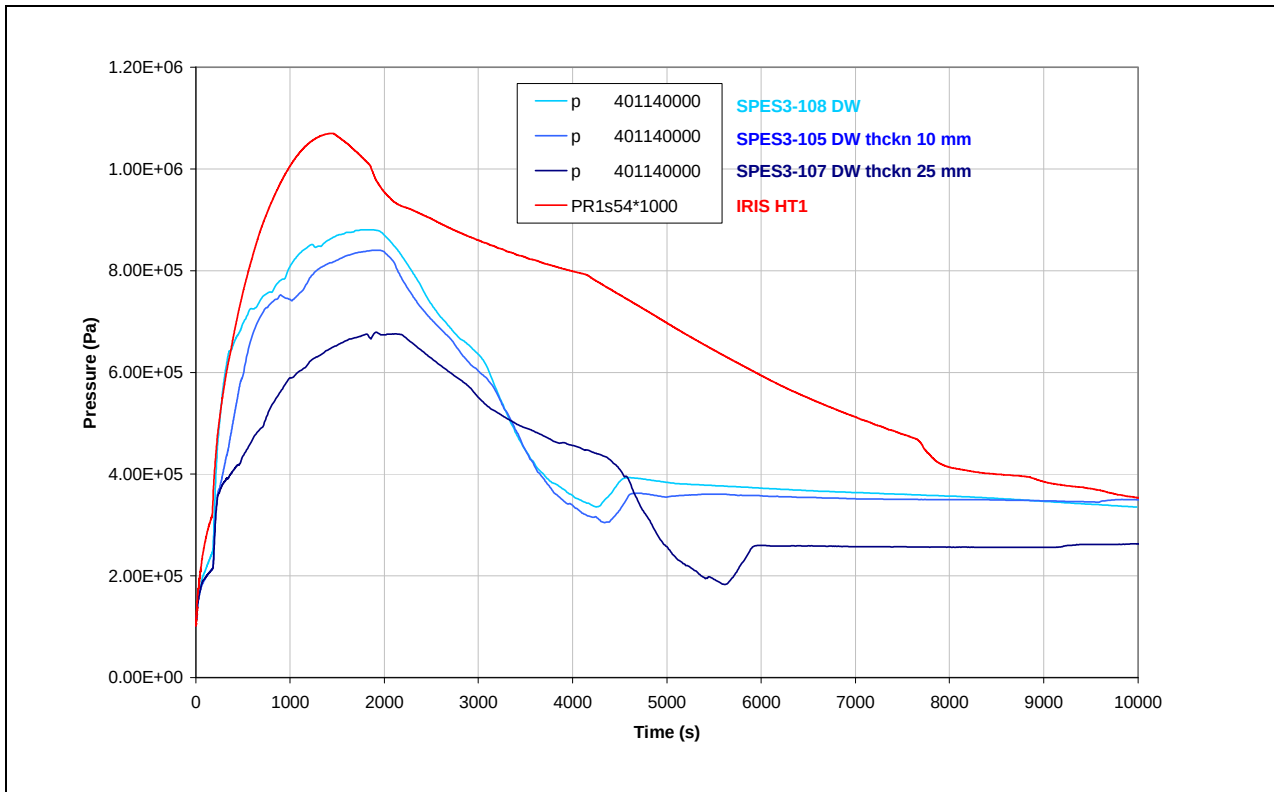


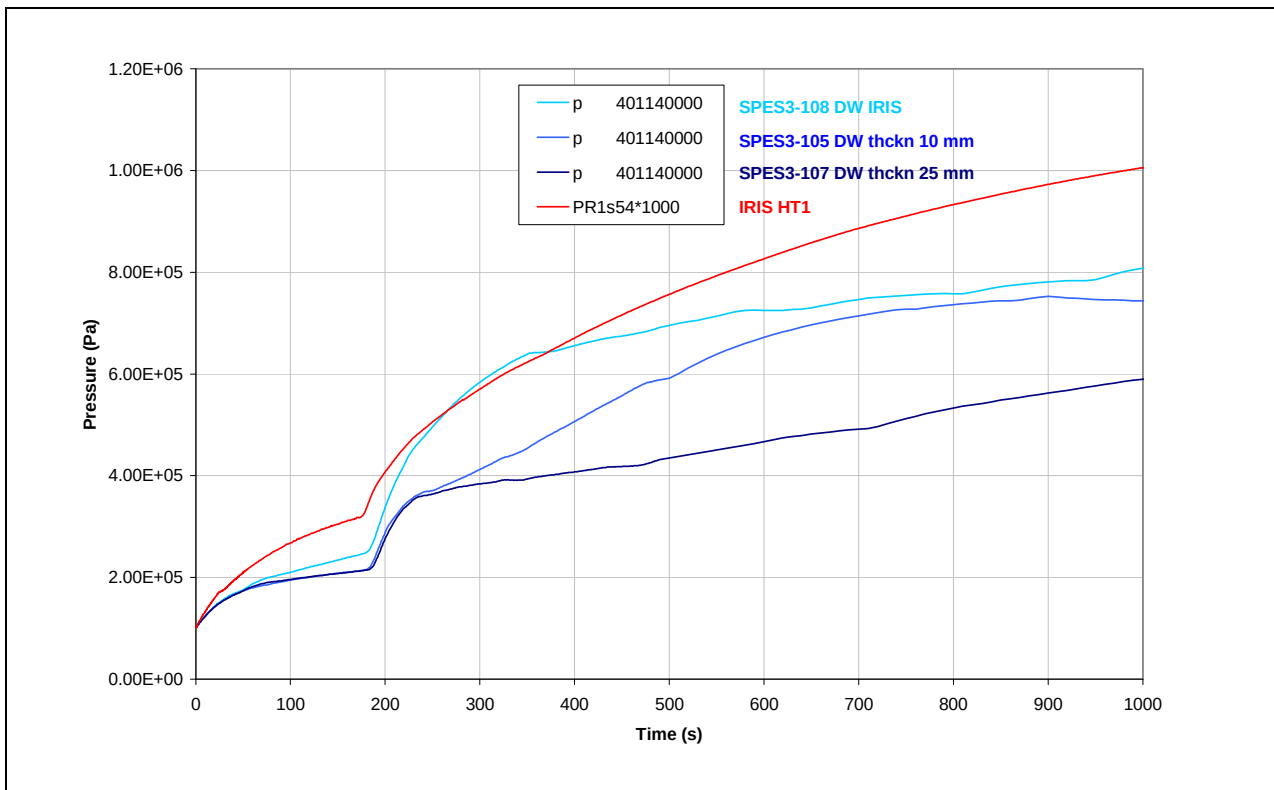
Fig.5. 14 – SPES3-107 and 99: SG tube primary side level



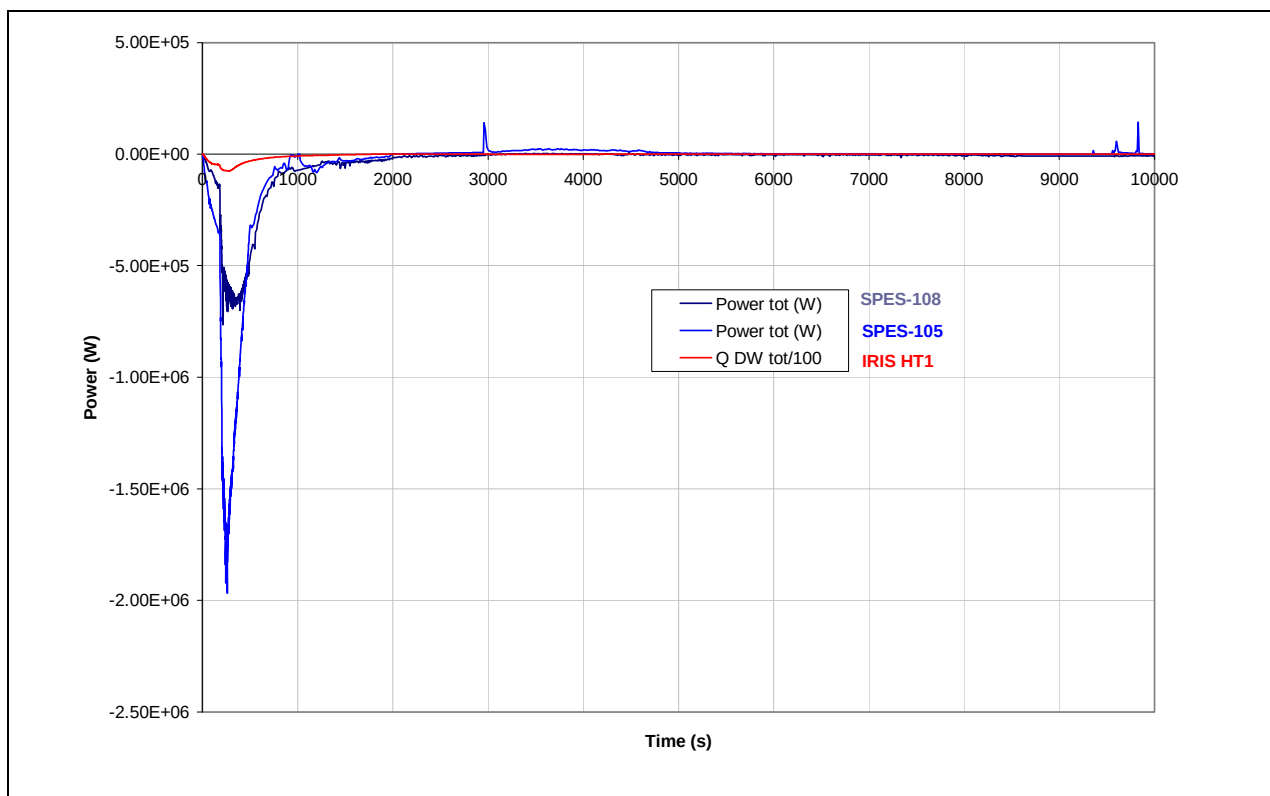
**Fig.5. 15 – SPES3-108, 105, 107 and IRIS HT1: DW pressure (window)**



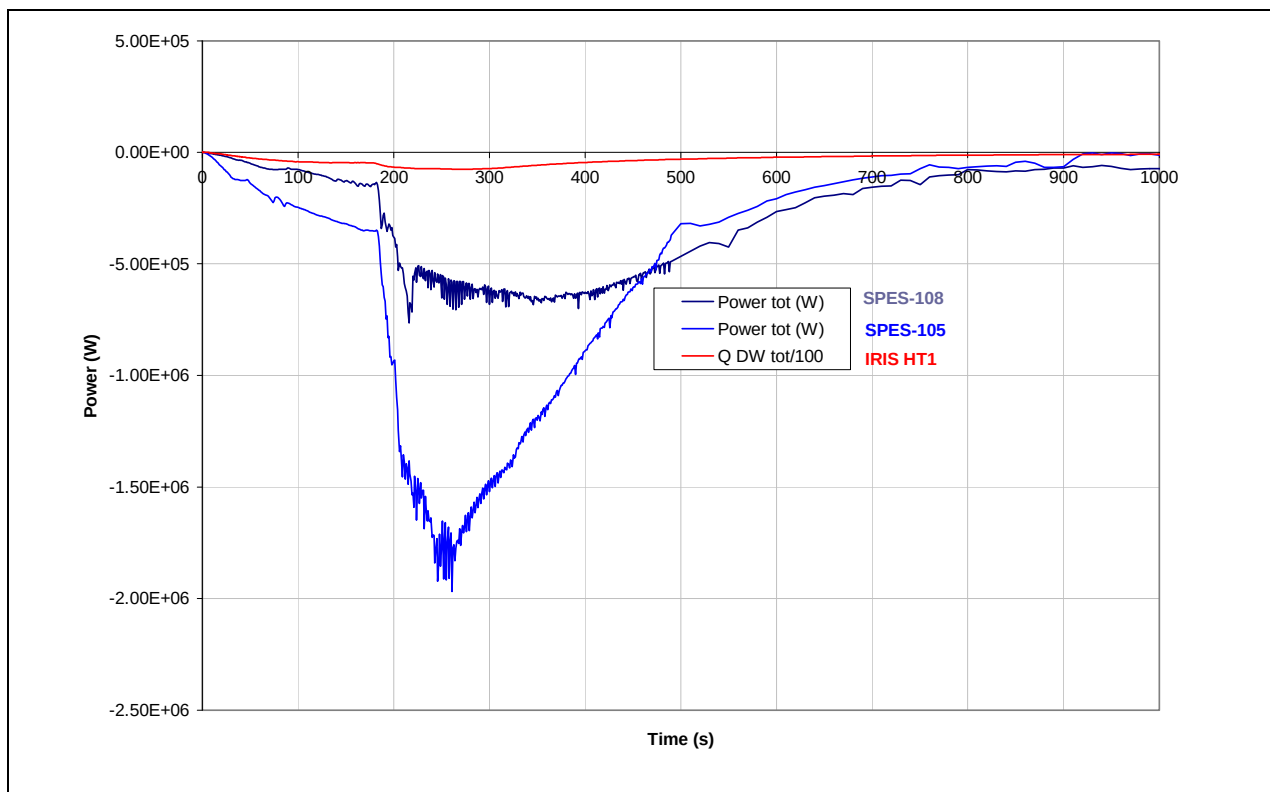
**Fig.5. 16 – SPES3-108, 105, 107 and IRIS HT1: DW pressure (window)**



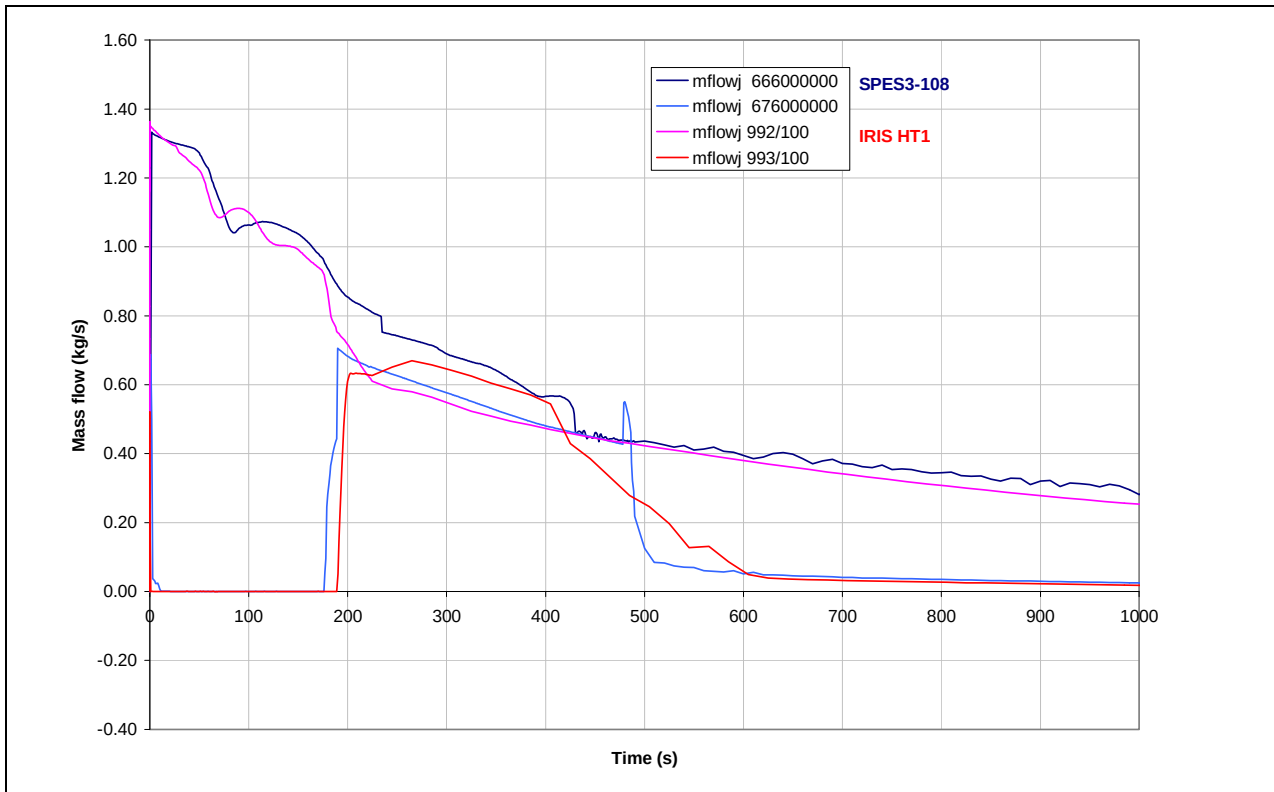
**Fig.5. 17 – SPES3-108, 105 and IRIS HT1: DW heat structure power (window)**



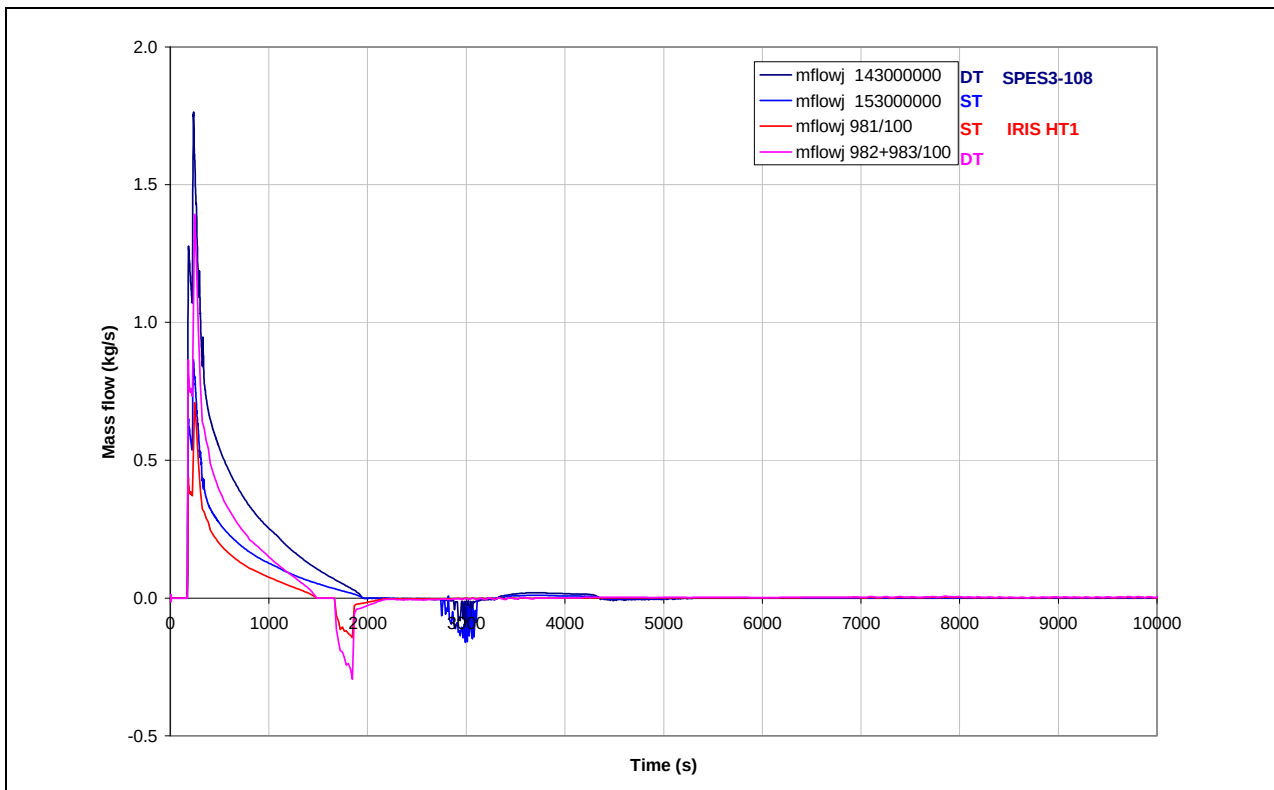
**Fig.5. 18 – SPES3-108, 105 and IRIS HT1: DW heat structure power (window)**



**Fig.5. 19 – SPES3-108 and IRIS HT1: DVI break mass flow (window)**

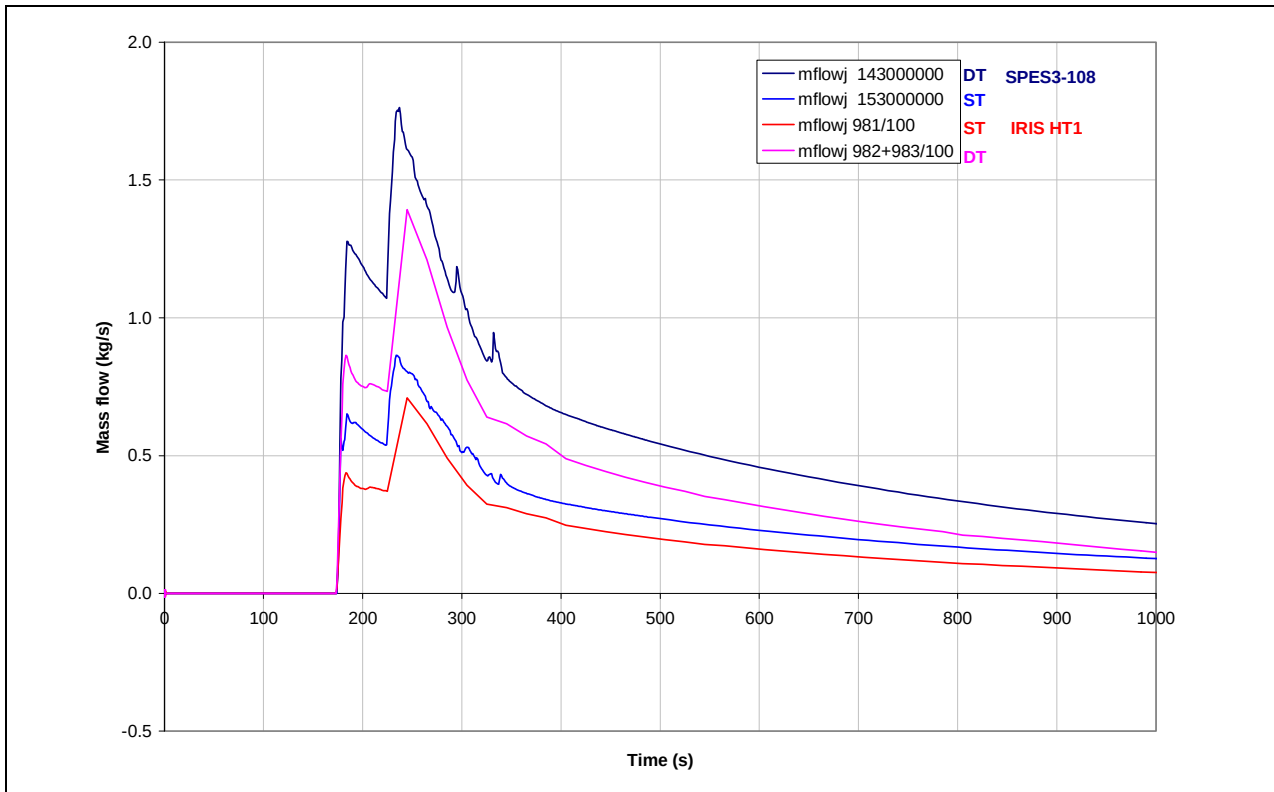


**Fig.5. 20 – SPES3-108 and IRIS HT1: ADS Stage-I mass flow (window)**





**Fig.5. 21 – SPES3-108 and IRIS HT1: ADS Stage-I mass flow (window)**



**Fig.5. 22 – SPES3-108, 105 and IRIS HT1: DW heat structure energy (window)**

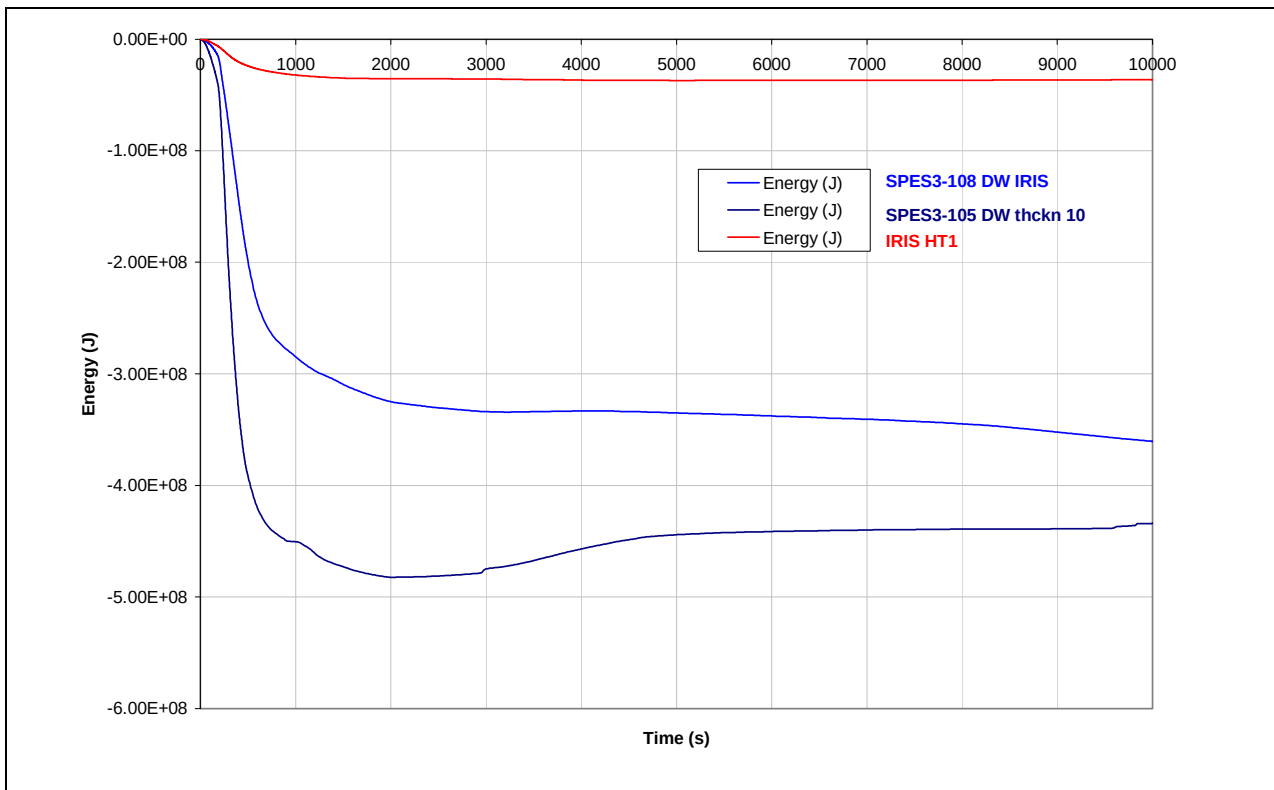


Fig.5. 23 – SPES3-108, 105 and IRIS HT1: DW heat structure energy (window)

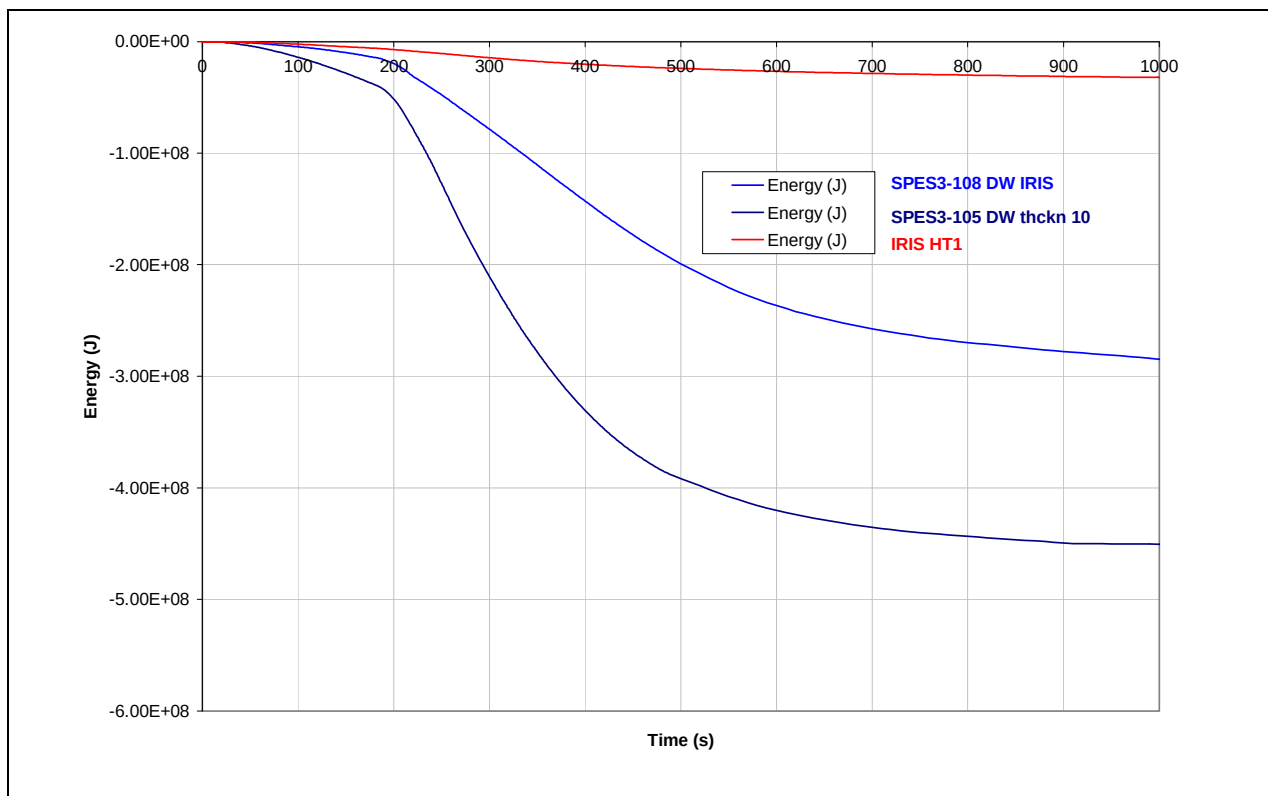


Fig.5. 24 – SPES3-108 and IRIS HT1: DW air quality (window)

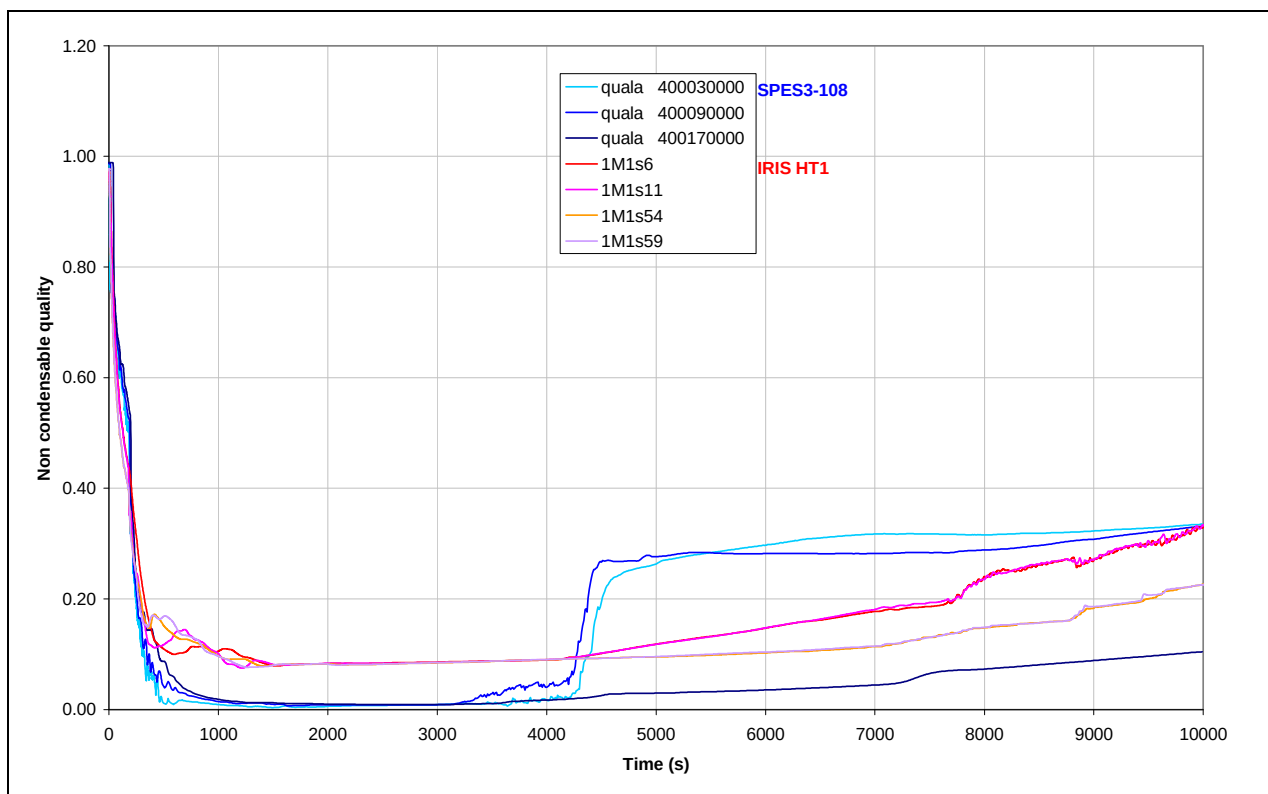


Fig.5. 25 – SPES3-108 and IRIS HT1: LGMS injection mass flow (window)

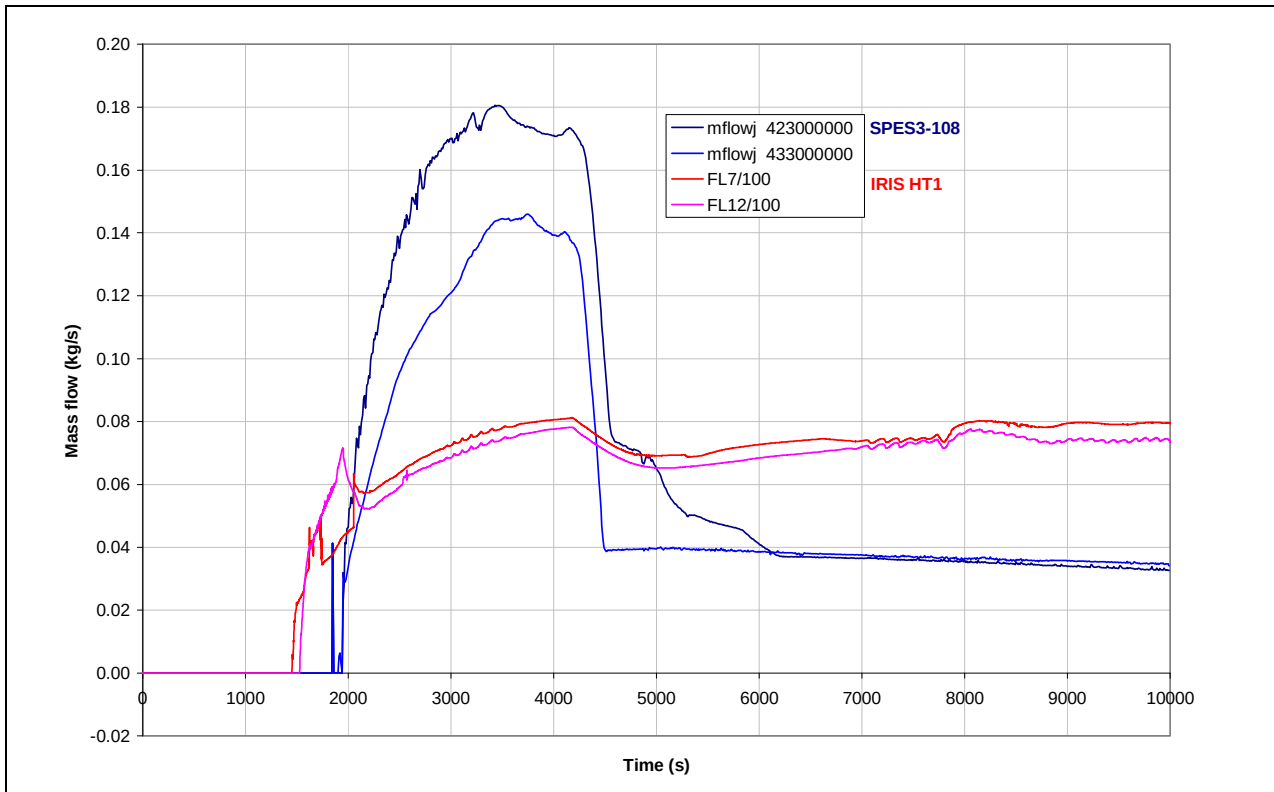
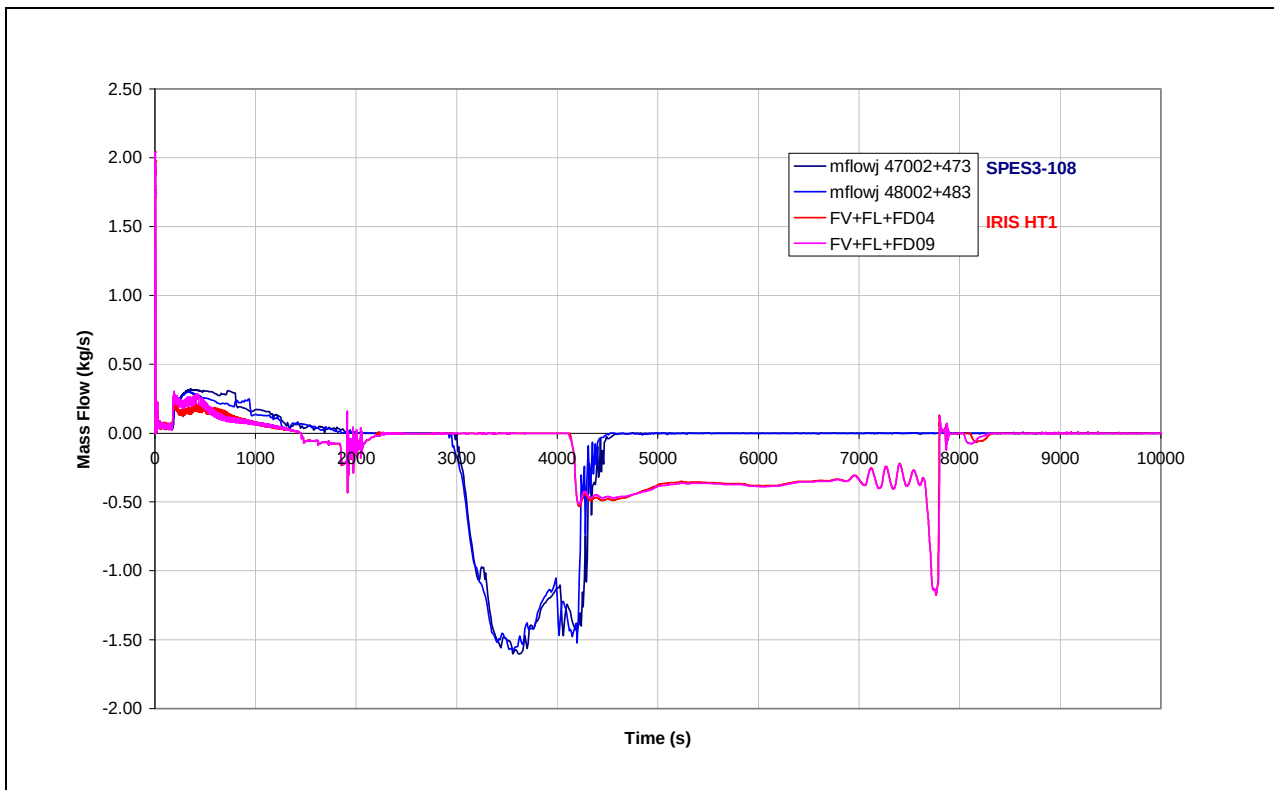
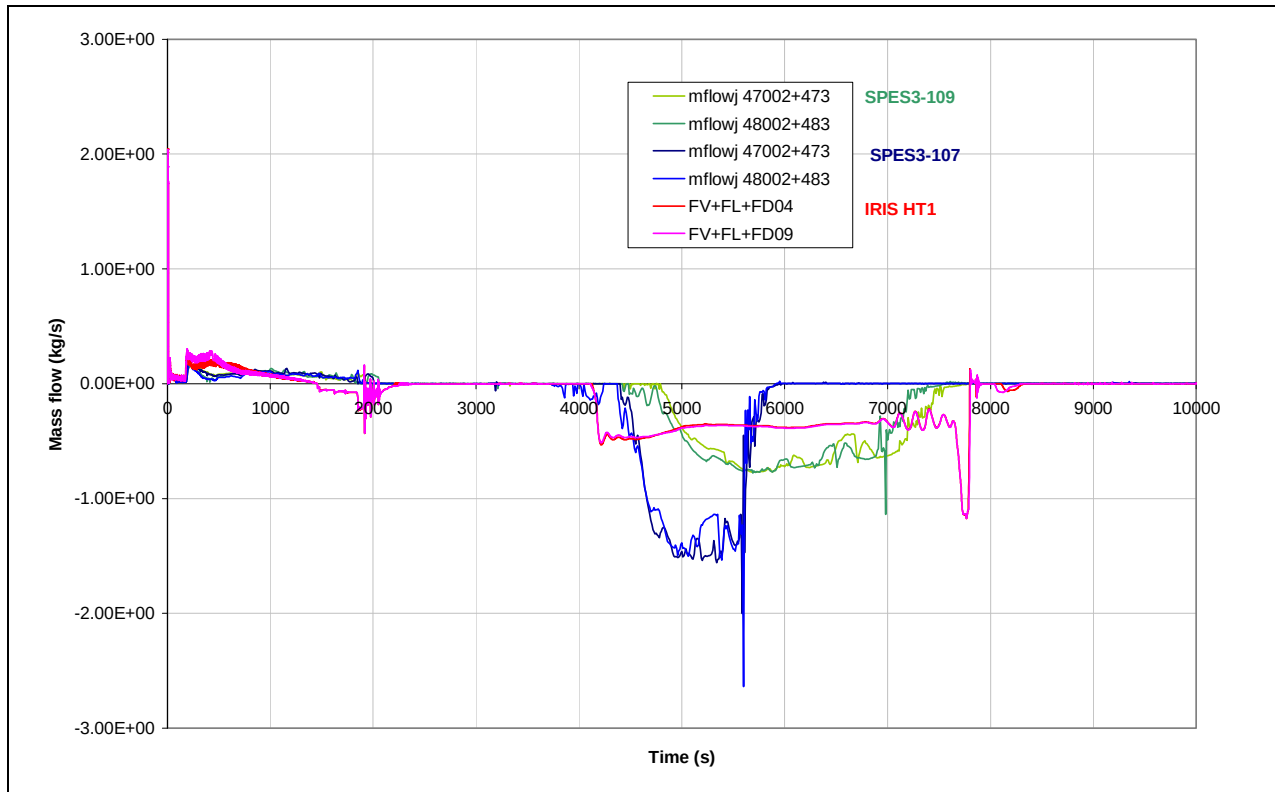


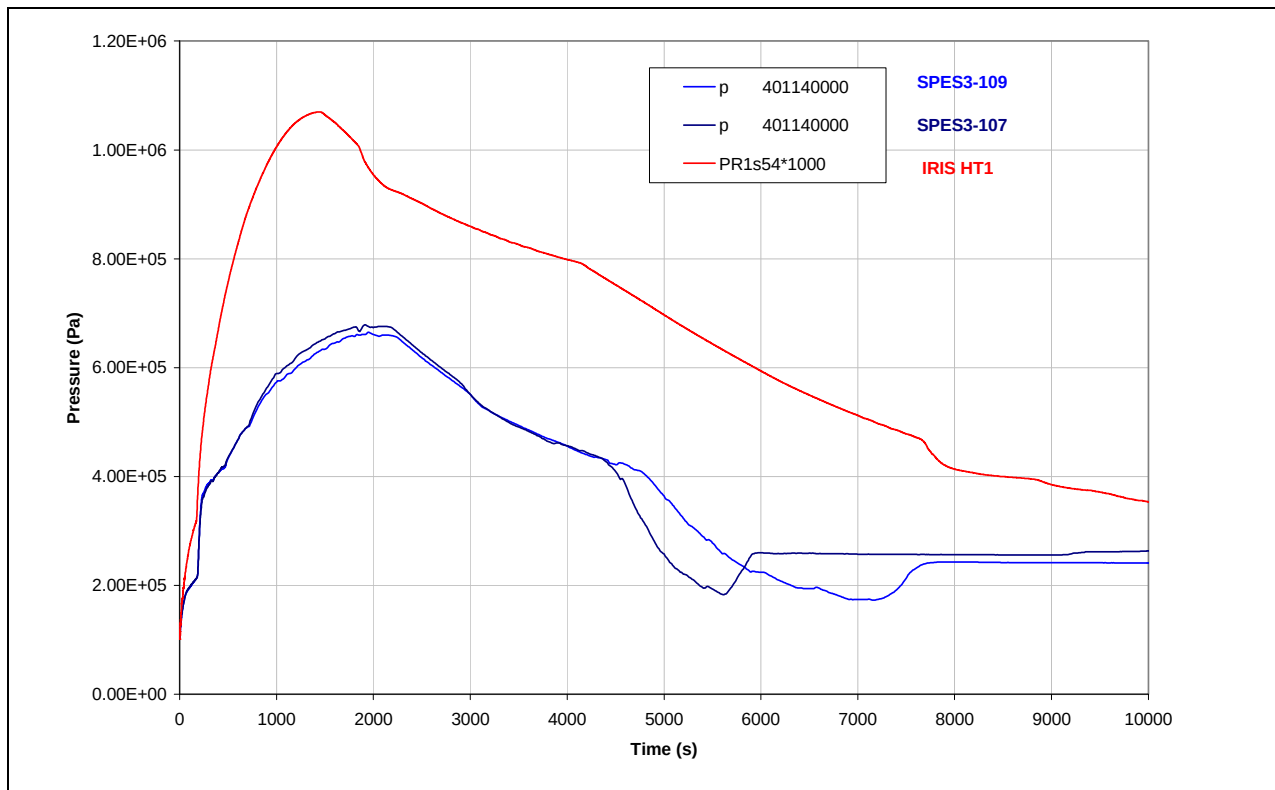
Fig.5. 26 – SPES3-108 and IRIS HT1: PSS to DW injection mass flow (window)



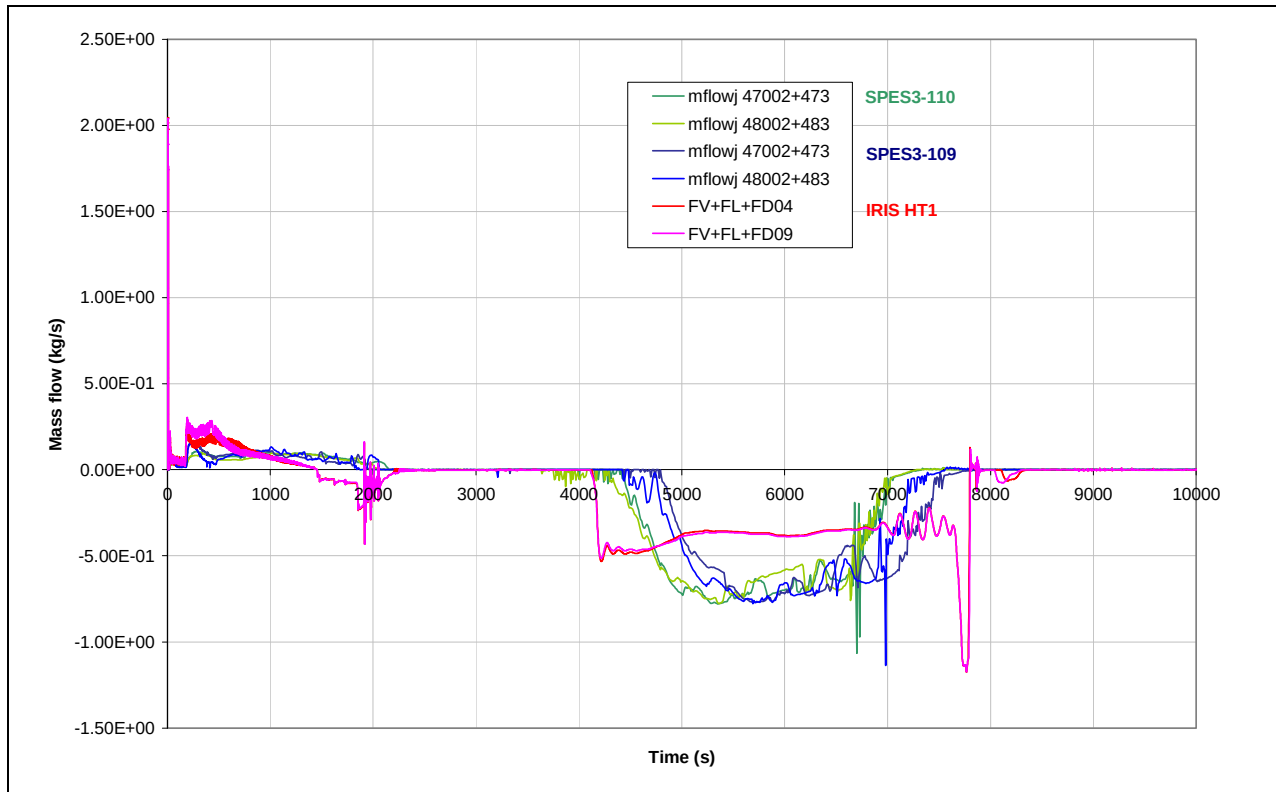
**Fig.5. 27 – SPES3-109, 107 and IRIS HT1: PSS to DW injection mass flow (window)**



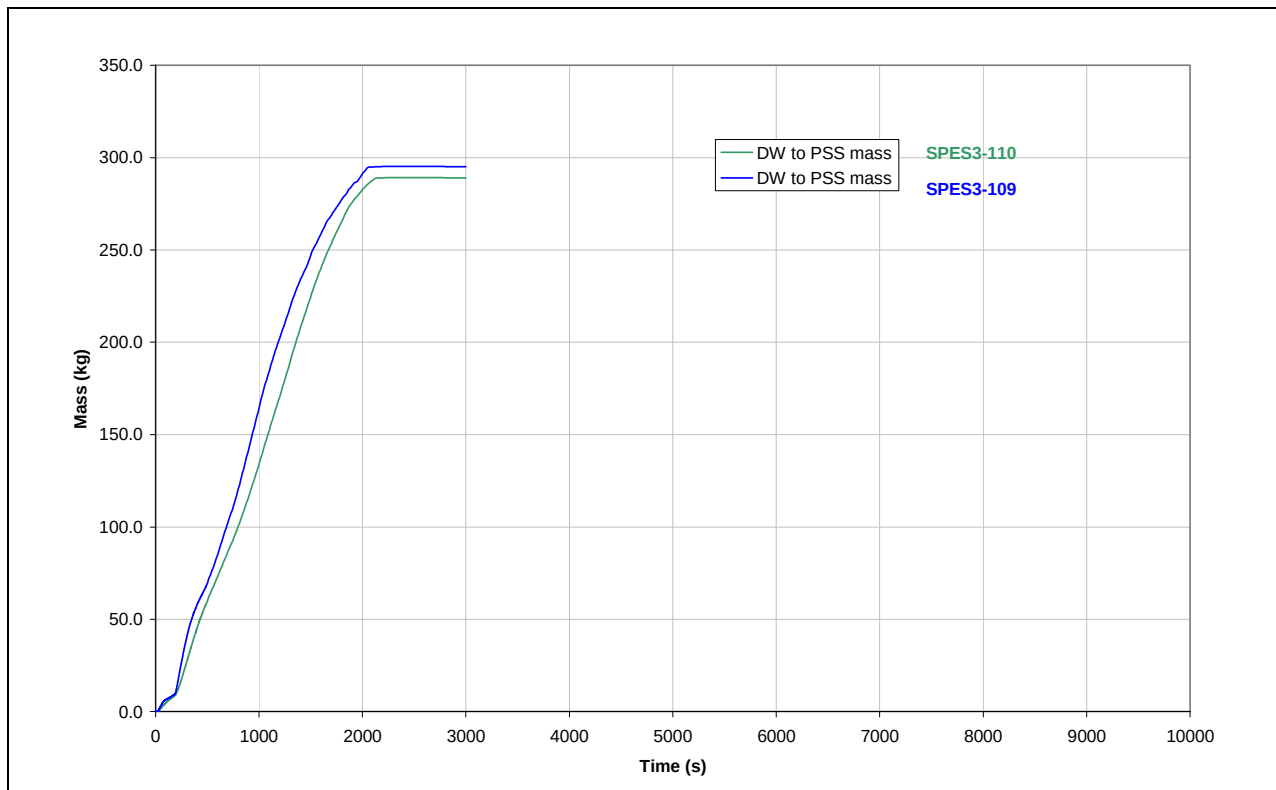
**Fig.5. 28 – SPES3-109, 107 and IRIS HT1: DW pressure (window)**



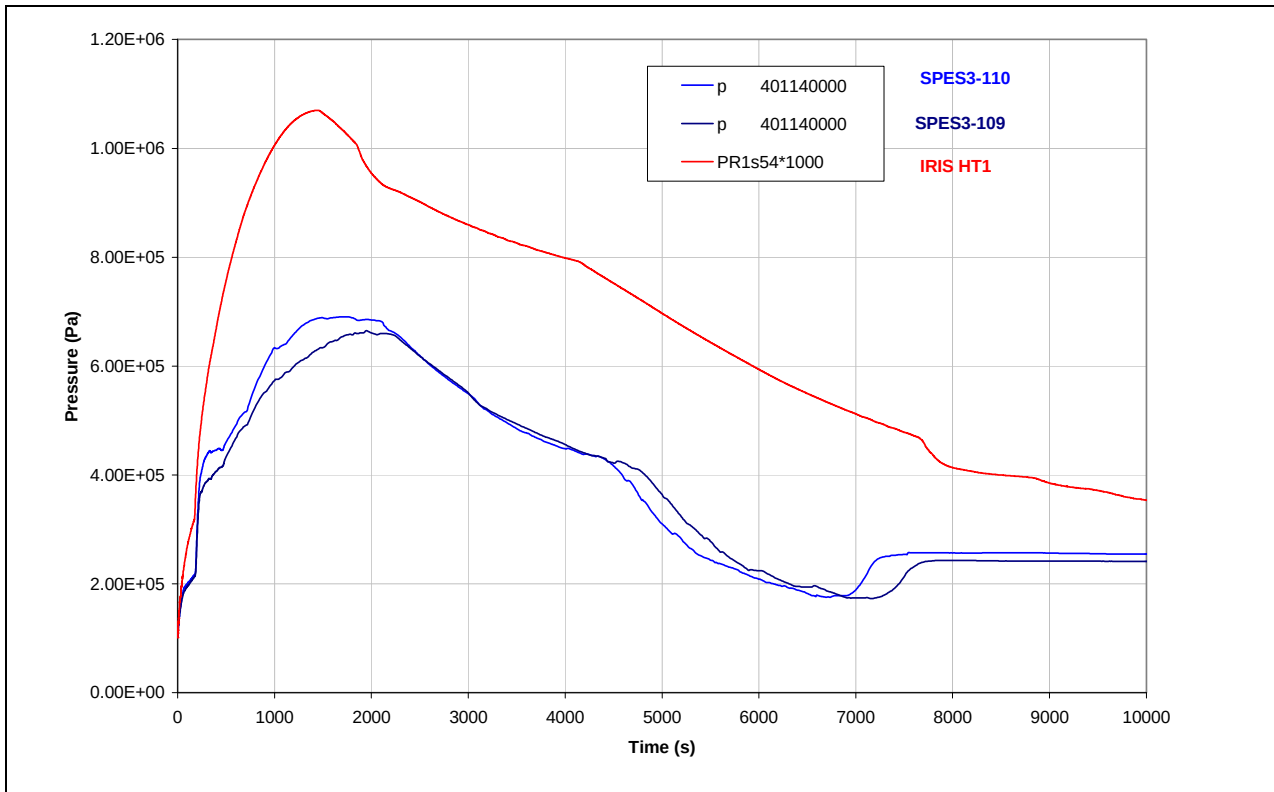
**Fig.5. 29 – SPES3-110, 109 and IRIS HT1: PSS to DW injection mass flow (window)**



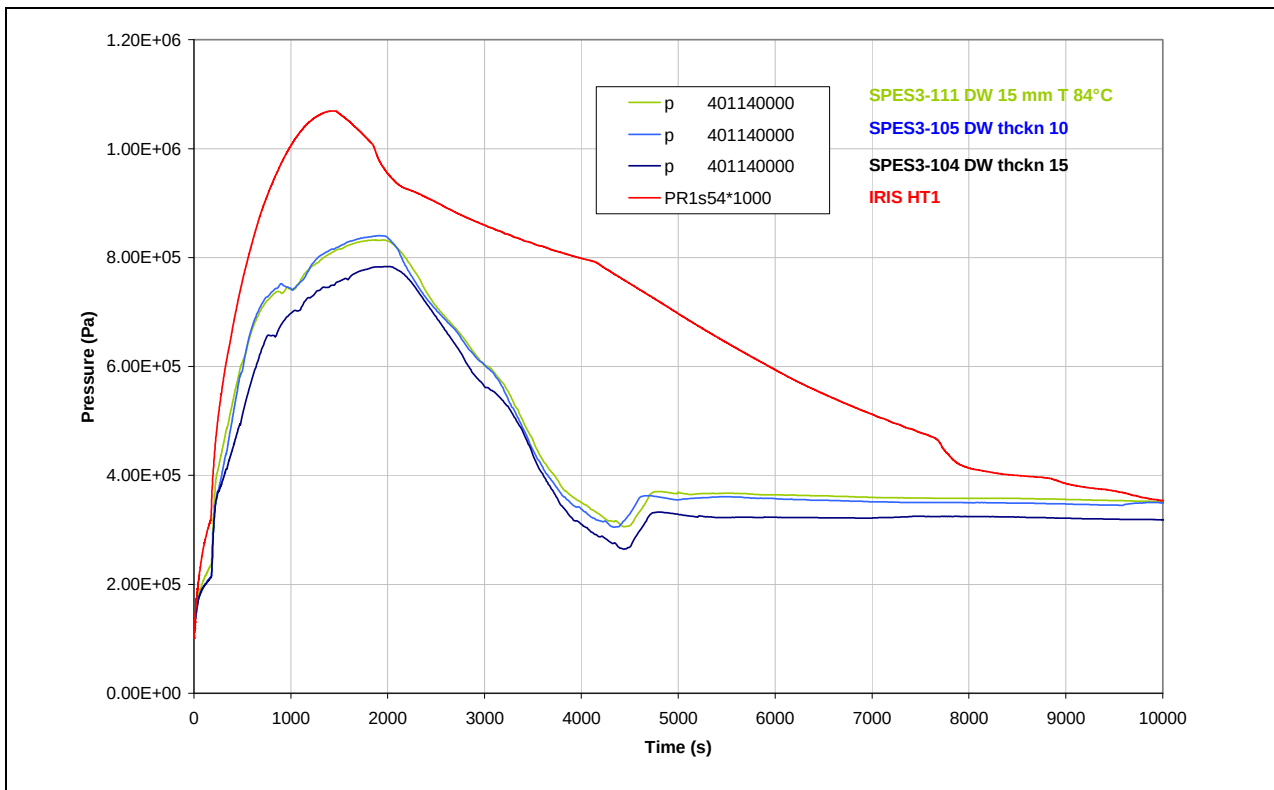
**Fig.5. 30 – SPES3-110, 109: DW to PSS mass (blowdown phase)**



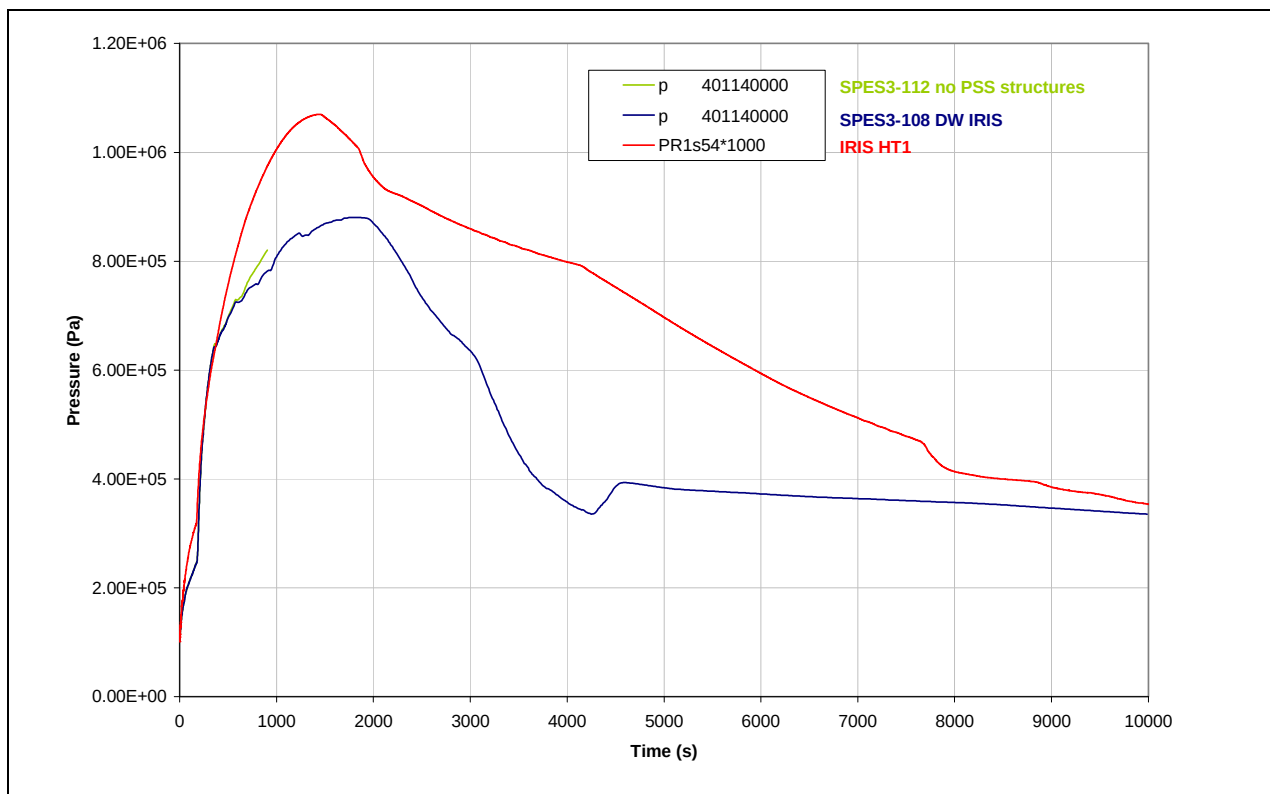
**Fig.5. 31 – SPES3-110, 109 and IRIS HT1: DW pressure (window)**



**Fig.5. 32 – SPES3-111, 105, 104 and IRIS HT1: DW pressure (window)**



**Fig.5. 33 – SPES3-112, 108, and IRIS HT1: DW pressure (window)**



**Fig.5. 34 – SPES3-115, 108, 107 and IRIS HT1: DW pressure (window)**

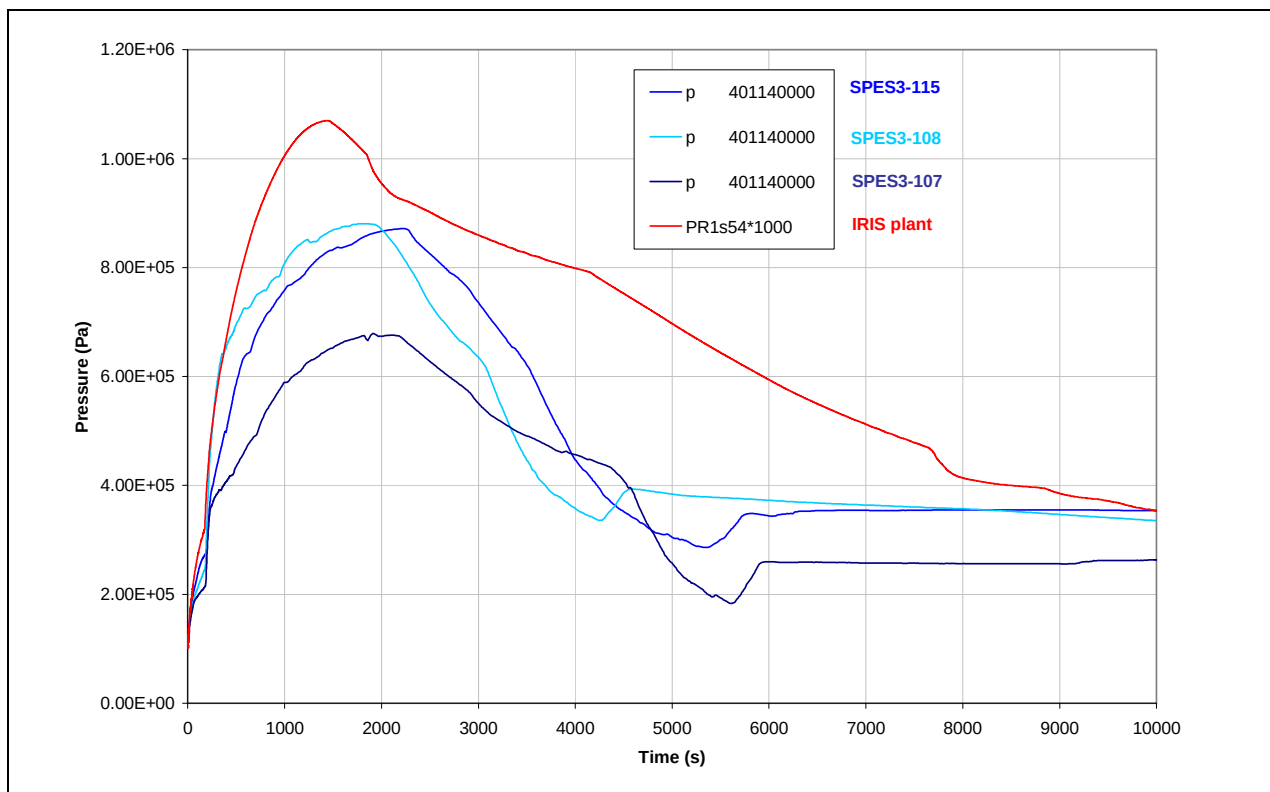


Fig.5. 35 – SPES3-115, 107 and IRIS HT1: LGMS injection mass flow (window)

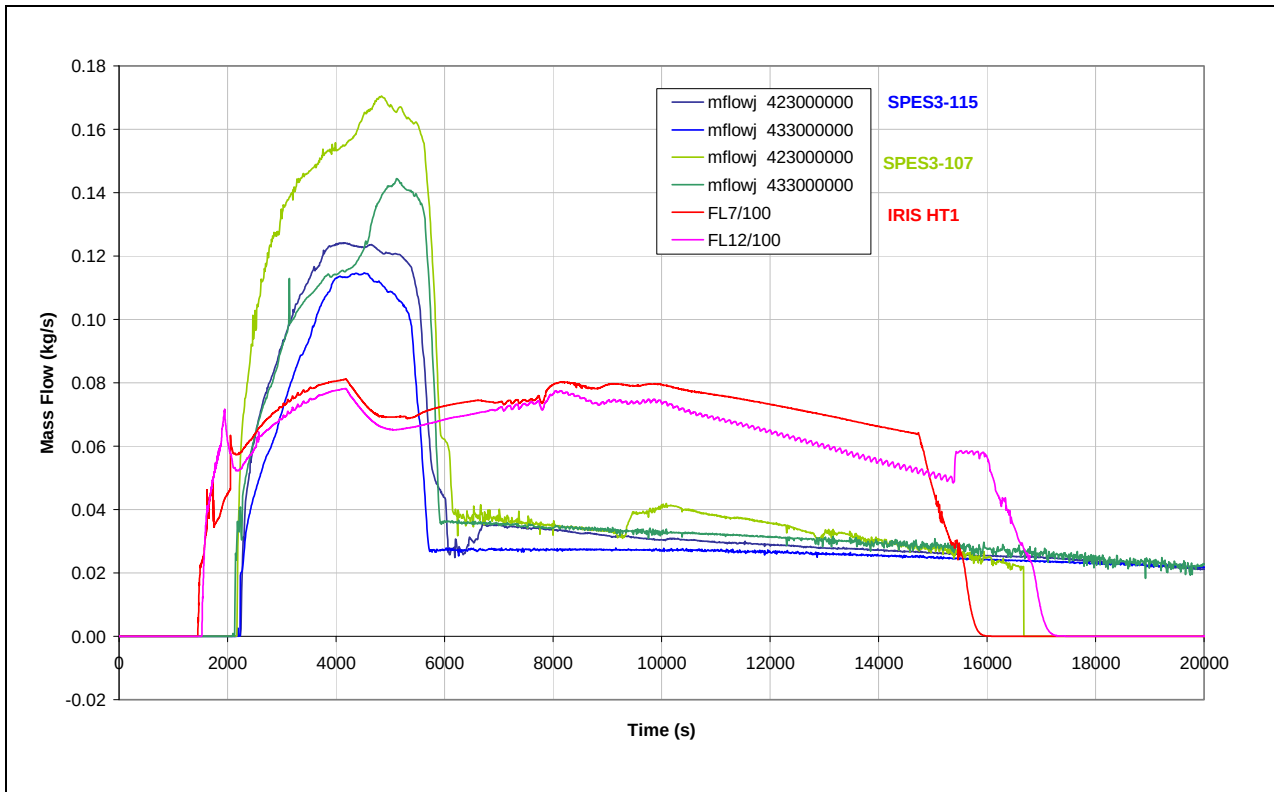


Fig.5. 36 – SPES3-115 and IRIS HT1: ADS ST and DT Stage-I mass flow (window)

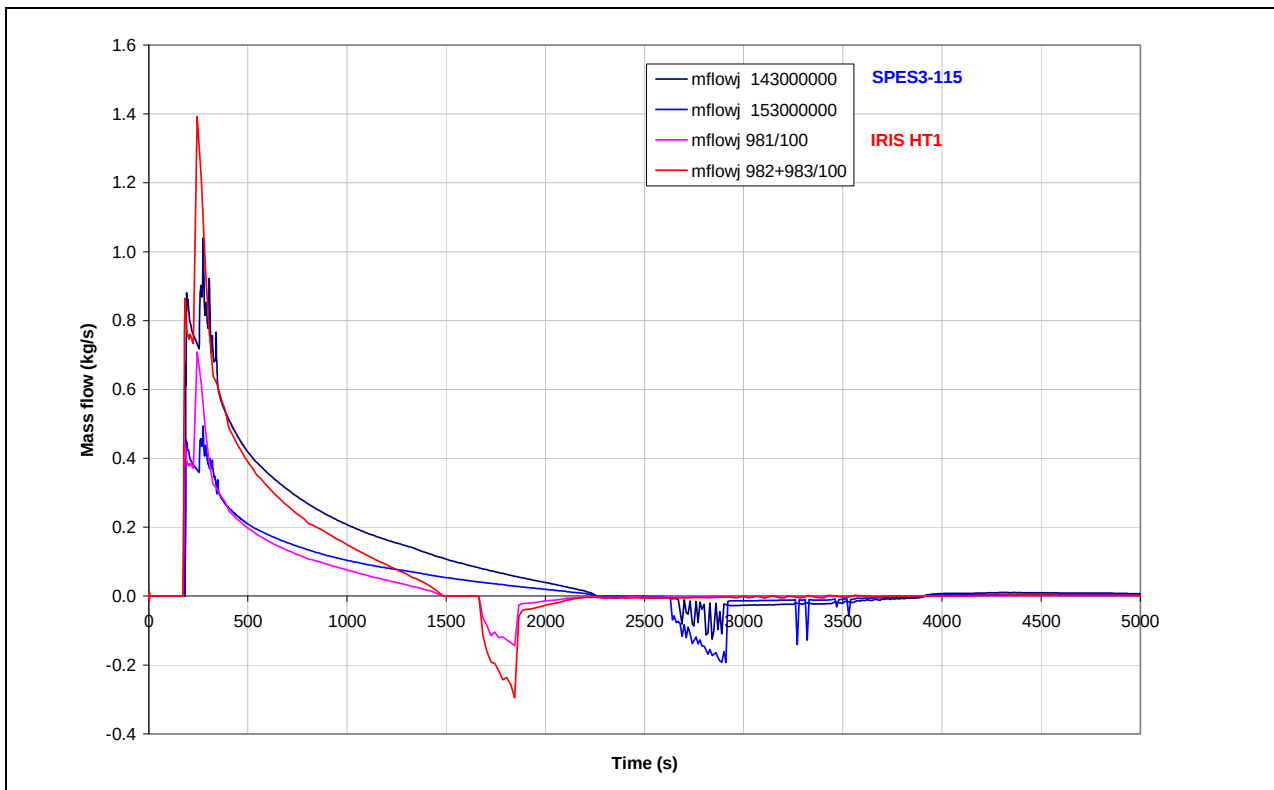




Fig.5. 37 – SPES3-115 and IRIS HT1: EHRs-A,B and C cold leg mass flow (window)

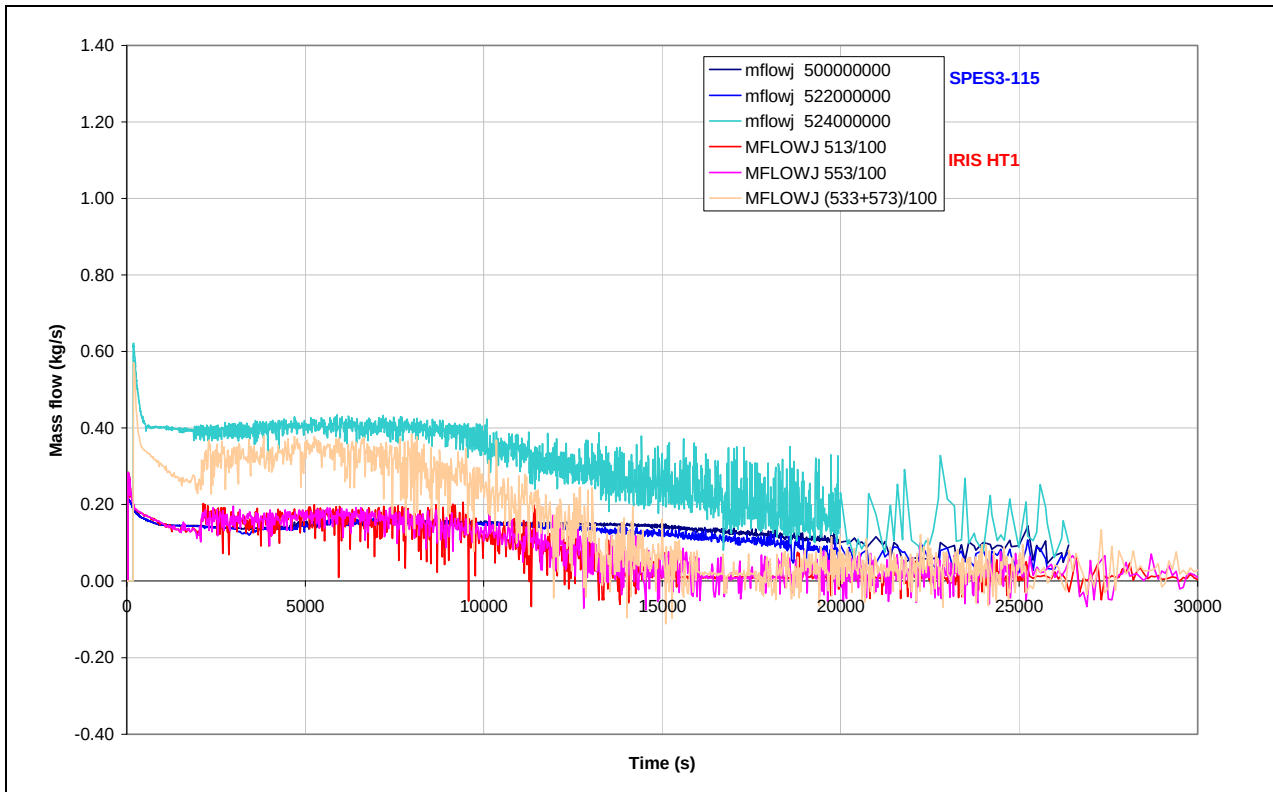


Fig.5. 38 – SPES3-118, 115 and IRIS HT1: DW pressure (window)

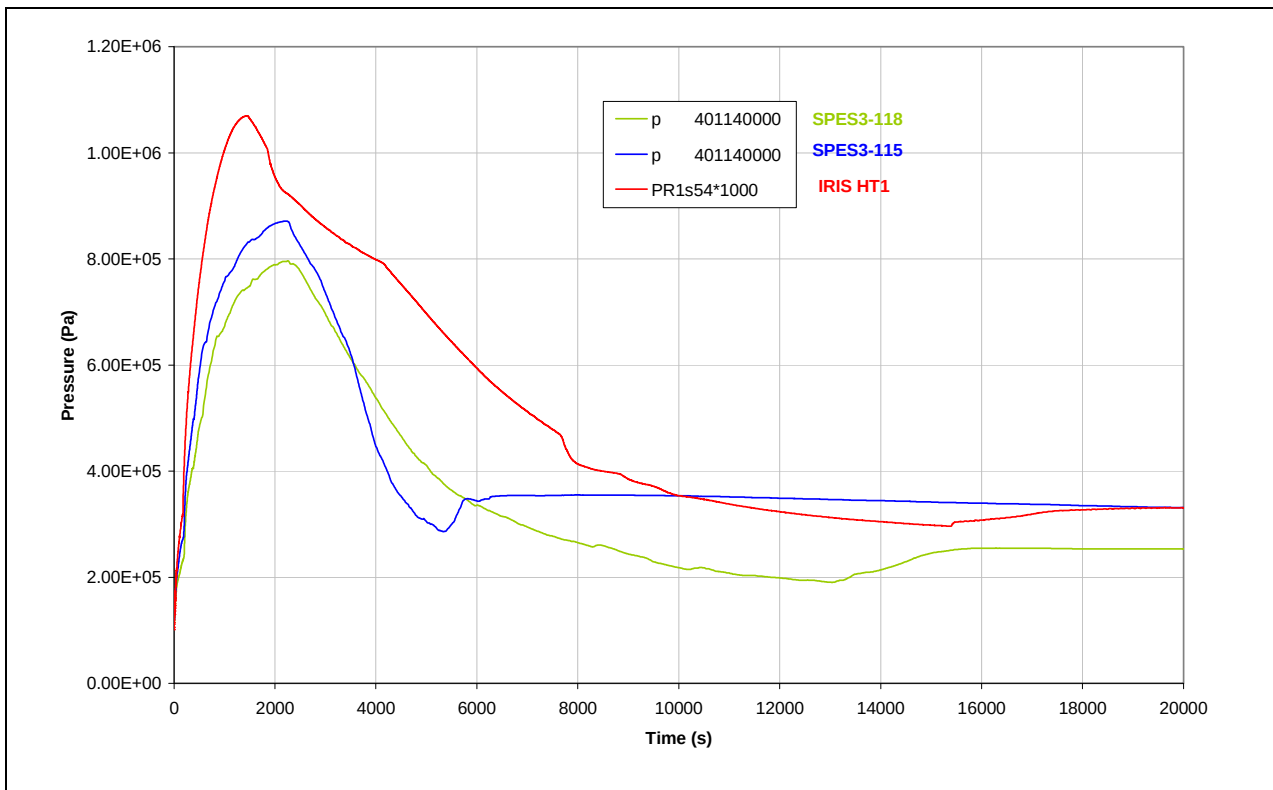


Fig.5. 39 – SPES3-118, 115 and IRIS HT1: LGMS injection mass flow (window)

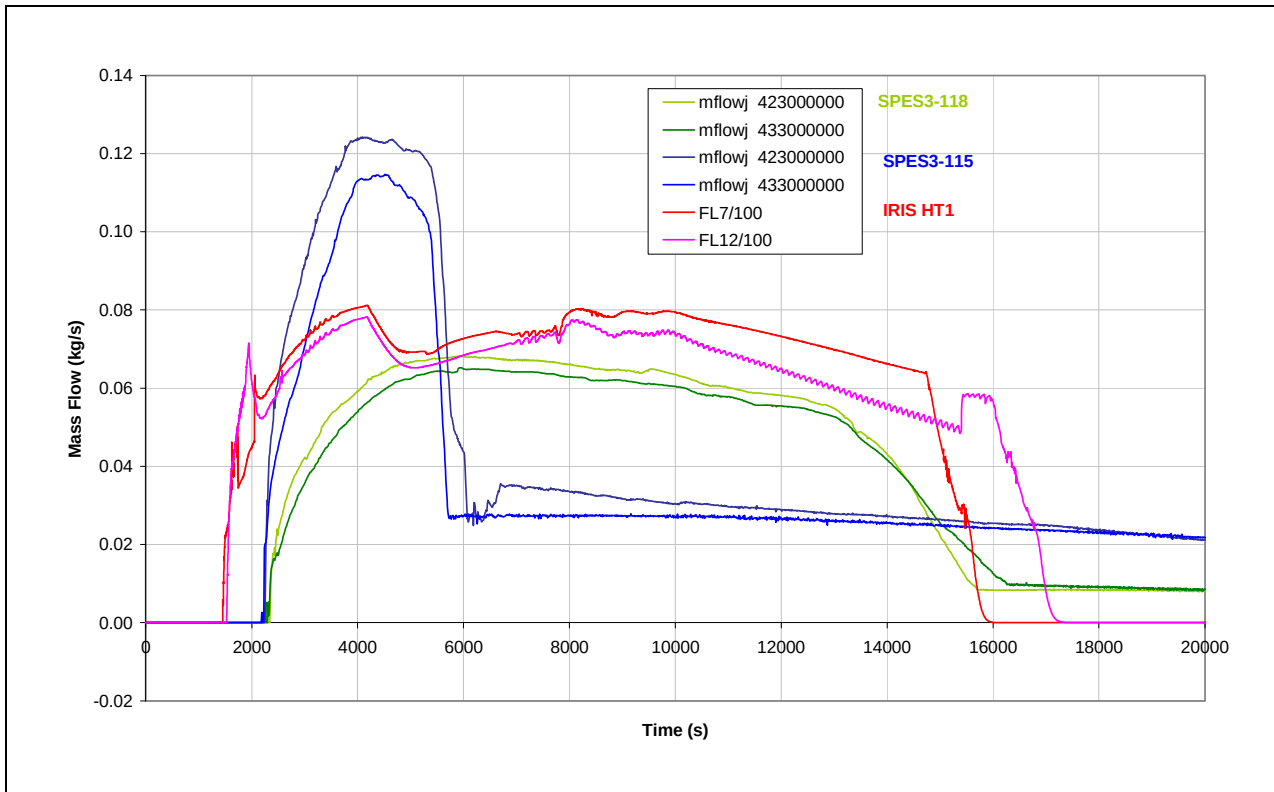
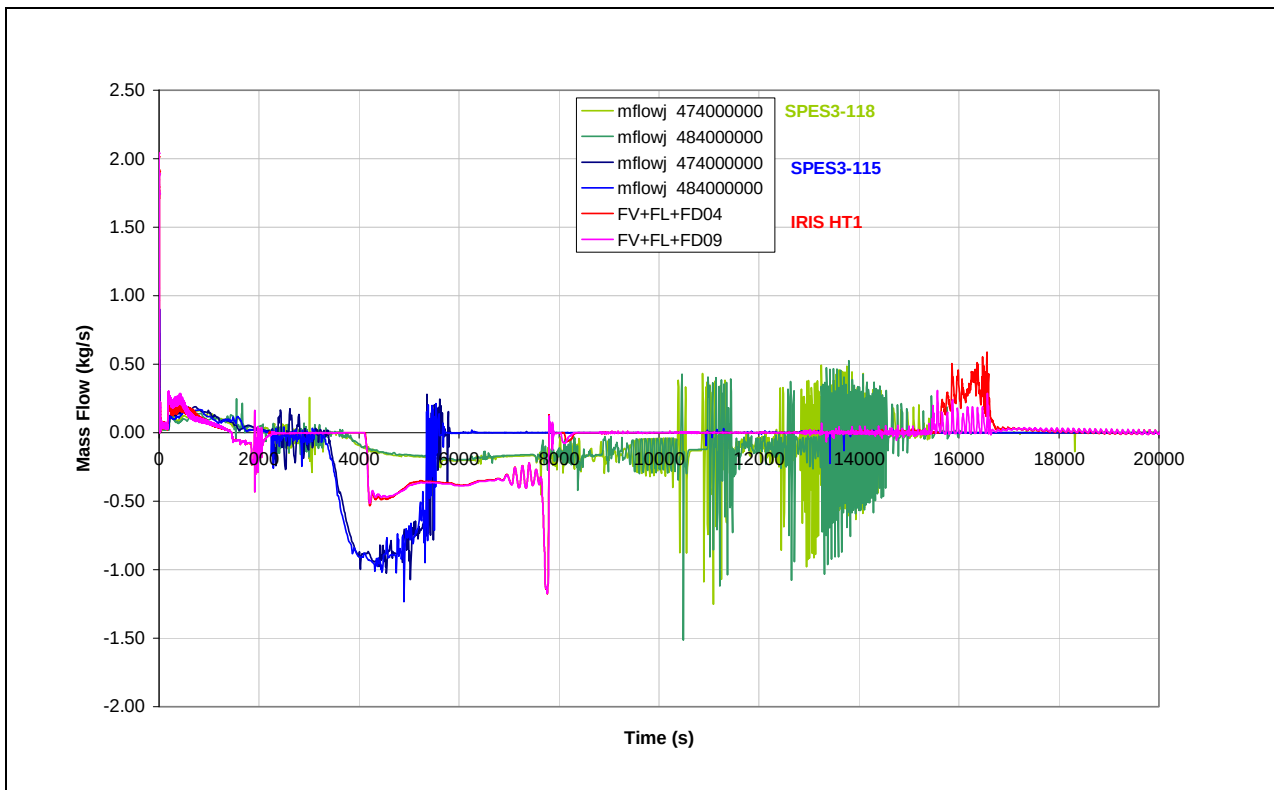
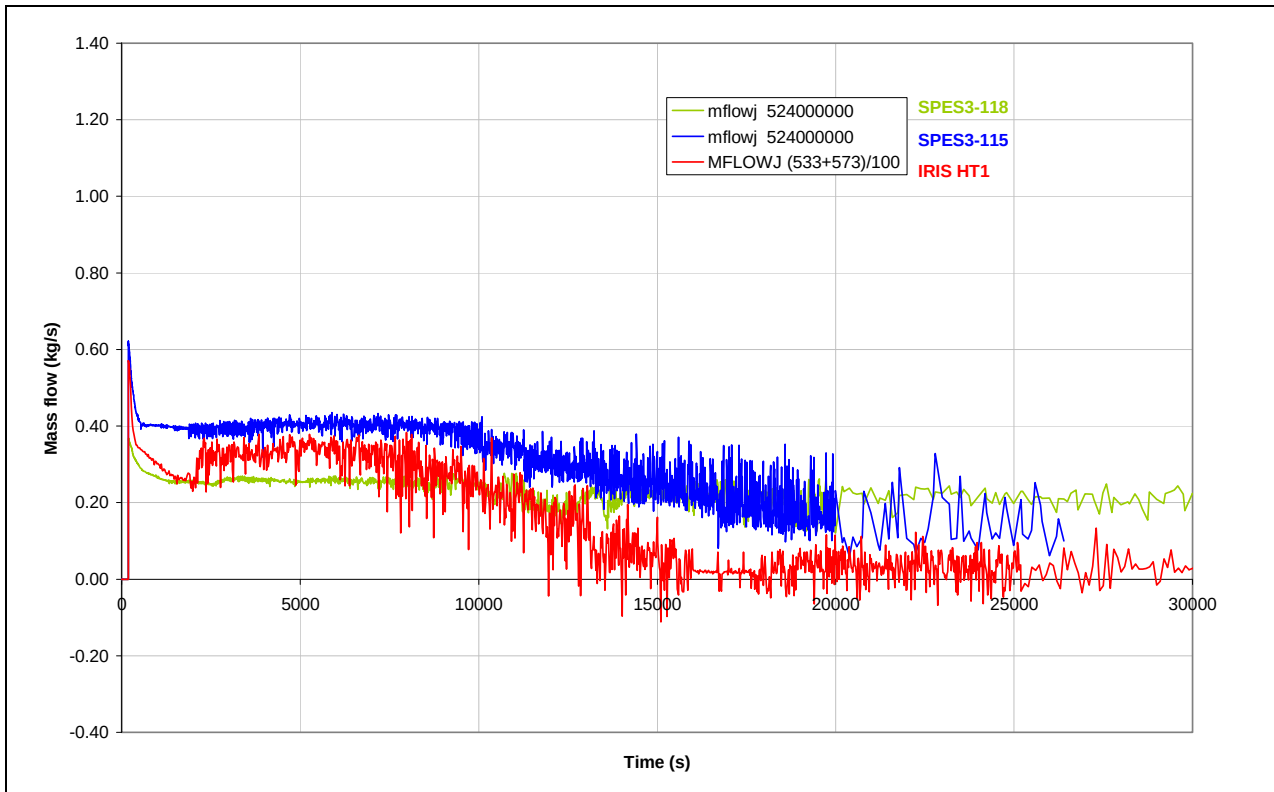


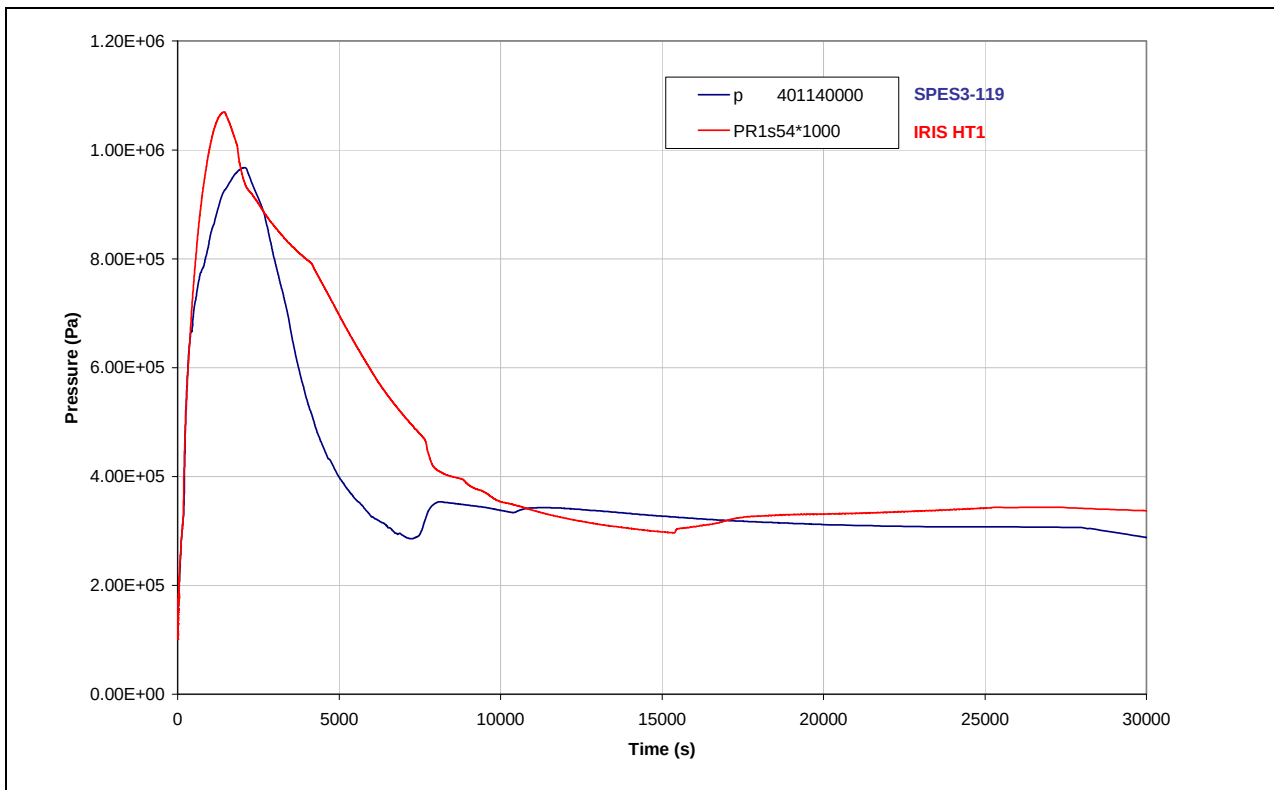
Fig.5. 40 – SPES3-118, 115 and IRIS HT1: PSS to DW injection mass flow (window)



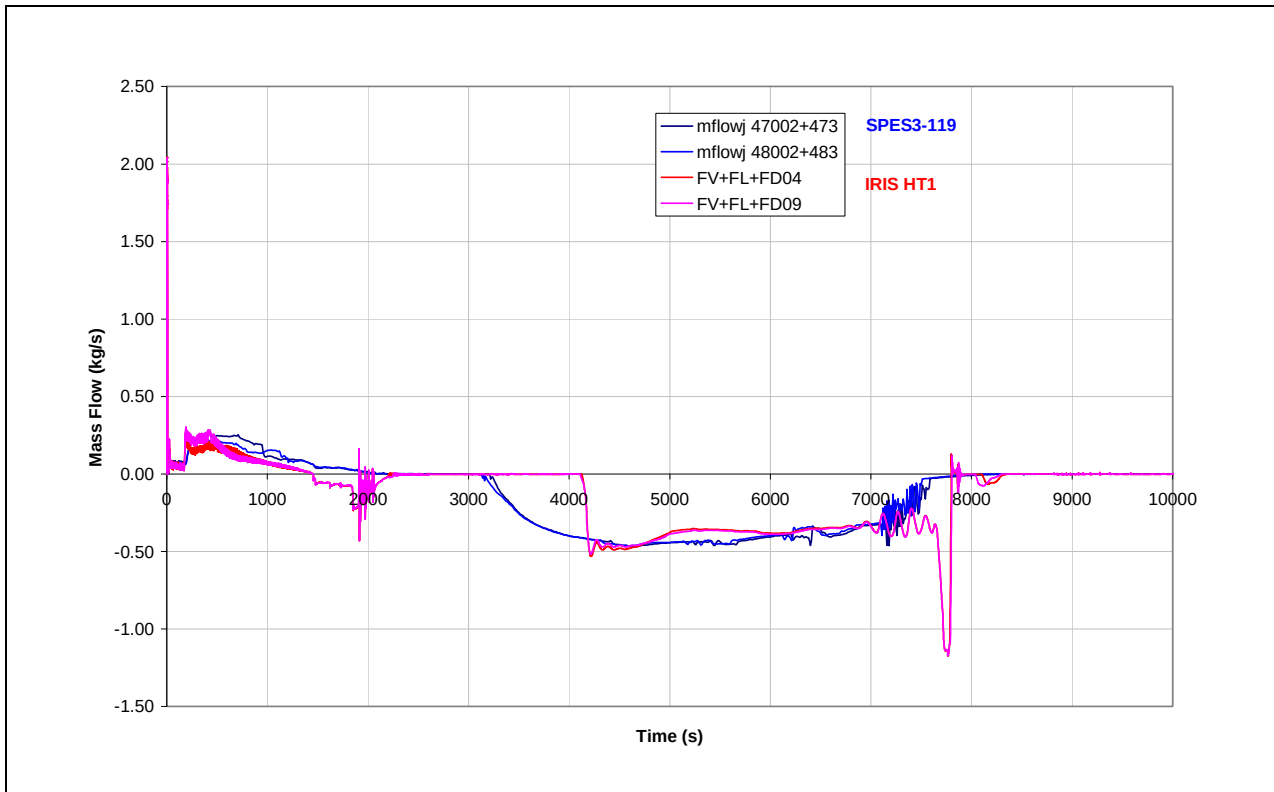
**Fig.5. 41 – SPES3-118, 115 and IRIS HT1: EHRS-C cold leg mass flow (window)**



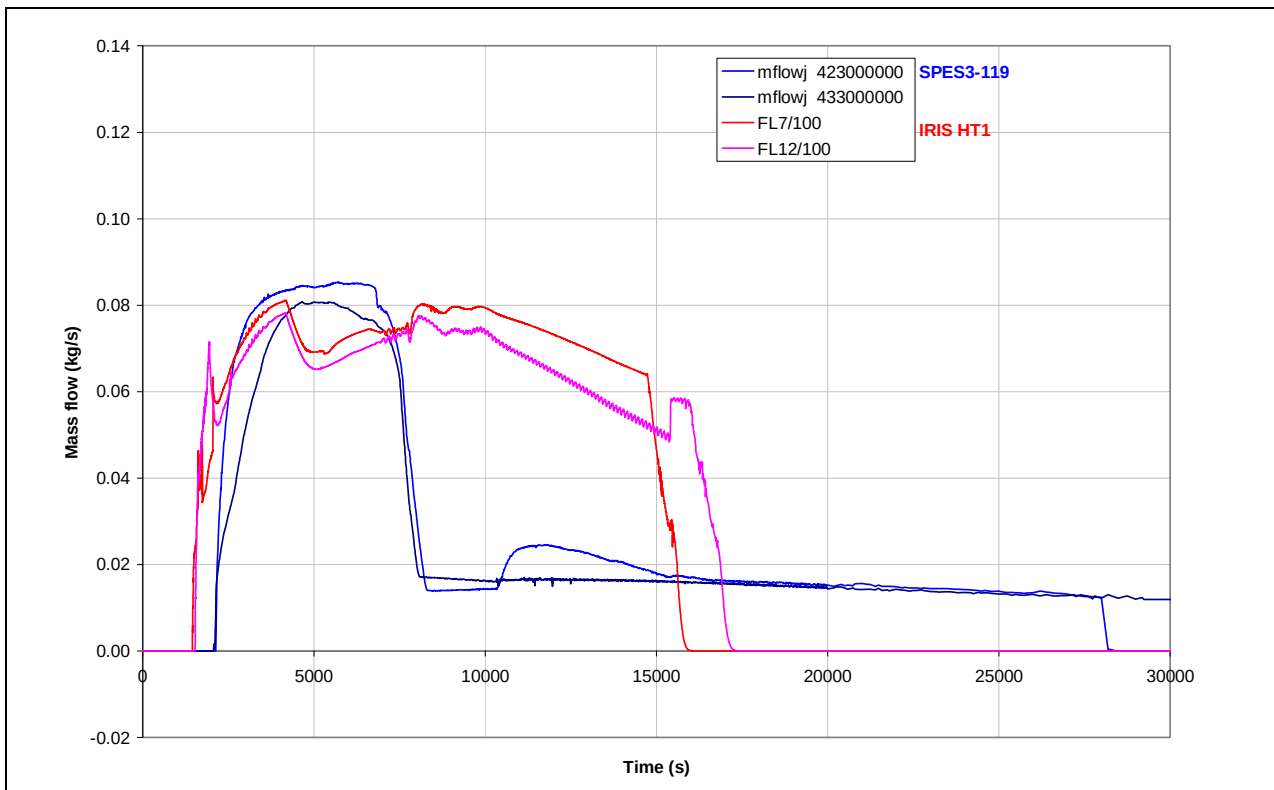
**Fig.5. 42 – SPES3-119 and IRIS HT1: DW pressure (window)**



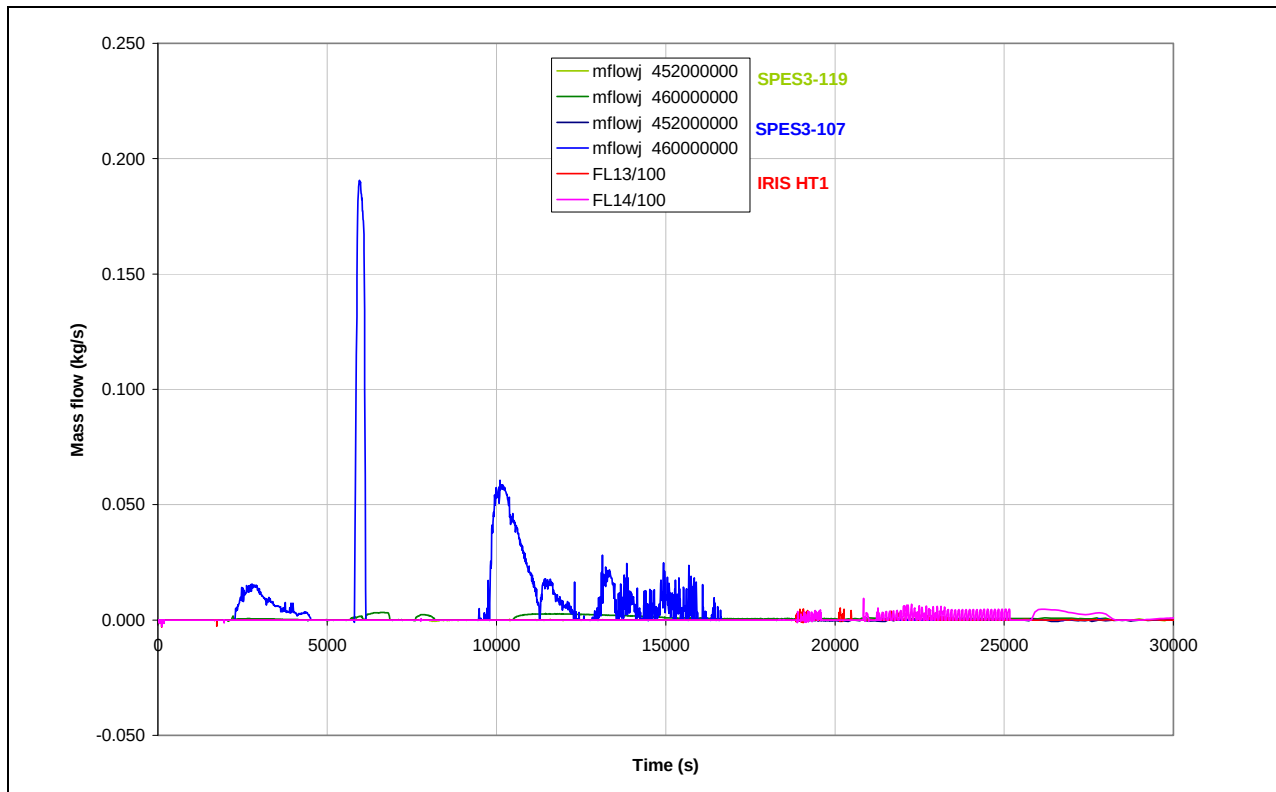
**Fig.5. 43 – SPES3-119 and IRIS HT1: PSS to DW injection mass flow (window)**



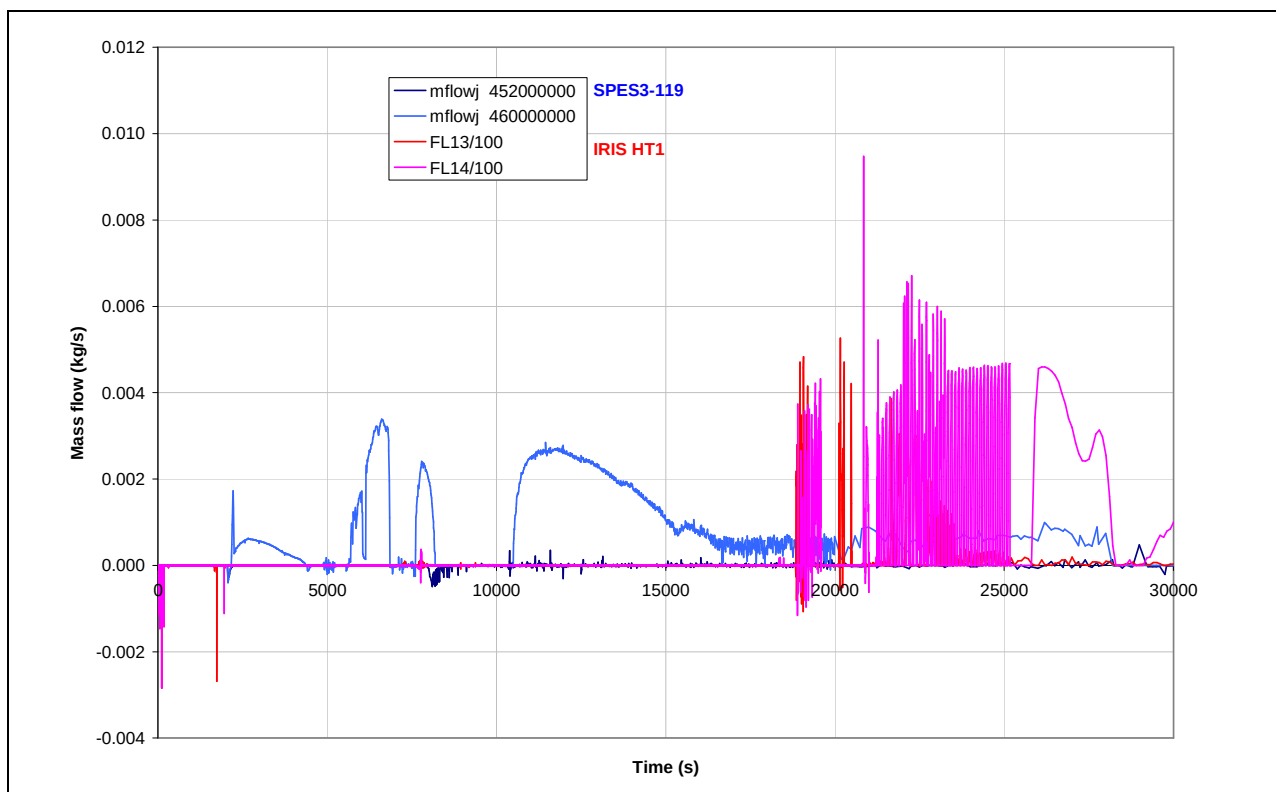
**Fig.5. 44 – SPES3-119 and IRIS HT1: LGMS injection mass flow (window)**



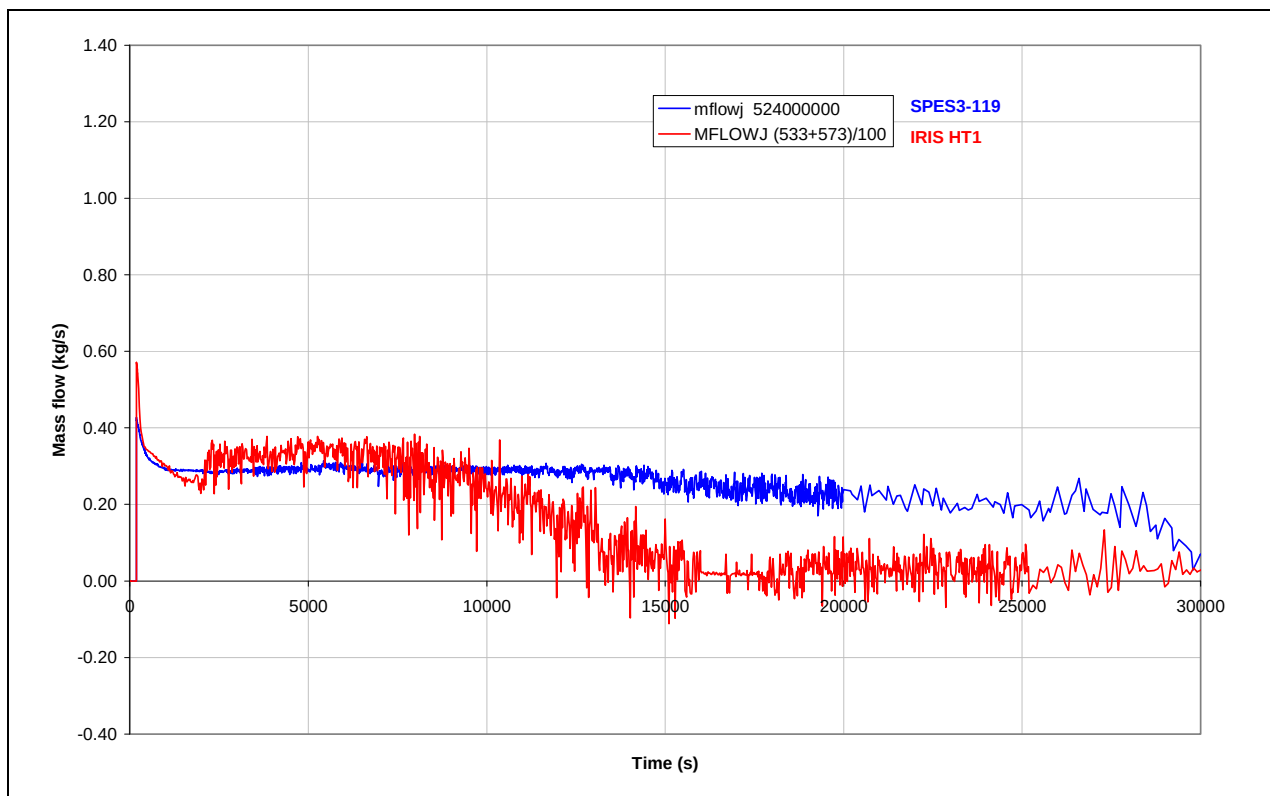
**Fig.5. 45 – SPES3-119, 107 and IRIS HT1: RC to DVI injection mass flow (window)**



**Fig.5. 46 – SPES3-119 and IRIS HT1: RC to DVI injection mass flow (window)**



**Fig.5. 47 – SPES3-119 and IRIS HT1: EHR5-C cold leg mass flow (window)**



**Fig.5. 48 – SPES3-120 and IRIS HT1: DW pressure (window)**

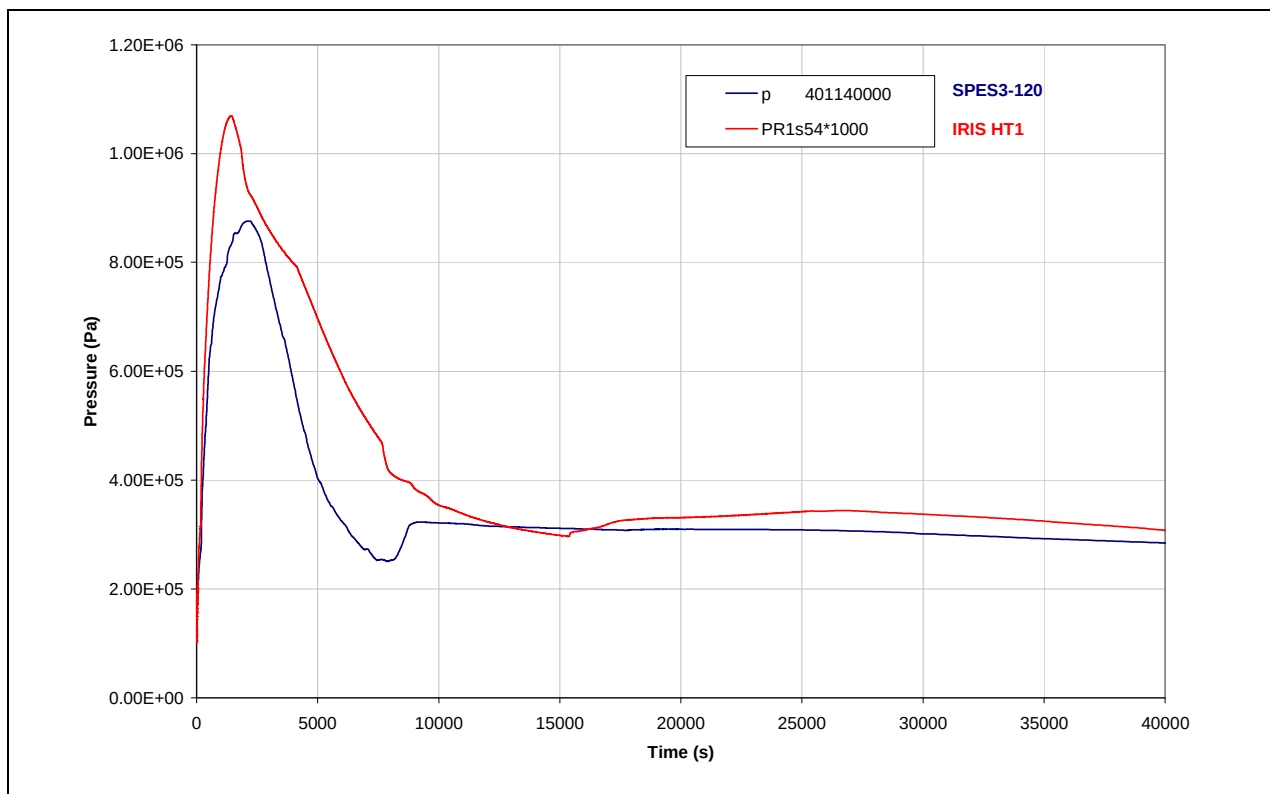


Fig.5. 49 – SPES3-120 and IRIS HT1: LGMS injection mass flow (window)

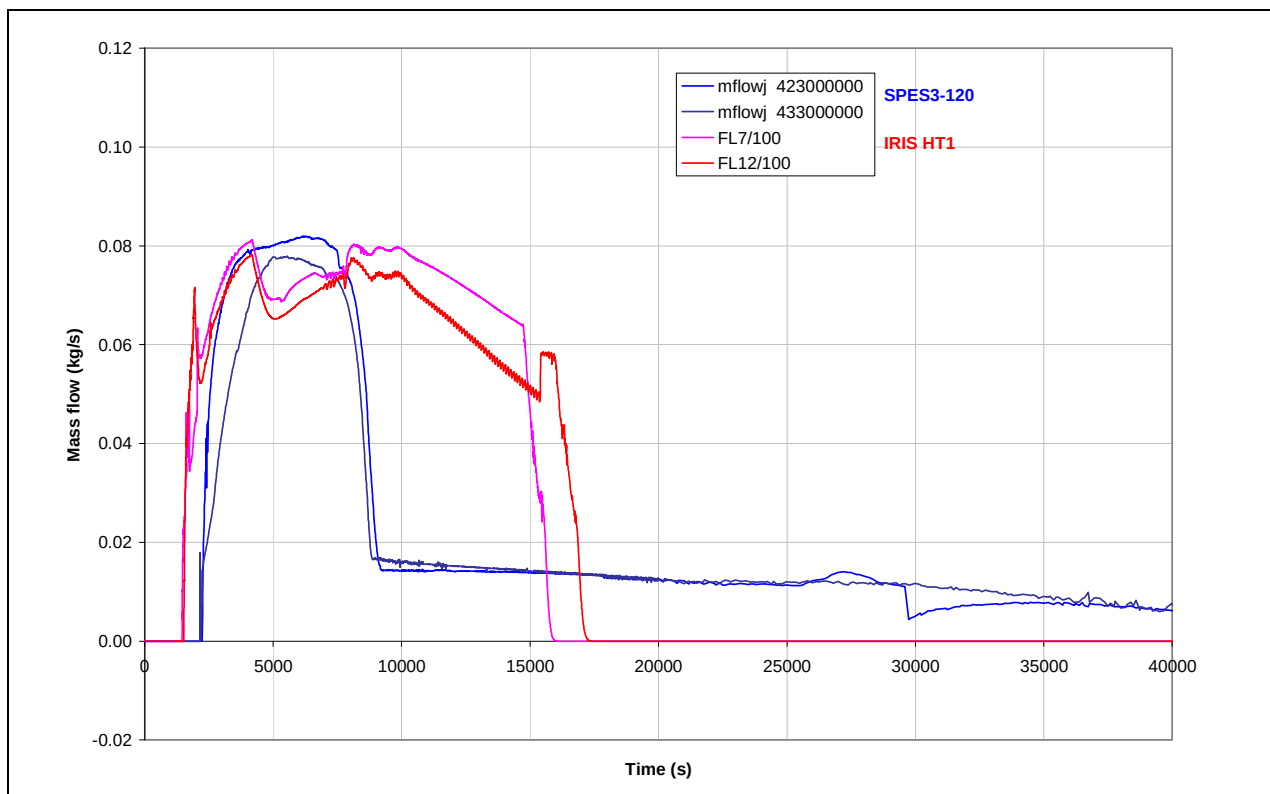


Fig.5. 50 – SPES3-120 and IRIS HT1: PSS to DW injection mass flow (window)

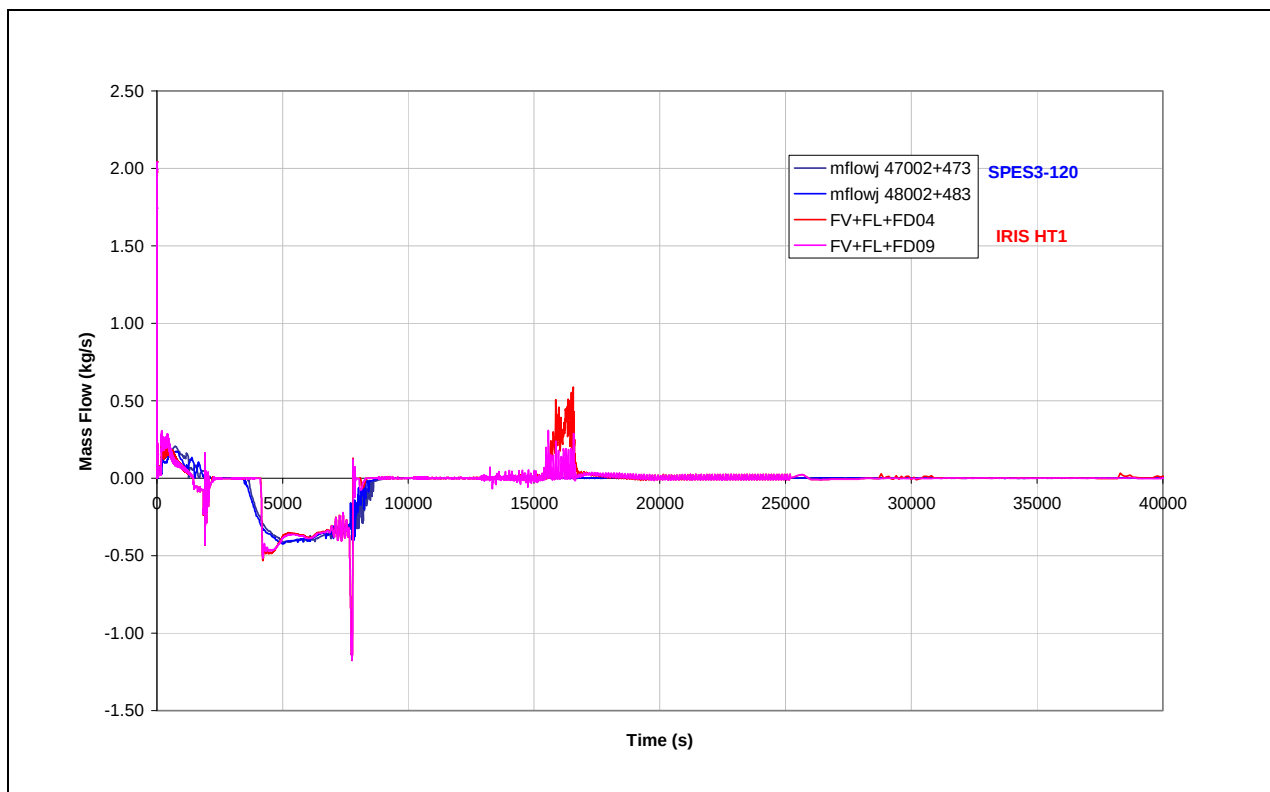


Fig.5. 51 – SPES3-120 and IRIS HT1: LGMS and DVI pressure (window)

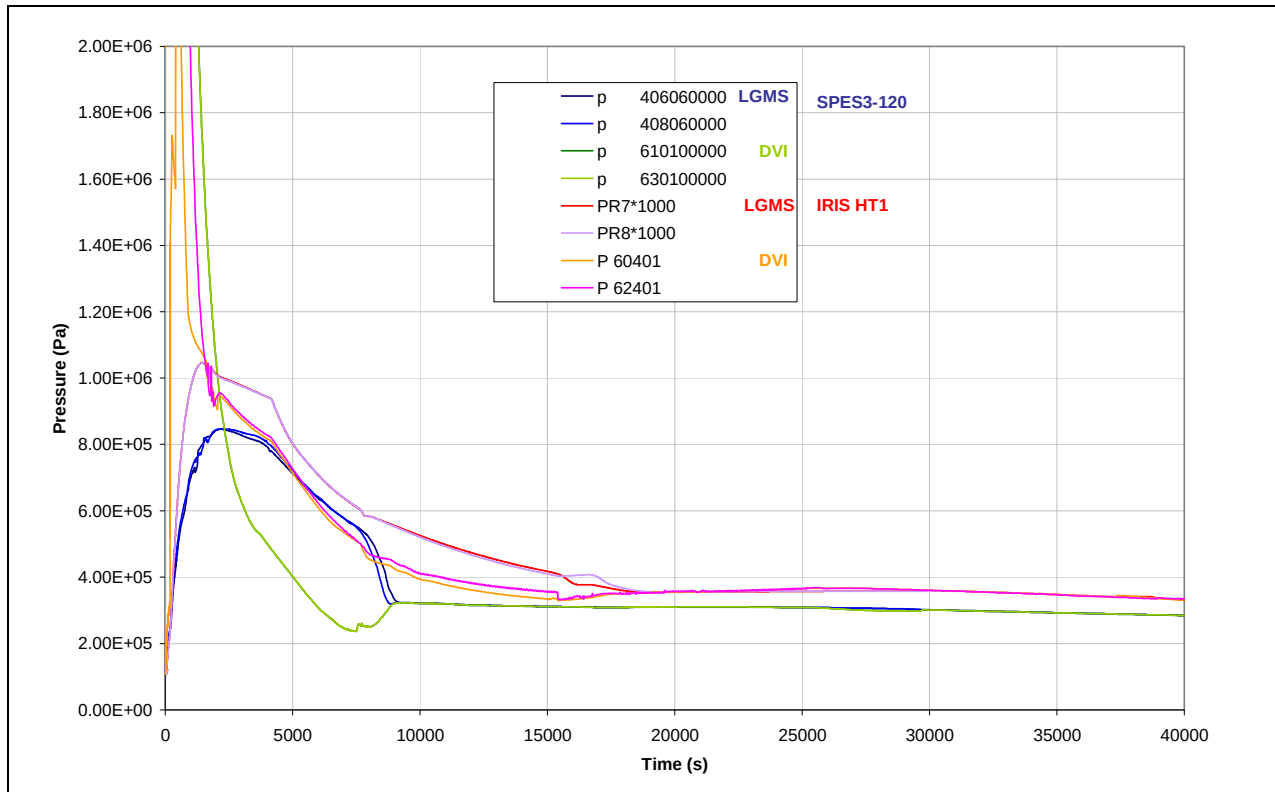
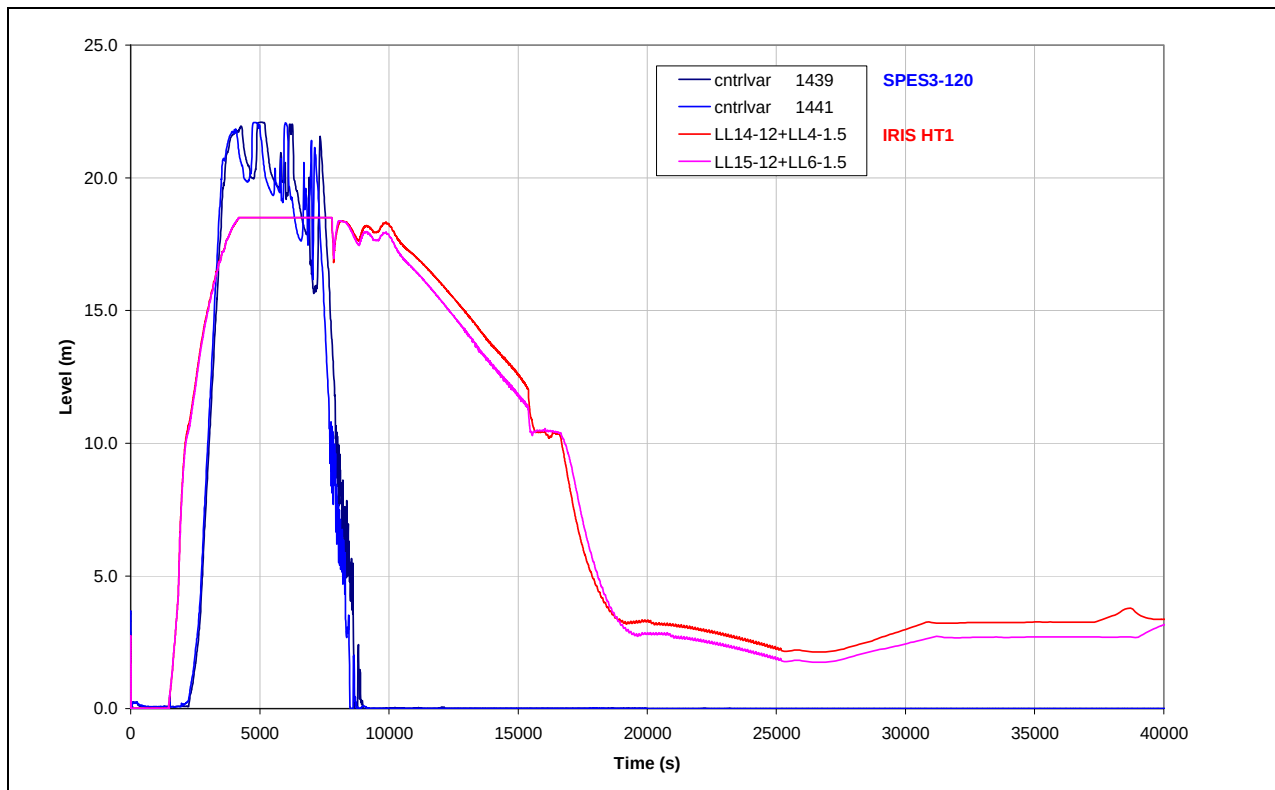
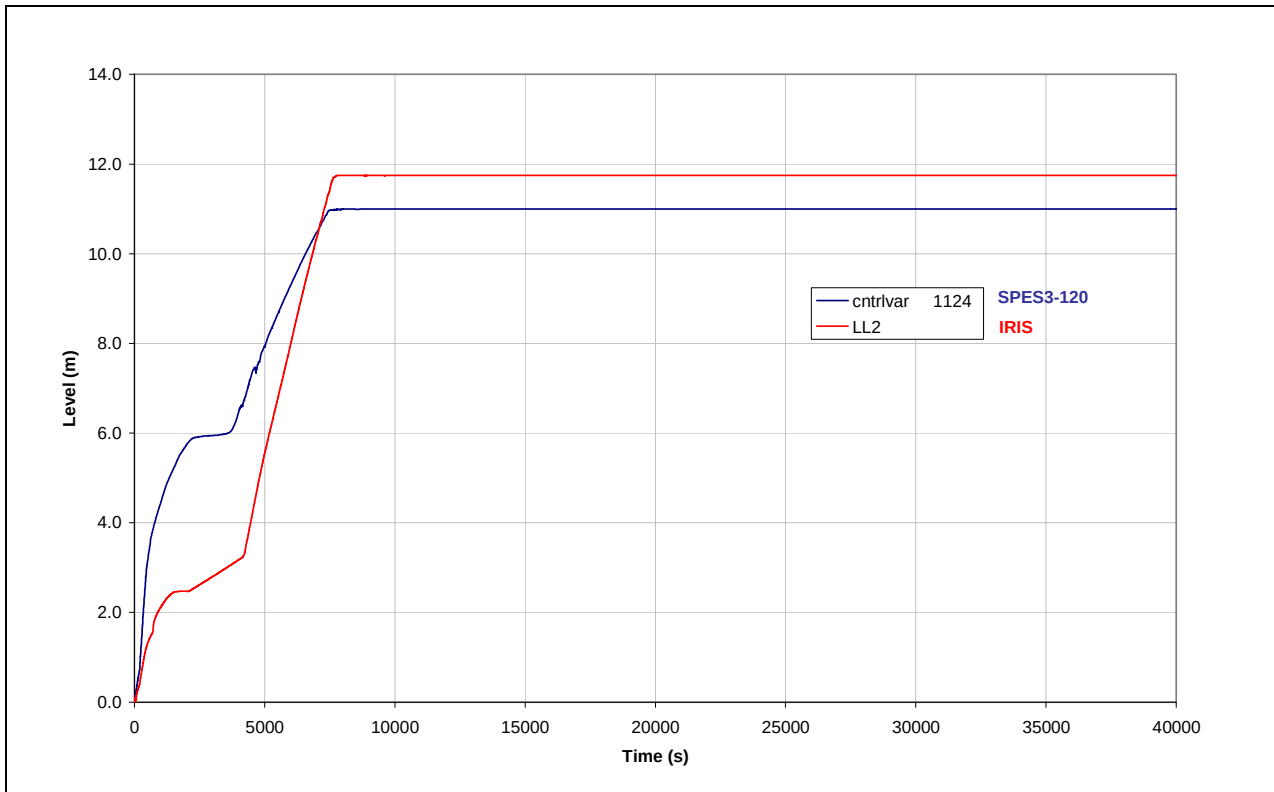


Fig.5. 52 – SPES3-120 and IRIS HT1: PSS vent pipe level (window)

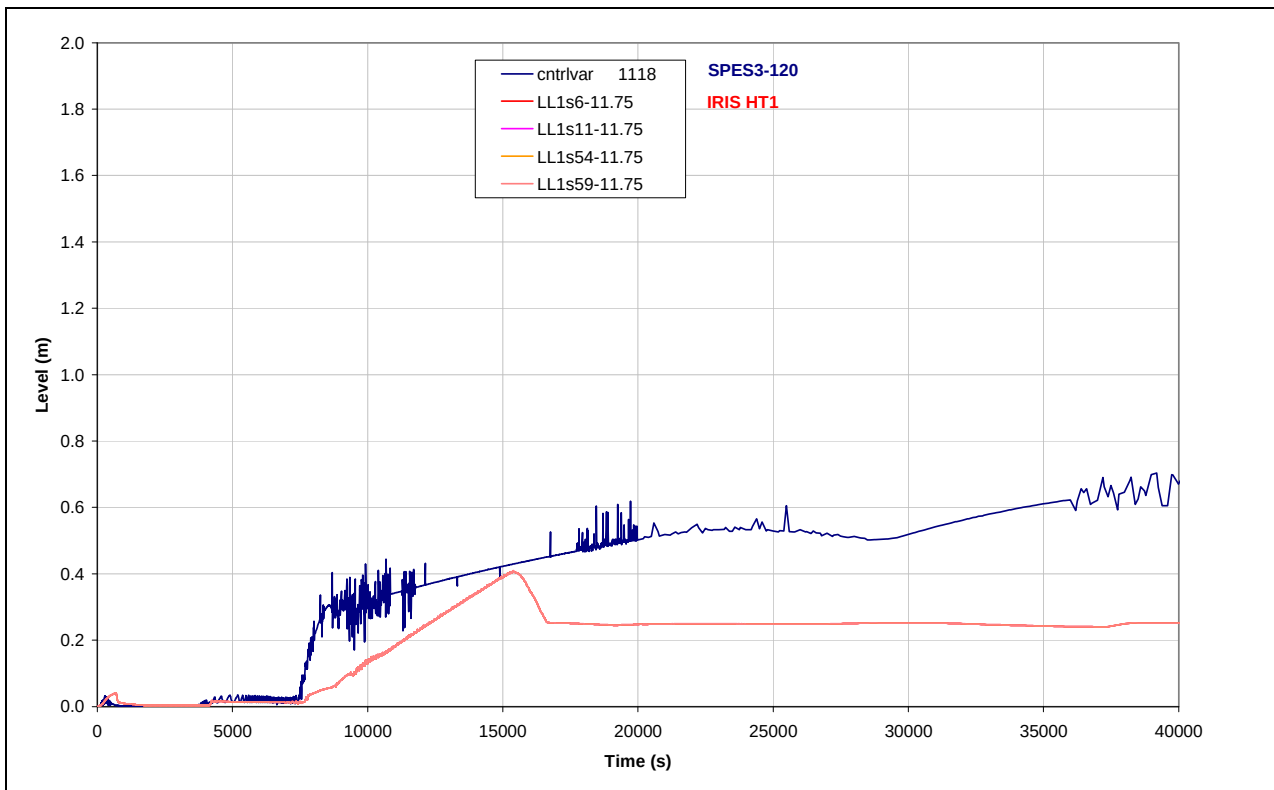




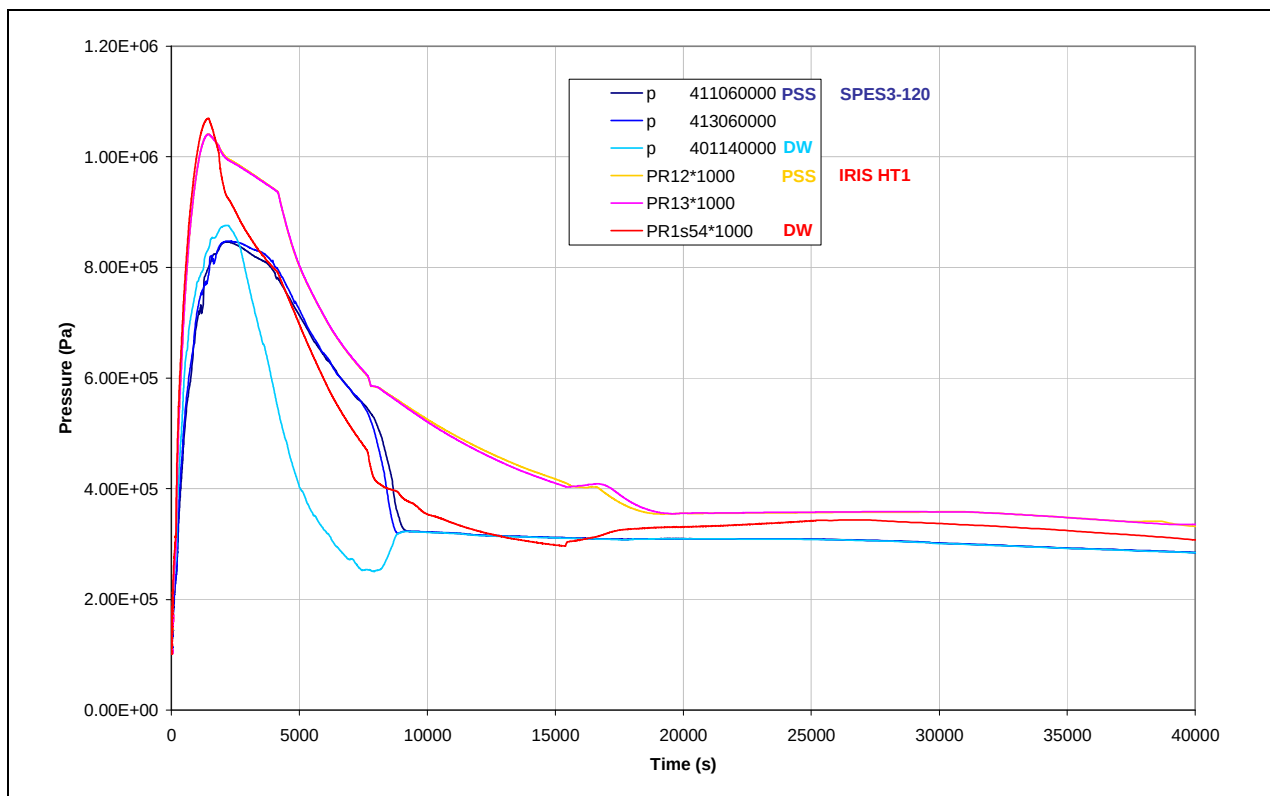
**Fig.5. 53 – SPES3-120 and IRIS HT1: RC level (window)**



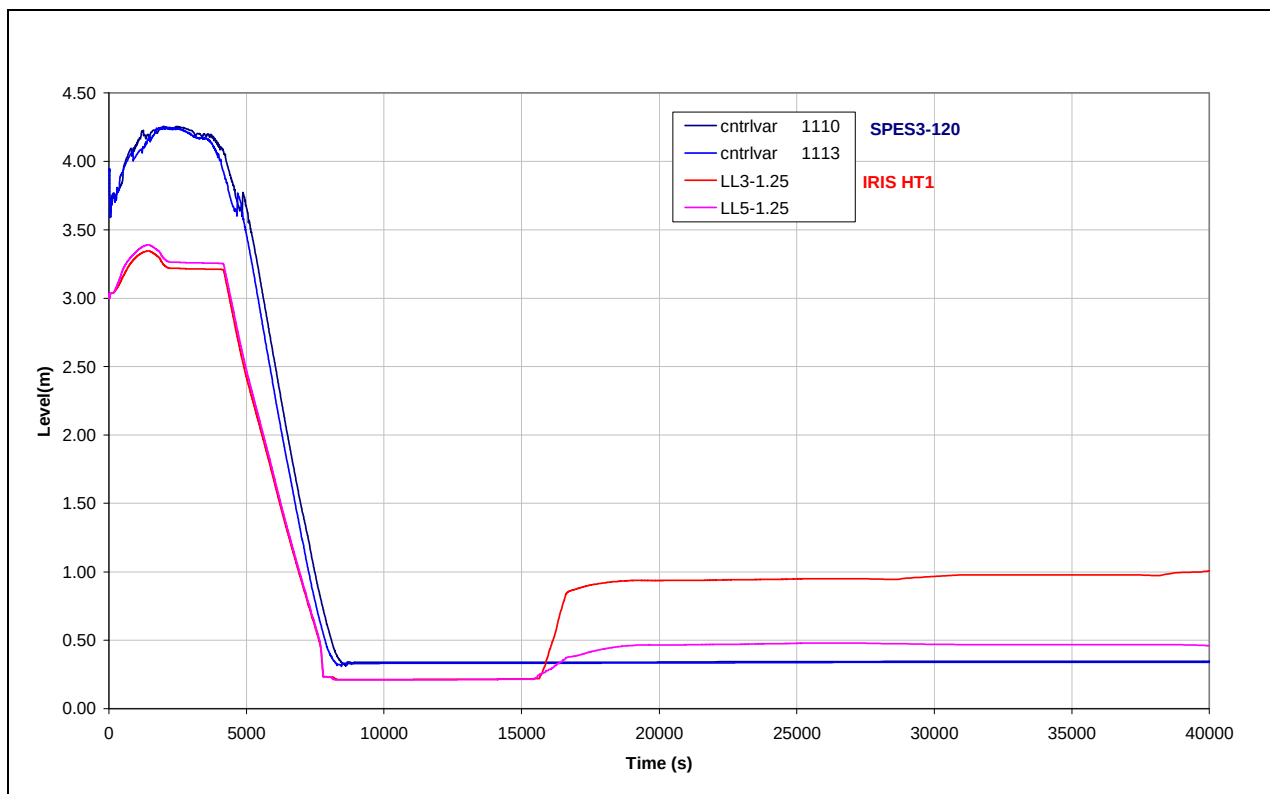
**Fig.5. 54 – SPES3-120 and IRIS HT1: DW level (window)**



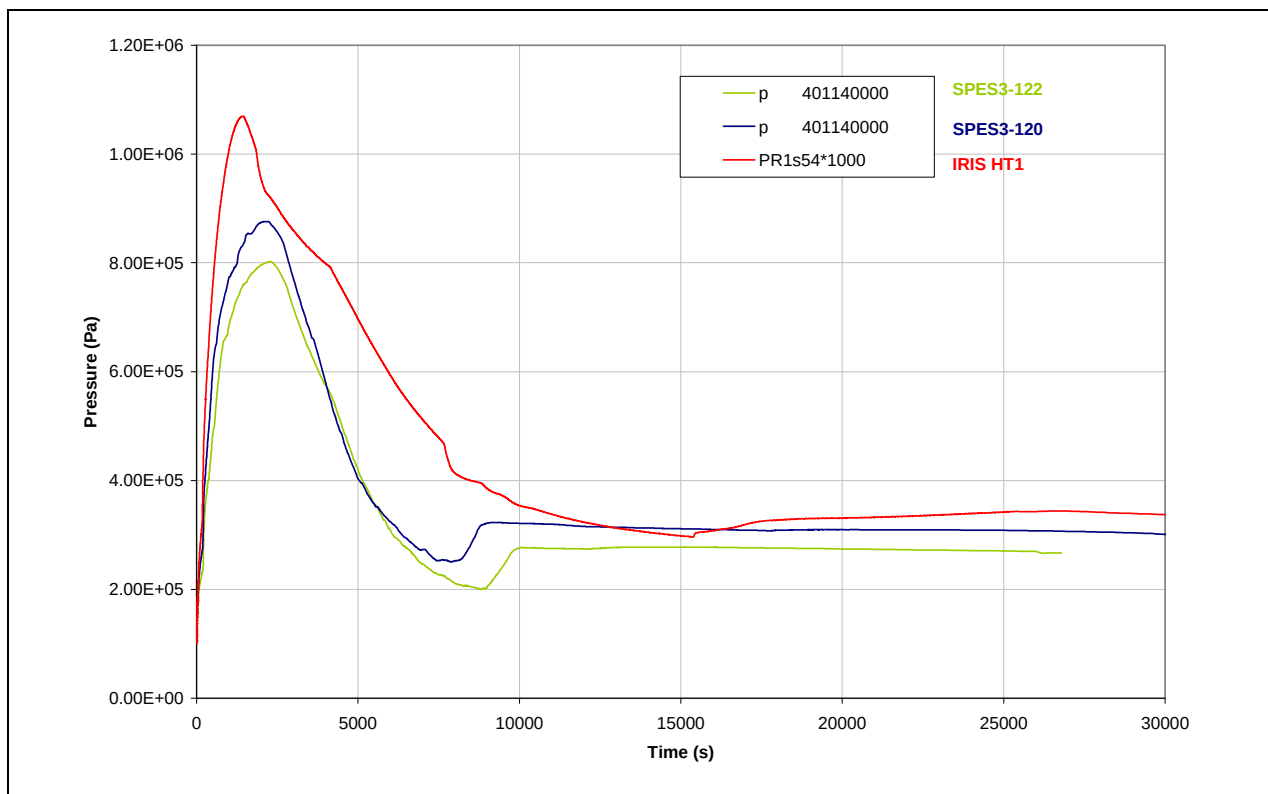
**Fig.5. 55 – SPES3-120 and IRIS HT1: PSS and DW pressure (window)**



**Fig.5. 56 – SPES3-120 and IRIS HT1: PSS level (window)**



**Fig.5. 57 – SPES3-122, 120 and IRIS HT1: DW pressure (window)**



**Fig.5. 58 – SPES3-124 and IRIS HT5g: DW pressure (window)**

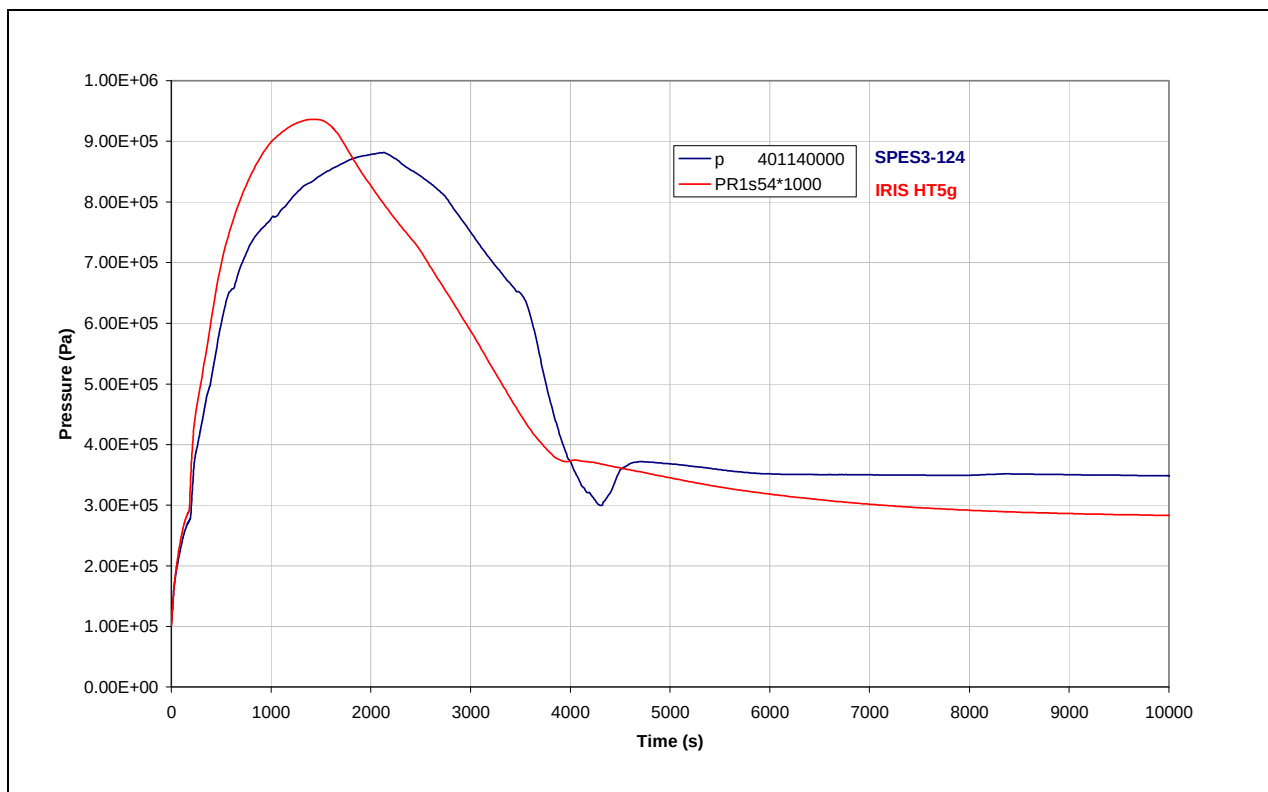


Fig.5. 59 – SPES3-124 and IRIS HT5g: DW pressure

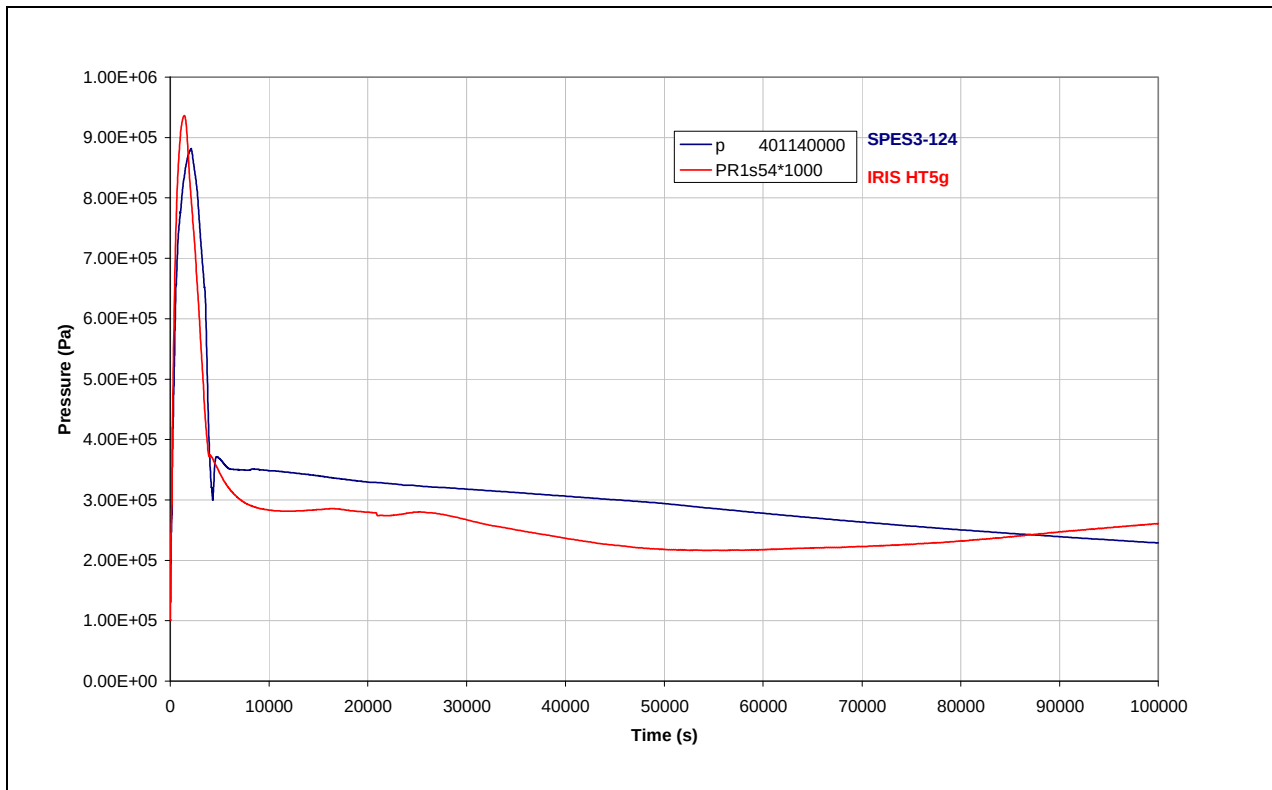


Fig.5. 60 – SPES3-124 and IRIS HT5g: DW to PSS mass flow (window)

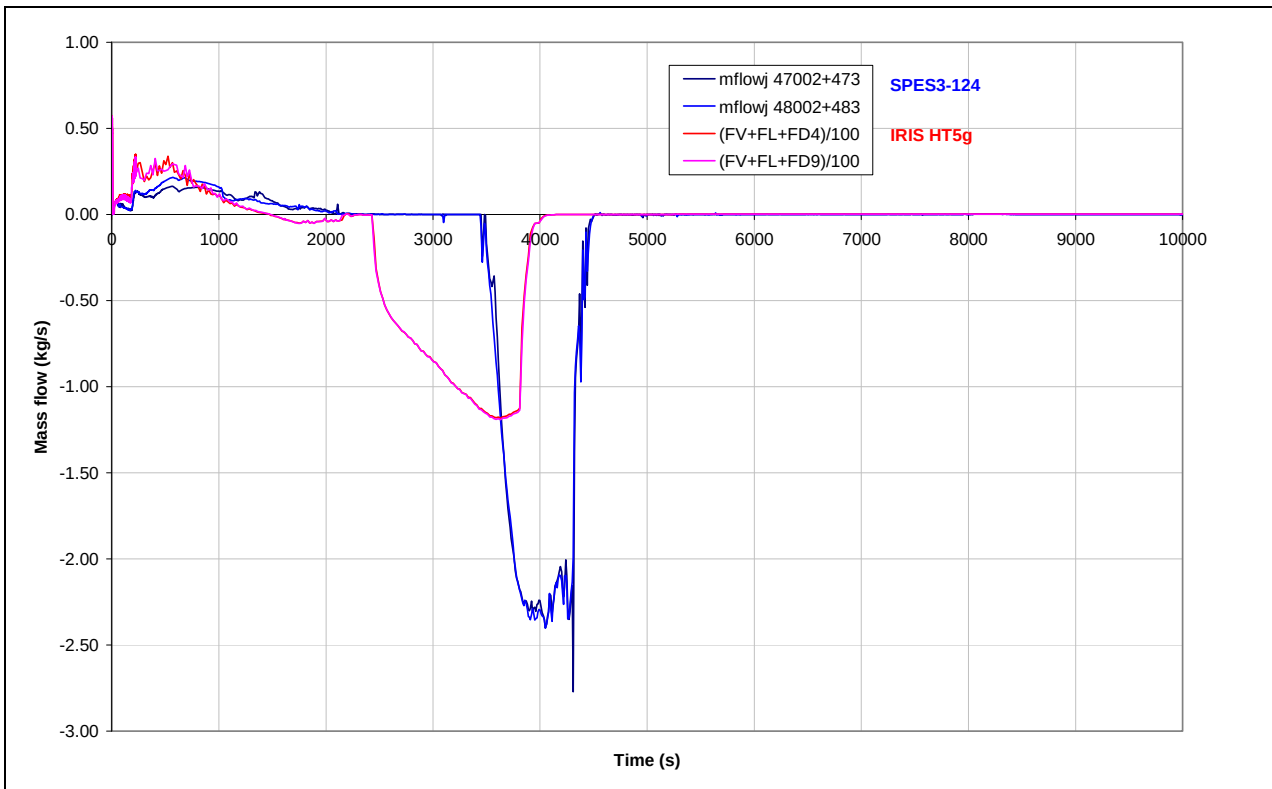


Fig.5. 61 – SPES3-124 and IRIS HT5g: PSS and DW pressure (window)

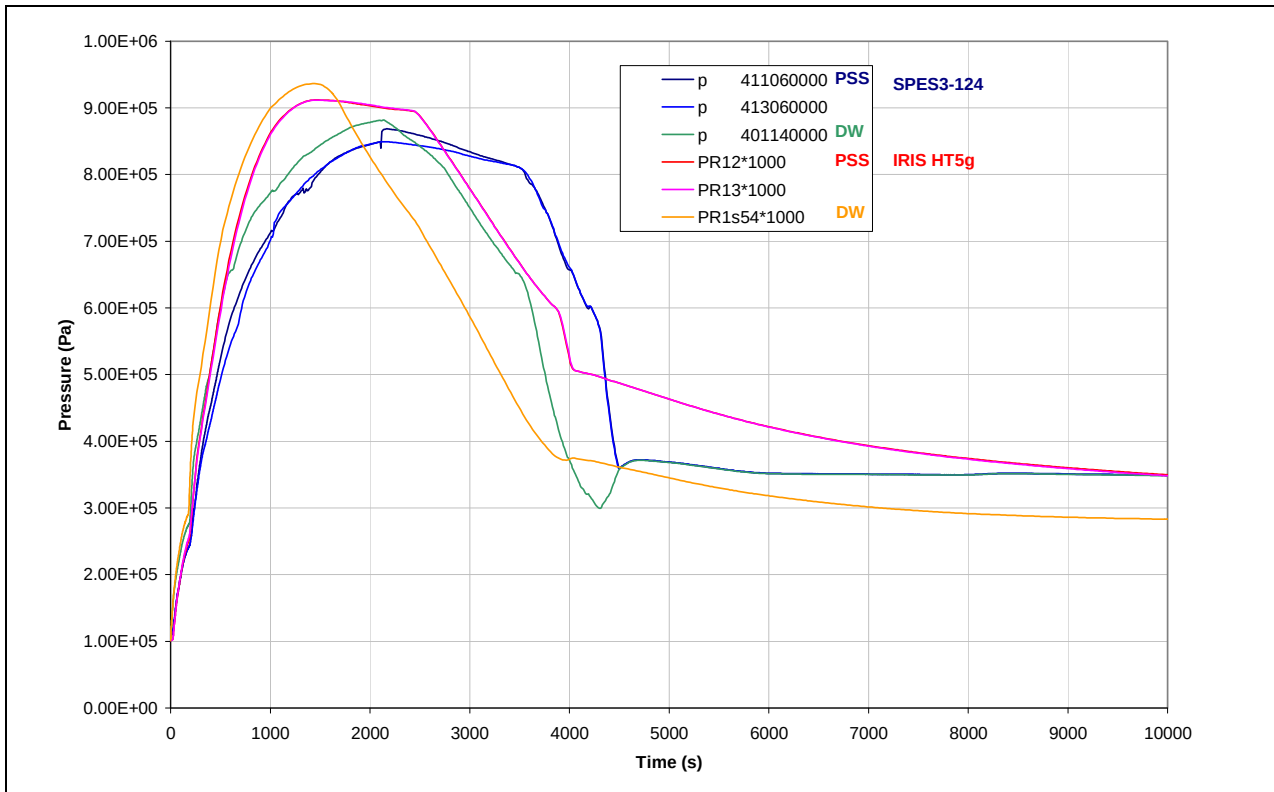


Fig.5. 62 – SPES3-124 and IRIS HT5g: PSS level (window)

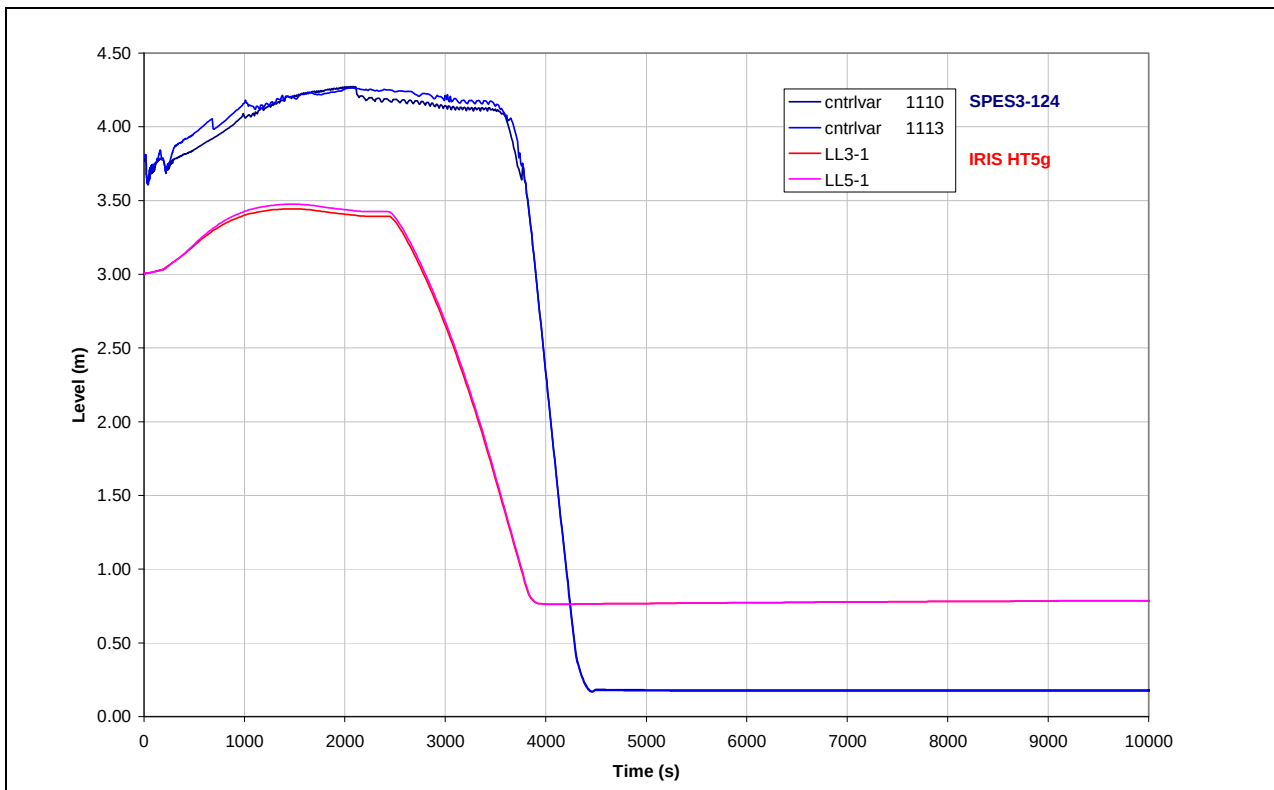


Fig.5. 63 – SPES3-124 and IRIS HT5g: PSS mass (window)

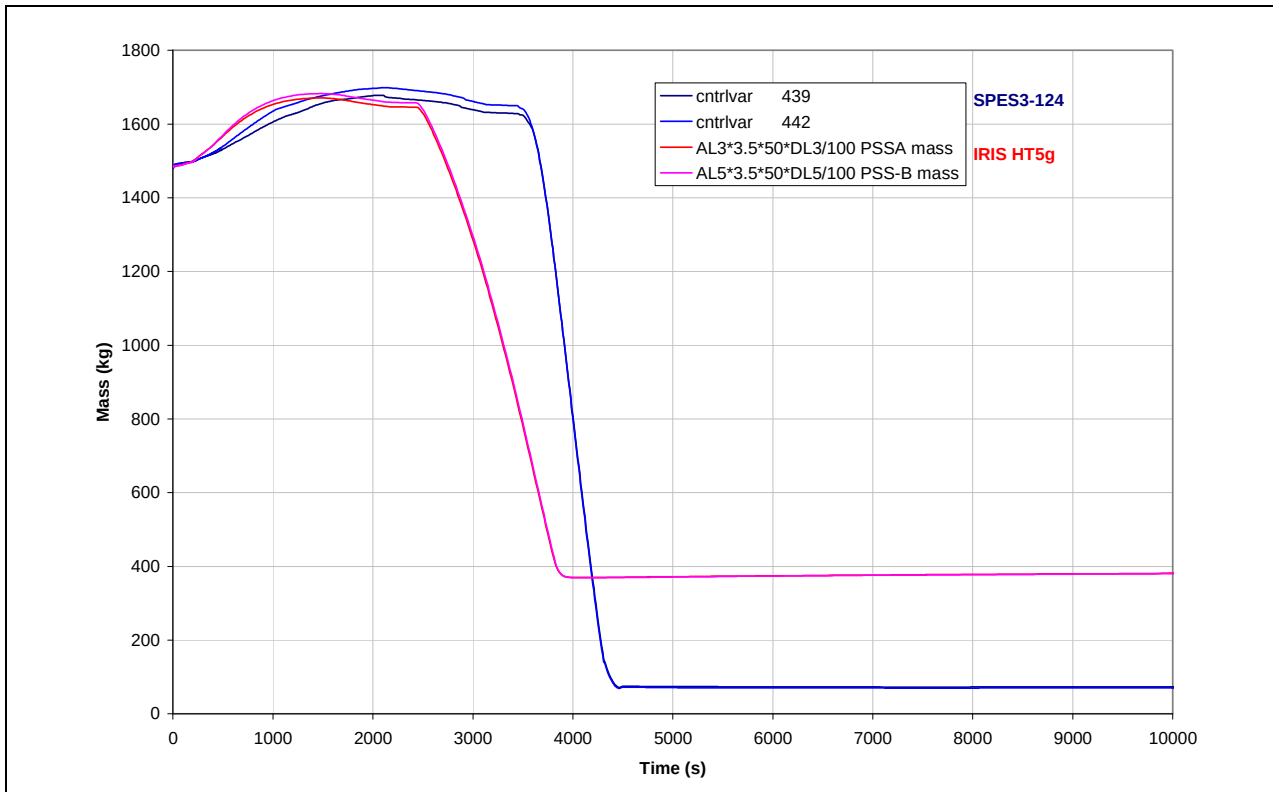
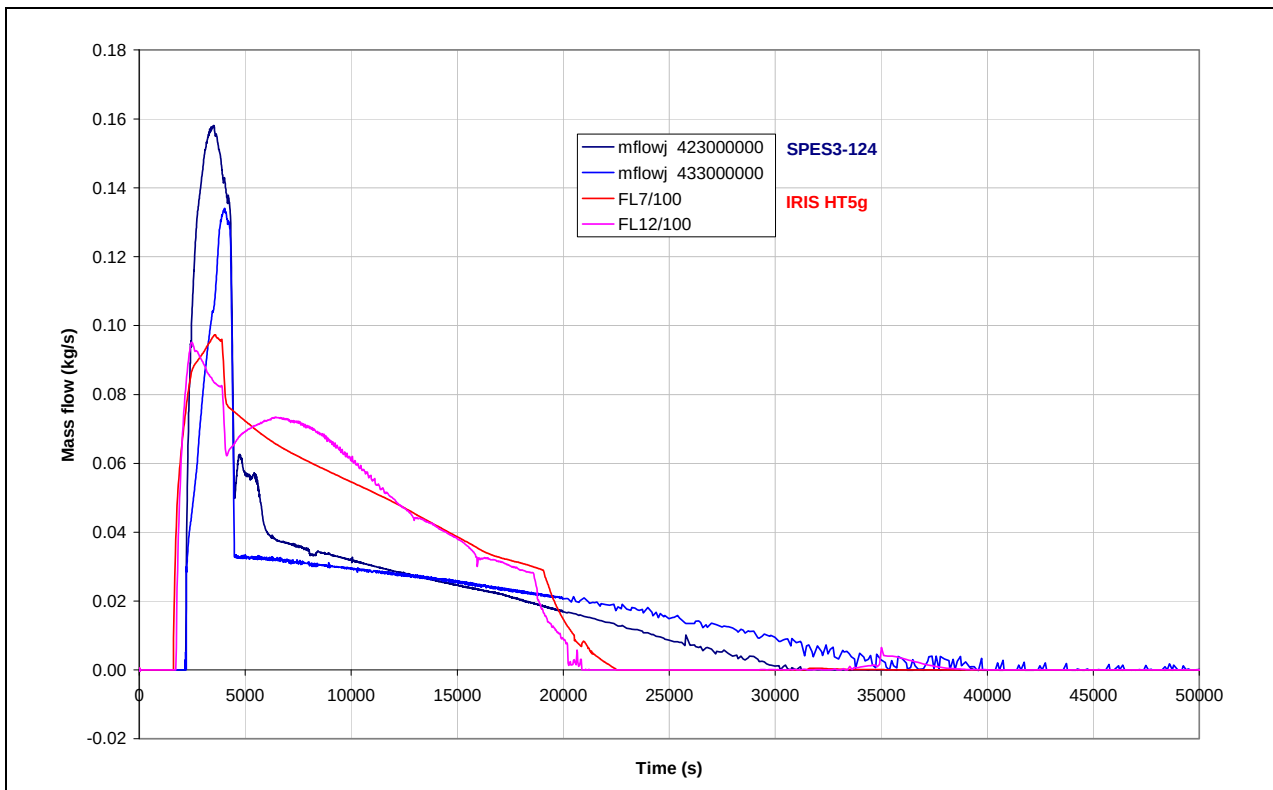
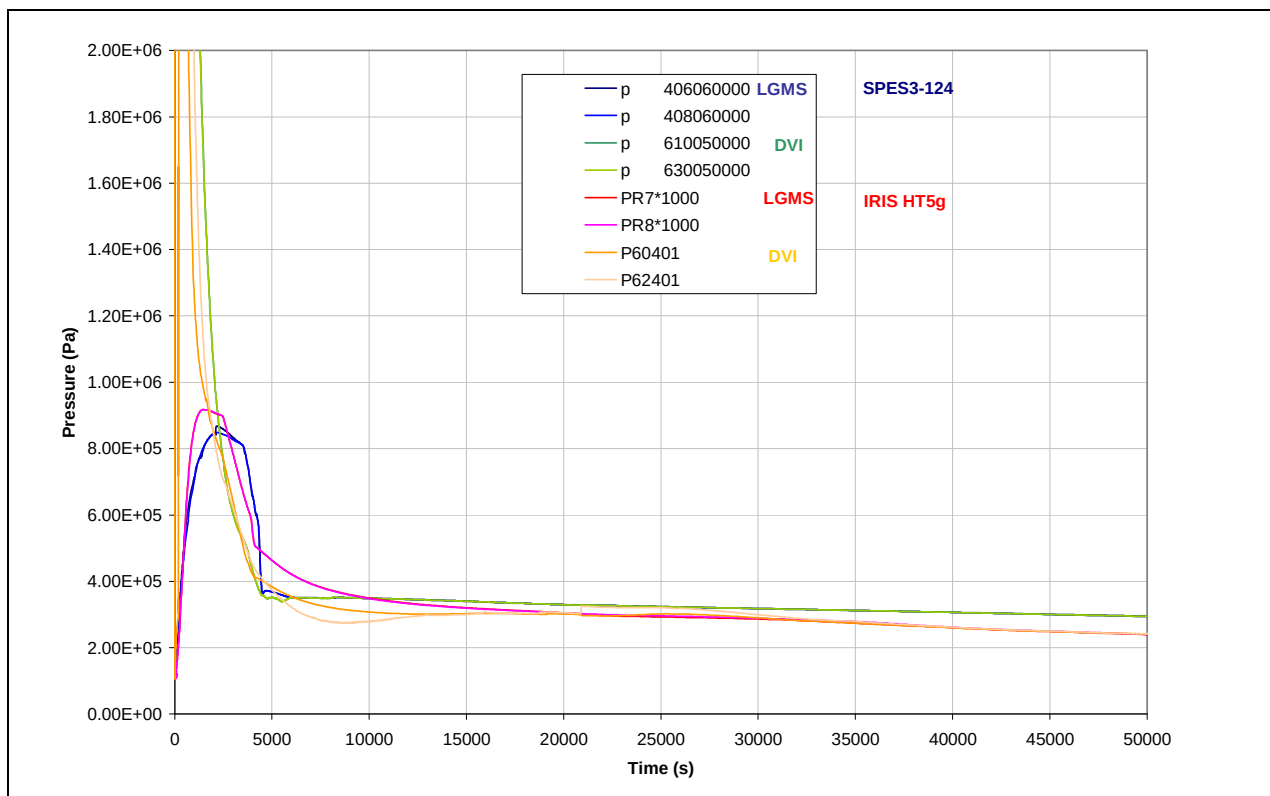


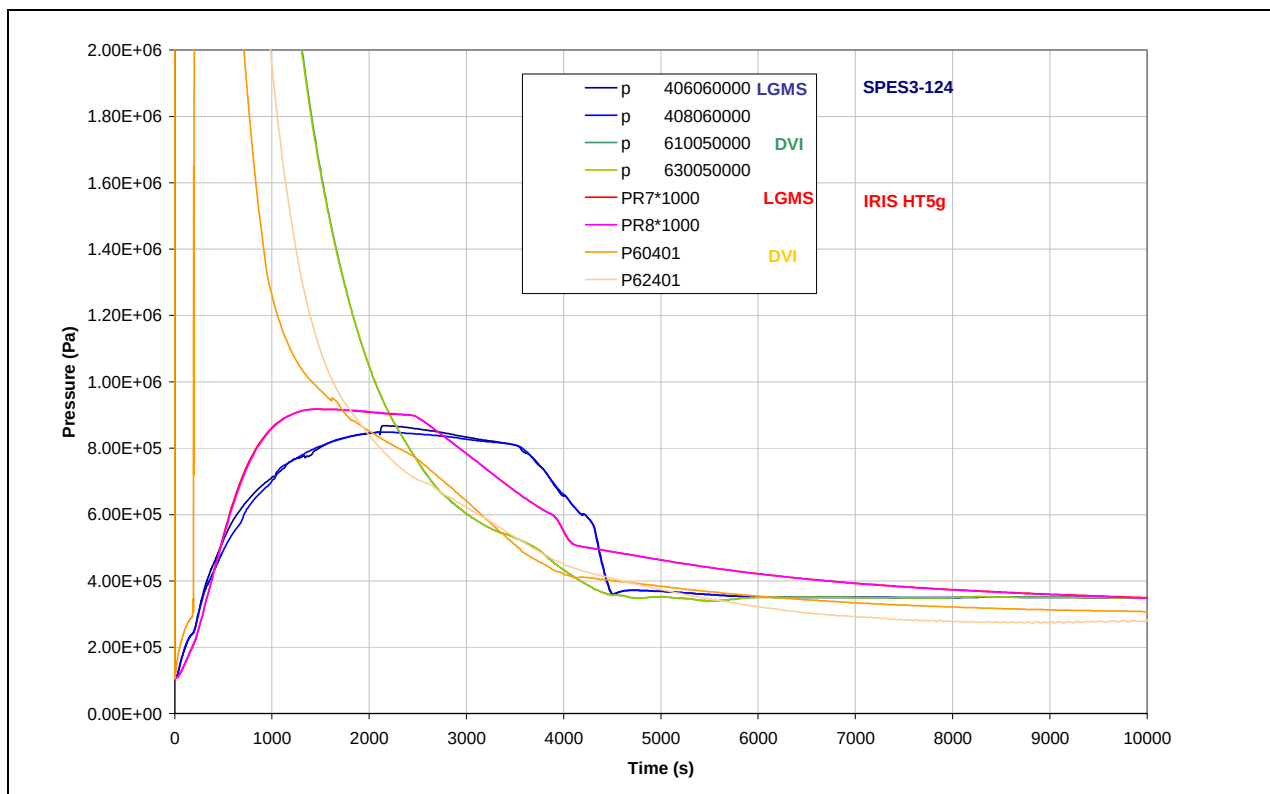
Fig.5. 64 – SPES3-124 and IRIS HT5g: LGMS injection mass flow (window)



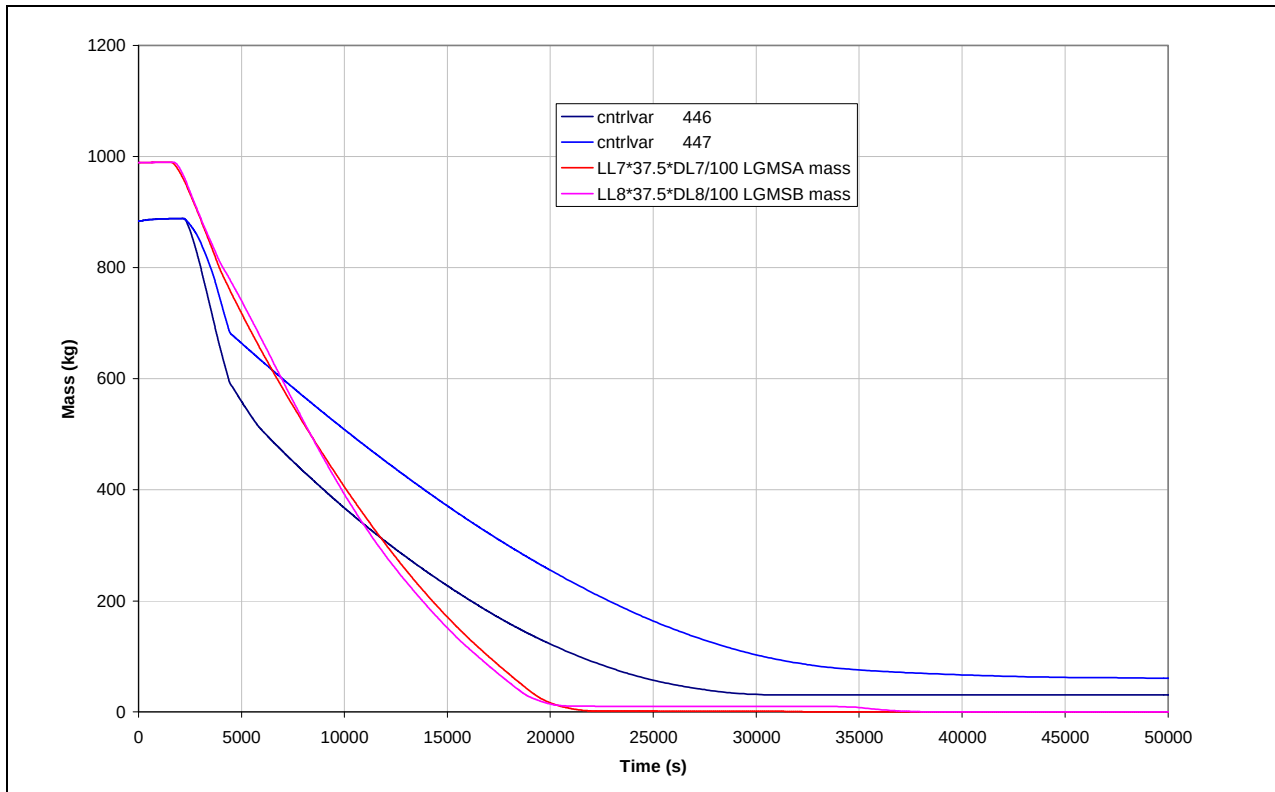
**Fig.5. 65 – SPES3-124 and IRIS HT5g: LGMS and DVI pressure (window)**



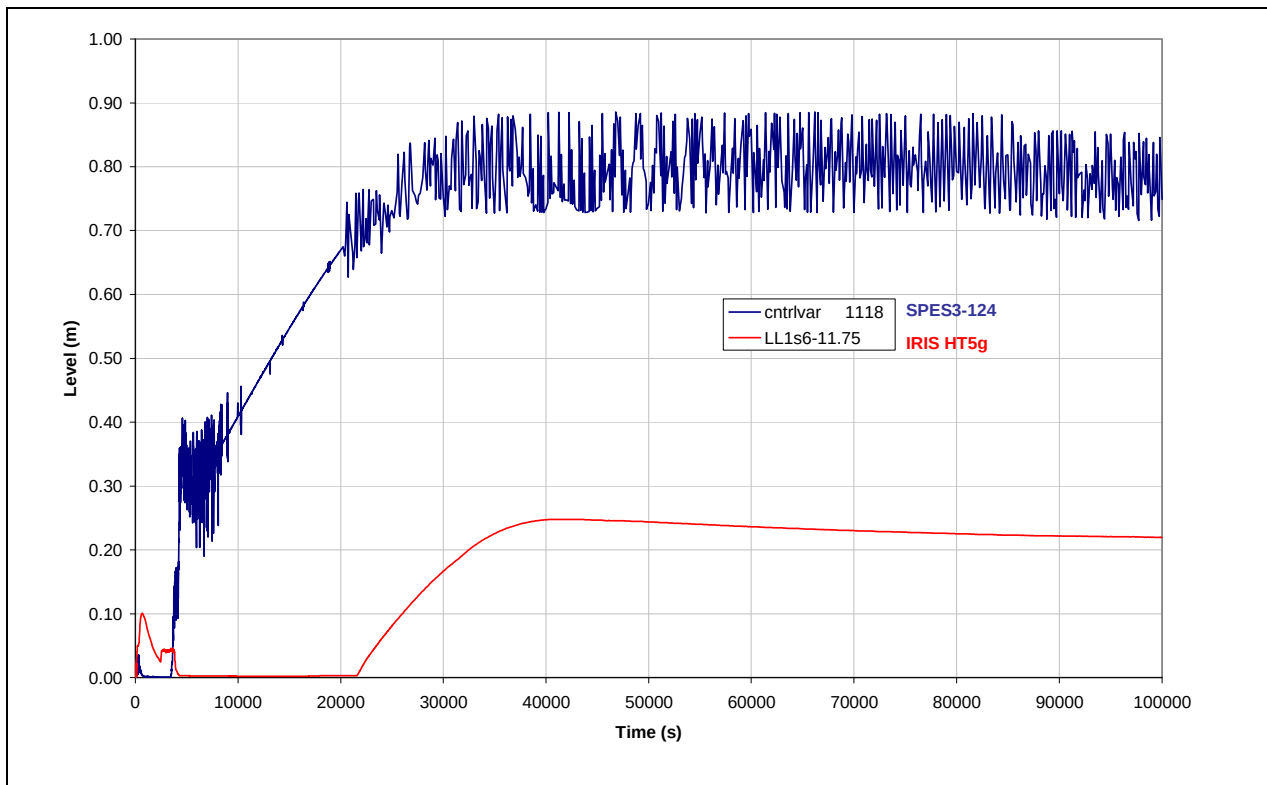
**Fig.5. 66 – SPES3-124 and IRIS HT5g: LGMS and DVI pressure (window)**



**Fig.5. 67 – SPES3-124 and IRIS HT5g: LGMS mass (window)**

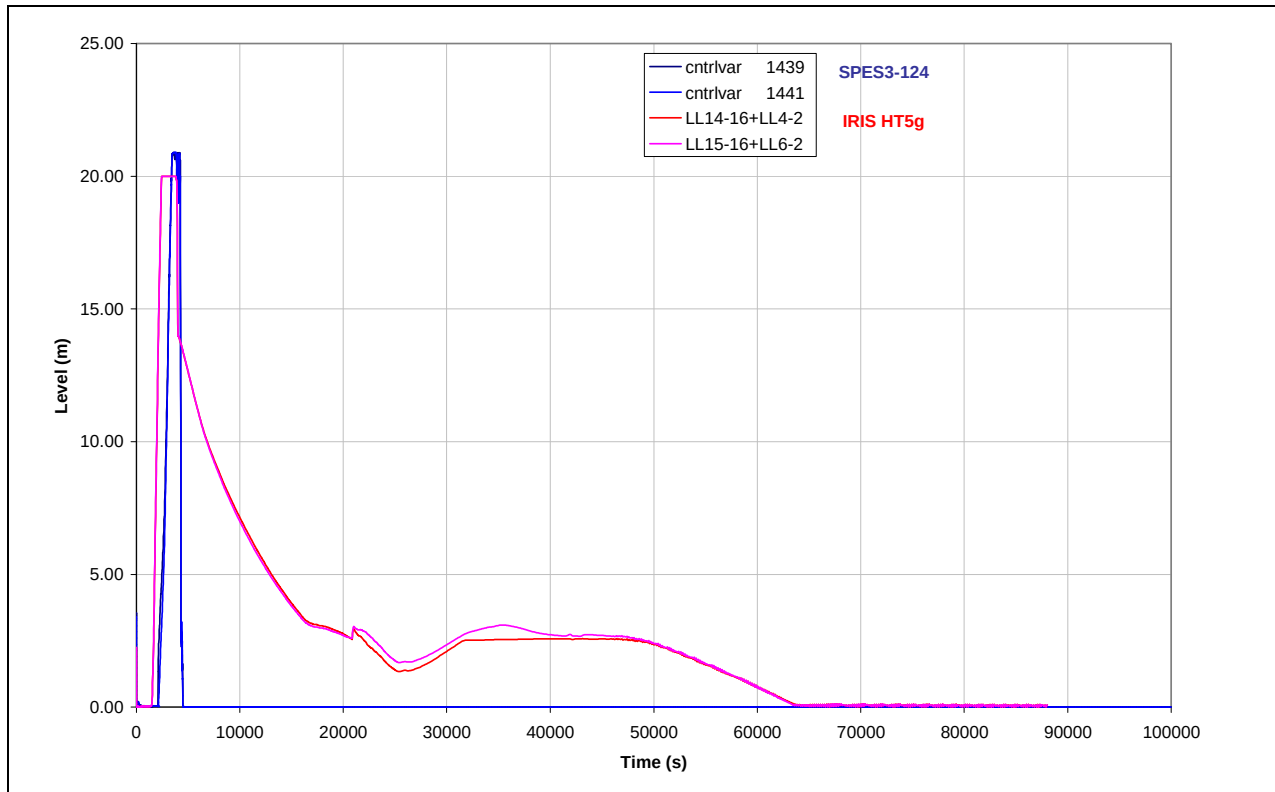


**Fig.5. 68 – SPES3-124 and IRIS HT5g: DW level (window)**

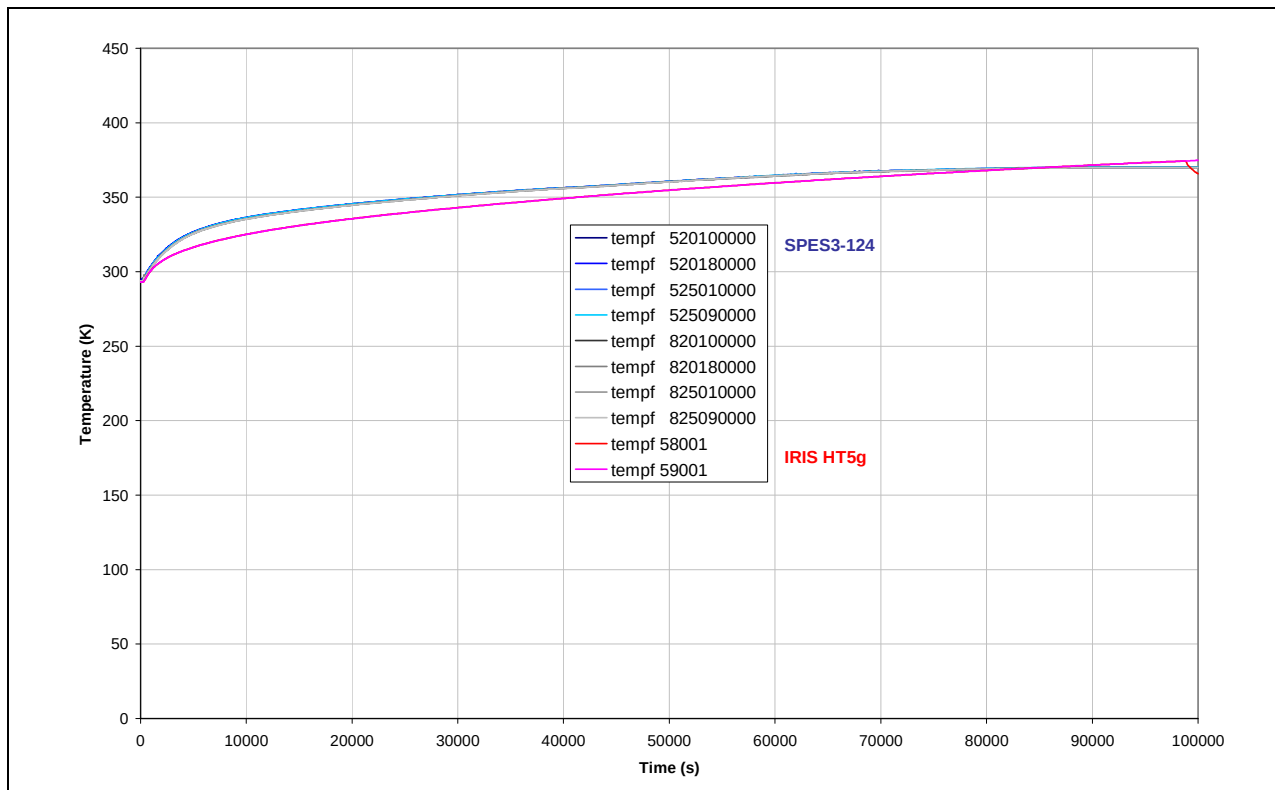




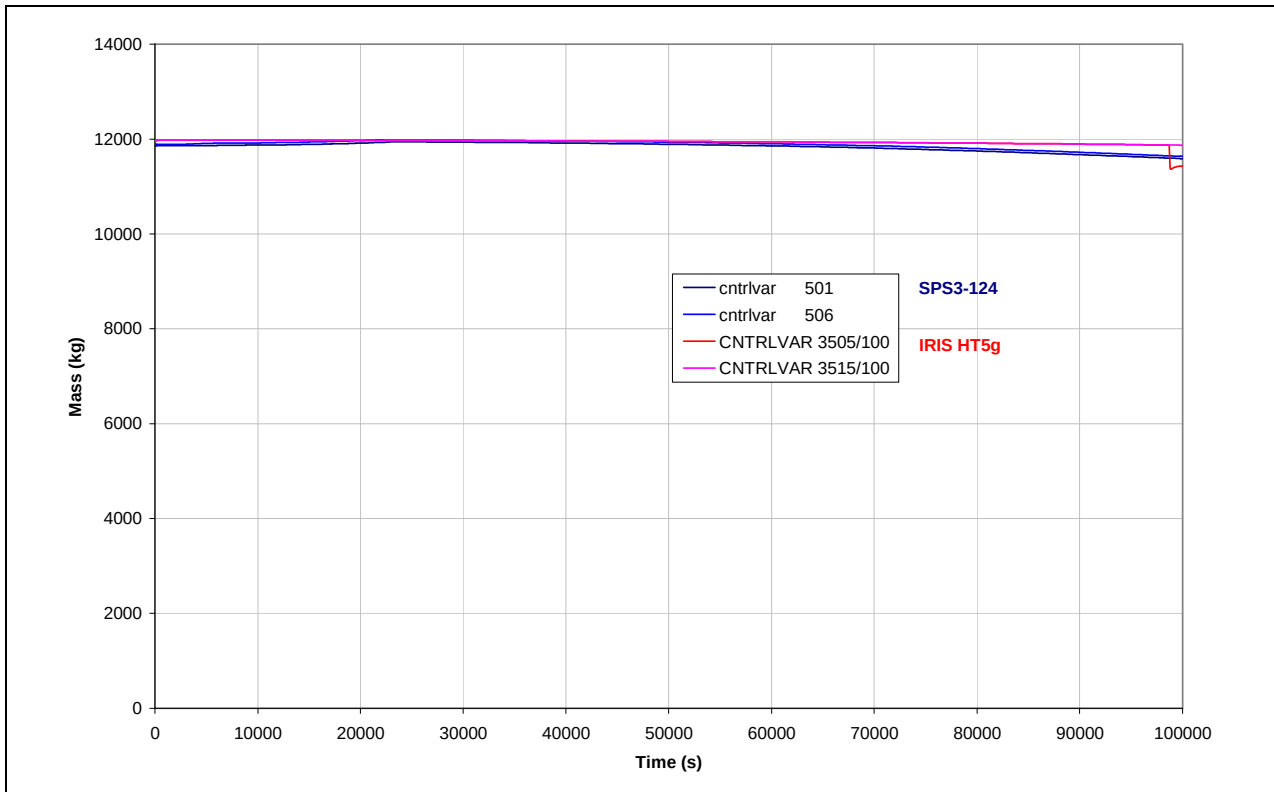
**Fig.5. 69 – SPES3-124 and IRIS HT5g: PSS vent pipe level**



**Fig.5. 70 – SPES3-124 and IRIS HT5g RWST temperature**



**Fig.5. 71 – SPES3-124 and IRIS HT5g RWST mass**



**Fig.5. 72 – SPES3-124 and IRIS HT5g RWST pressure**

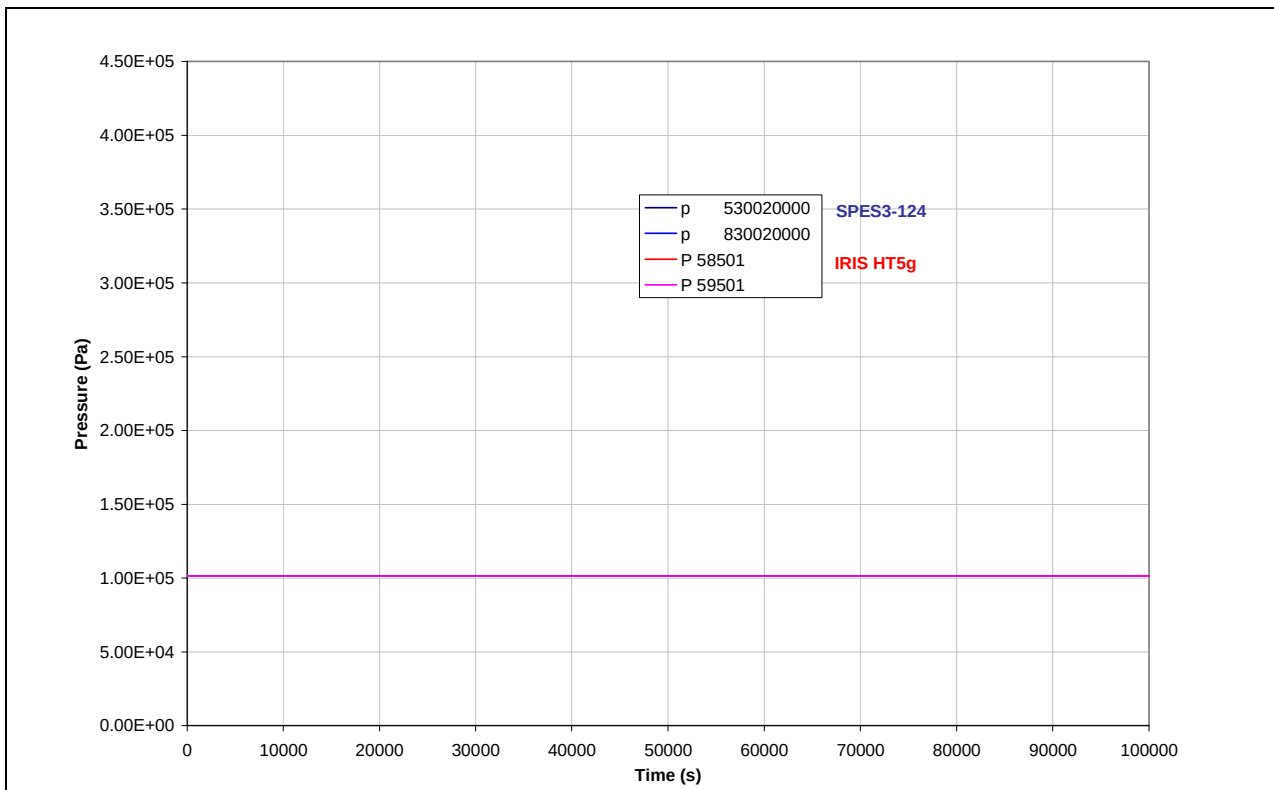


Fig.5. 73 – SPES3-124 and IRIS HT5g RWST power

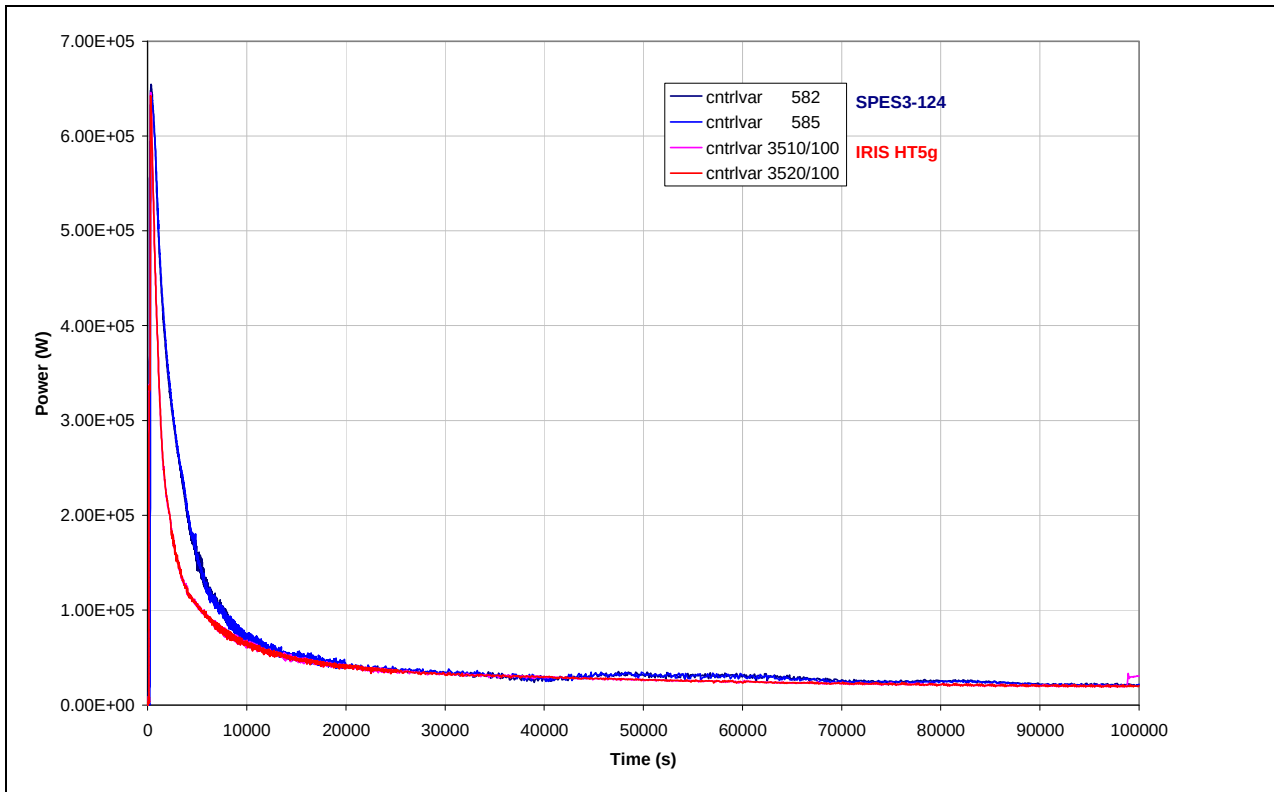
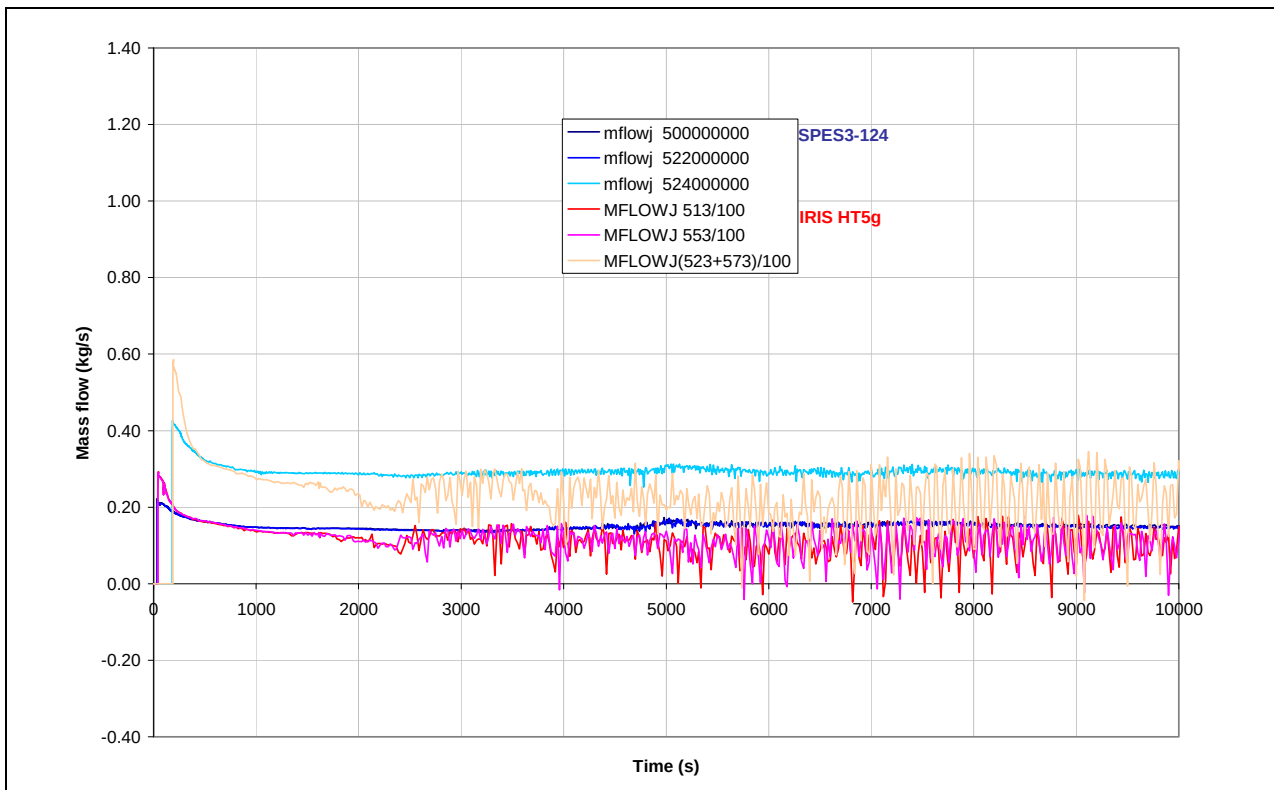
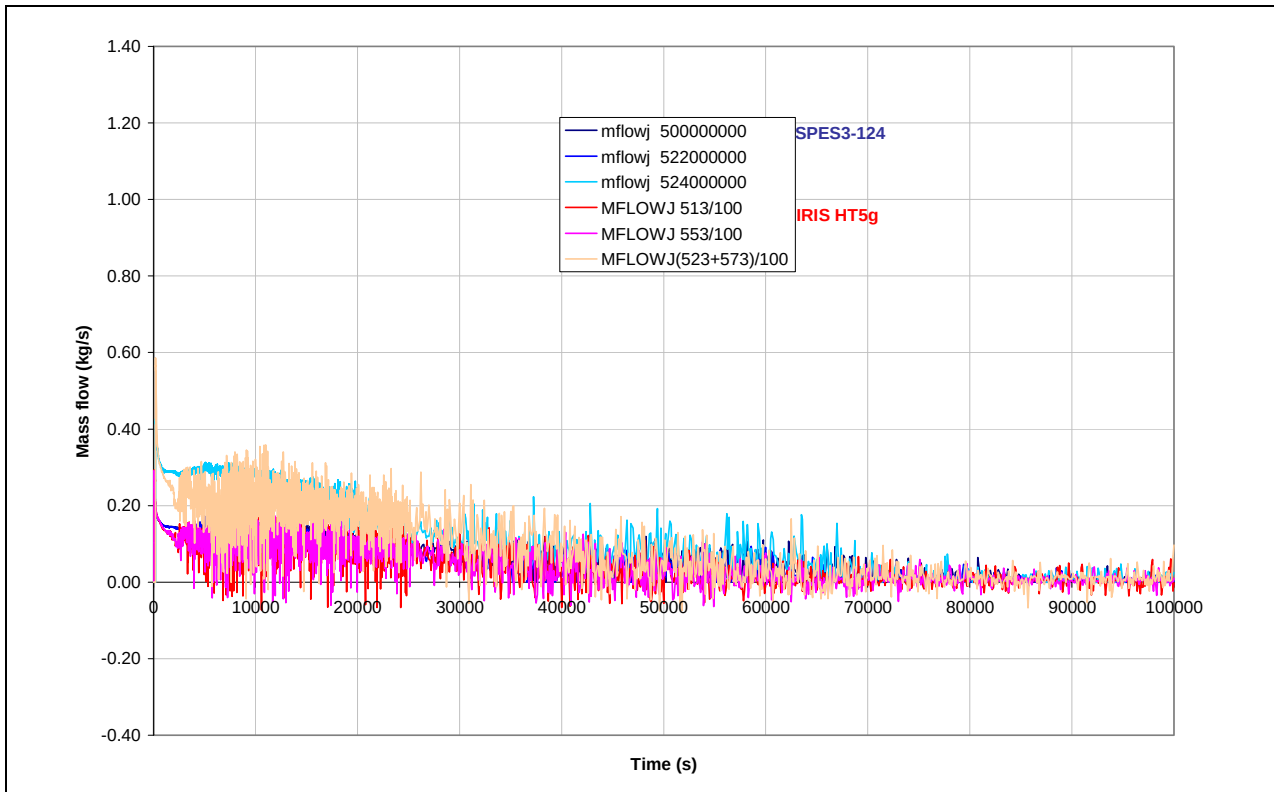


Fig.5. 74 – SPES3-124 and IRIS HT5g EHRs cold leg mass flow (window)



**Fig.5. 75 – SPES3-124 and IRIS HT5g EHRs cold leg mass flow**



## 6. DVI DEG BREAK: SPES3-127 AND IRIS-HT5G (INTERMEDIATE STEP COMPARISON)

SPES3-127 and IRIS HT5g represent an intermediate step of the design and model review process where the comparison between SPES-3 and IRIS is aimed at verifying if the performed design modifications led to an acceptable similarity of the main quantities and phenomena during the transient.

All the steps that have led to the evolution from SPES3-97 to SPES3-127 and from IRIS HT1 to IRIS HT5g are described in detail in Chapter 5 for SPES3 and in [13] for IRIS.

The following paragraphs describe the comparison between SPES3-127 and IRIS HT5g results. The comparison between SPES3 and IRIS variables is performed by scaling IRIS by 1:100 (mass flowrate, power, mass) and directly overlapping the curves.

The main SPES3-127 characteristics are reported below:

*SPES3-127: intermediate case following the design review*

- As in case SPES3-124 (Chapter 5):

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle 10 mm;

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHRS-A and B cold leg calibrated orifice diameter 5 mm;

EHRS-C cold leg calibrated orifice diameter 7 mm;

RC to DVI line calibrated orifice diameter 1 mm;

Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);

Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);

LGMS to DVI line calibrated orifice diameter 3.6 mm;

Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);

Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);

PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom);

DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C.

- New for this case

PSS bottom modeled with three branches, Fig.3. 9.

## 6.1 SPES3-127 and IRIS HT5g

The full power steady conditions, starting point for the transient, are summarized in Tab.6. 1 for SPES3 and IRIS. A general agreement of the steady conditions is observed. The largest differences are at the SG steam superheating (4 °C higher in SPES3) and collapsed level (0.27 m lower in SPES3). The differences in the SG outlet temperature can be justified by small differences in the SG outlet pressure, loop pressure drops, and heat transfer to metal structures.

The list of the main events occurring during the transient with timing and quantities is reported in Tab.6. 2.

### 6.1.1 Transient phases and description

The first 10 s of SPES3 data (-10 s to 0 s) are steady state conditions. The IRIS data start from the break occurrence.

All times of the events are given with respect to the break time assumed as time 0 s.

#### *Break*

The break mass flow peaks and flow trends, RV side (identified as SPLIT), are very similar in SPES3 and IRIS until the ADS intervention (182 s in SPES3 and 176 s in IRIS), Fig.6. 1. Later, during the phase of critical flow, until the containment and primary pressure equalization (2260 s in SPES3 and 1830 s in IRIS), the SPES3 mass flow is greater than IRIS one, driven by the higher SPES3 primary side pressure (higher pressure due to the lower mass lost through the ADS and probably by the larger thermal inertia of RV metal structures), Fig.6. 1, Fig.6. 2, Fig.6. 3. When the break flow is no more critical, some differences are observed, mostly related to the containment-RV differential pressure that drives water in a sense or the opposite, Fig.6. 4, Fig.6. 5, Fig.6. 9, Fig.6. 10.

The break mass flow containment side (identified as DEG) is related to the safety injection of EBT (182 s in SPES3 and 176 s in IRIS) and later of LGMS (2154.7 s in SPES3 and 1624 s in IRIS), Fig.6. 2, Fig.6. 57, Fig.6. 68.

A reverse flow from containment to RV is observed through the SPLIT line, after the RC level has reached the DVI elevation up to the DW, accordingly to phases when the containment pressure is higher than the RV pressure, Fig.6. 2, Fig.6. 3, Fig.6. 26, Fig.6. 27.

#### *Blowdown, RV depressurization, containment pressurization*

The blowdown phase depressurises the RV with mass and energy transfer to the containment.

The SPES3 and IRIS PRZ pressures are shown in Fig.6. 6, Fig.6. 7, Fig.6. 8. The depressurization rate is very similar until the ADS intervention (182 s in SPES3 and 176 s in IRIS), then SPES3 pressure is higher than IRIS due to the lower mass discharged through the ADS and probably for the heat release from RV metal structures (oversized in SPES3), Fig.6. 12. After the containment and RV pressures are coupled (2260 s in SPES3 and 1830 s in IRIS) the SPES3 PRZ pressure stays above, correspondingly to the SPES3 containment one, Fig.6. 9, Fig.6. 10.

While the PRZ depressurises, the containment pressure increases as shown in Fig.6. 6, Fig.6. 7, Fig.6. 4, Fig.6. 5, Fig.6. 9. The SPES3 and IRIS DW pressurization trend is similar even if delayed in SPES3 due to the greater containment heat structures, Fig.6. 4. The pressure increase around 180 s is due to the ADS

Stage-I intervention that discharge mass and energy into the DW, Fig.6. 12. After that, pressure increases up to reach a peak of 0.880 MPa in SPES3 at 2130 s and 0.936 MPa in IRIS at 1405 s. When the RV and DW pressures equalize, the ADS Stage-I mass flow stops and the DW pressure decreases thanks to the LGMS injection into the RV (intact loop) and into the RC (broken loop), Fig.6. 9, Fig.6. 68.

A faster DW depressurization occurs when a reverse flow from the PSS to the RV starts through the vent lines, Fig.6. 14, at 3260 s (PSS-B) – 3400 s (PSS-A) s in SPES3 and 2430 s in IRIS.

### *Steam dumping into PSS*

The containment space (DW and RC) pressurization causes the transfer of a steam-gas mixture from the DW to the PSS through the vent lines (starting at 15 s in SPES3 and 23 s in IRIS) lasting until mass flow exits the ADS-Stage-I, Fig.6. 12, Fig.6. 14. The mass transferred from PSS to the DW is shown in Fig.6. 15. Due to the different shape of the PSS in SPES3 and IRIS, starting with the same initial mass and ending the injection at the same final level (sparger elevation), the total mass injected from PSS to DW results about 97 kg greater in SPES3 than IRIS, Fig.6. 15, Fig.6. 16.

The non-condensable gas quality in the DW is shown in Fig.6. 17 and Fig.6. 18. The way steam sweeps away gas from the DW seems similar in SPES3 and IRIS, even if the air quality remains higher in IRIS containment than SPES3 one. Moreover, the DW air quality increases more in IRIS than SPES3 in the last phase of PSS to the DW injection as if a larger quantity of air were transferred back from the PSS, Fig.6. 18, Fig.6. 14.

Steam is dumped underwater through the PSS sparger and gas (air in SPES3 and N<sub>2</sub> in IRIS) pressurizes the PSS and LGMS gas space, Fig.6. 19, Fig.6. 20, Fig.6. 21, Fig.6. 22. The PSS and LGMS pressure follows the DW pressure trend and, after the containment depressurization for LGMS and PSS injection, it is lower in IRIS than SPES3, Fig.6. 23, Fig.6. 24. Anyway, an important difference between SPES3 and IRIS occurs when the PSS injection into the DW stops. In SPES3, all containment volumes reach the same pressure while in IRIS, the LGMS and PSS remain more pressurised than the DW, Fig.6. 23, Fig.6. 24. In IRIS, the PSS and DW volumes remain separated, from the pressure point of view, as the PSS to DW vent pipes remain partially full of water after the PSS injection to the DW is over, preventing non-condensable gas to flow from PSS to DW and pressure equalization, Fig.6. 25. In SPES3, the PSS to DW vent pipes empty after the injection is over and pressure equalizes. Notwithstanding the modification of vent pipe length, connection elevation to DW and PSS sparger elevation, both in IRIS and SPES3, identified as the cause for this behaviour in SPES3-97 and IRIS HT1 (Chapter 4), the phenomenon is still present in SPES3-127 and IRIS HT5g.

Fig.6. 16 shows the PSS levels. The initial value is different in SPES3 and IRIS due to the different tank shape with the same liquid mass contained. The final value of level, with respect to the PSS bottom, is the same and it corresponds to the PSS sparger elevation. Modifications of the PSS bottom RELAP5 model as reported in Fig.3. 9, avoid the level to decrease below the sparger (non-physical phenomenon evidenced up to SPES3-124, Chapter 5), anyway the sparger junction uncover allows air to pass from PSS to DW as described above.

The PSS water temperature increases, Fig.6. 28, Fig.6. 29, thanks to the mass transfer from the DW, Fig.6. 14. Temperature increases more in SPES3 than IRIS notwithstanding the lower mass transferred from the DW to the PSS, in SPES3, during the first phase of injection, Fig.6. 30. This can be explained considering the higher SPES3 PRZ pressure and the consequently higher energy fluid exiting the RV and entering the DW and PSS, Fig.6. 6.

Both the liquid and gas temperatures are reported in Fig.6. 28, Fig.6. 29. In IRIS, the top gas temperature is generally higher than the liquid one (GOTHIC code results not clearly explainable here), while in the PSS lower part, the gas temperature is closer to liquid one than in SPES3. This can be explained by the initial heat structure preheating in the gas zone of SPES3 PSS that limits the gas temperature decrease.

Temperatures always remain below saturation at the maximum PSS pressure and also when pressure decreases (maximum temperature reached in SPES3 is 119 °C at 0.85 MPa and in IRIS 95 °C at 0.26 MPa). In the long term, the SPES3 PSS temperature decreases more than IRIS one, probably due to the higher heat losses to the environment.

#### *S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation*

The high containment pressure set-point (1.7e5 Pa) is reached at 31.4 s in IRIS and 30 s in SPES3 and it triggers the S-signal.

The S-signal (Safeguard) starts the reactor SCRAM, isolates the three secondary loops and actuates the EHRS-A and B.

Power released to the fluid in the core is shown in Fig.6. 31 and Fig.6. 32 and very similar trends are observed between SPES3 and IRIS.

Power transferred to the steam generators is shown in Fig.6. 33 and Fig.6. 34. The peak of removed power occurs following the EHRS-C intervention with similar values in SPES3 and IRIS (~1.6 MW around 340 s), after that, removed power in SPES3 is higher than in IRIS until about 8500 s to become very similar for the rest of the transient.

The MFIV and MSIV of the secondary loops are contemporarily closed in 5 s both in SPES3 and IRIS. The secondary loop mass flows are shown in Fig.6. 35 and Fig.6. 36. They stop at the secondary loop isolation and re-start at the EHRS actuation. The EHRS-A and B in SPES3 are actuated at the secondary side isolation and a natural circulation flow establishes. The corresponding EHRS-1 and 3 in IRIS are actuated with 10 s delay with respect to the secondary loop isolation, and a short pause in secondary loop flow is observed, Fig.6. 35. The EHRS-C in SPES3 and EHRS-2 and 4 in IRIS are actuated at LM-signal, starting the secondary loop natural circulation after about 150 s from the loop isolation, Fig.6. 35. For a direct comparison of the eight SG mass flow in IRIS and three SGs in SPES3 (loop C consists of two tube rows), the SG mass flow curves have been summed in IRIS. It appears that, at the EHRS actuation, the IRIS mass flow is about 25% higher than SPES3 one, but in about 150 s the IRIS mass flows equalize SPES3.

The SPES3 EHRS-A and B and the EHRS-1 and 3 in IRIS are actuated by opening in 2 s the related isolation valves. The peak flowrate of 0.215 kg/s is reached at 37 s in SPES3 while a peak of 0.285 kg/s is reached in IRIS at 44 s. Between 500 s and 10000 s, a quite steady condition is reached with the SPES3 natural circulation higher and less oscillating than in IRIS, Fig.6. 37 (blue and orange curves). After 10000 s, larger oscillations appear in SPES3 and mass flows decrease getting closer to IRIS ones. After about 70000 s, mass flows are very similar in the two plants, Fig.6. 38.

Power removed by the EHRSs is shown in Fig.6. 39 and Fig.6. 40. The SPES3 EHRS-A and B peaks of removed power occur at 244 s with a value of 348 kW each, while the IRIS EHRS-1 and 3 power peaks of 352 kW occur at 160 s. The average power removed by the SPES3 EHRS-A and B in the long term is around 11.5 kW each, while the IRIS EHRS-1 and 3 is about 10.15 kW each.

The secondary side pressures are shown in Fig.6. 41 and Fig.6. 42. After isolation, pressure increases due to the heat transfer from the primary side that makes water contained in the SG tubes evaporate. The SG tube levels decrease until water stored in EHRS heat exchangers is poured into the loops and power begins to be removed, Fig.6. 43, Fig.6. 44, Fig.6. 33. Similar trends are observed for SPES3 and IRIS, even if SPES3 level is about 1 m below, until 3000 s. Between 3000 s and 10000 s the SPES3 SG tube level decreases down to 2 m below IRIS one, leaving a larger surface available for the heat transfer with the primary side and the consequently larger exchanged power, Fig.6. 43, Fig.6. 34. After 10000 s, the SPES3 SG level slowly increases getting closer to IRIS.

The SG pressure peaks are reached around 65 s in SPES3 and 56 s in IRIS, then pressure decreases after some oscillations lasting until about 200 s, Fig.6. 41. IRIS pressure decreases more than SPES3 one, until about 3000 s, then, the larger power removal by EHRS, 3000 s to 10000 s, Fig.6. 39, corresponding to the



larger SG power, Fig.6. 34, reduces SPES3 SG pressure that stabilizes about 0.03 MPa below IRIS, Fig.6. 42.

#### *Pump coastdown and primary circulation through RI-DC check valves*

The PRZ levels of SPES3 and IRIS are shown in Fig.6. 45. The early phase of level decrease, until the ADS Stage-I intervention (182.2 s in SPES3 and 176 s in IRIS), is due to the loss of mass from the break. In this phase, mass lost from the break, RV side (DVI split) is very similar in IRIS and SPES3, Fig.6. 46. The observed difference in PRZ level can be explained hypothesizing flow instabilities due to steam bubbles at the PRZ surge holes in IRIS, not occurring in SPES3. The level increase after the ADS Stage-I actuation is similar in the two cases until the ADS stop when the containment and RV pressure equalize (1830 s in IRIS and 2260 in SPES3). The liquid fraction at the pump inlet is reported in Fig.6. 47. Due to the loss of mass from the break, the pump uncovers soon. Water sucked at the ADS Stage-I maintains a certain liquid fraction at the pump suction until about 400 s in IRIS, while the SPES3 pump is uncovered soon after the PRZ early emptying. This can be explained considering the different position of the pump in the two plants, inside the RV in IRIS and outer and connected by piping in SPES3, less interested by the water path to the ADS through the PRZ surge holes.

The pump coastdown is triggered by a Low PRZ level signal delayed of 15 s (113.22 s in SPES3 and 145 s in IRIS). Soon after the pump suction is uncovered, the RV natural circulation through the pump interrupts.

The core inlet flow is shown in Fig.6. 48 and Fig.6. 49 and it is similar for IRIS and SPES3. The SPES3 mass flow is lower than IRIS between 1500 s and 9000 s, probably related to the void fraction of fluid at the check valves, but later the values are very similar, even if IRIS shows stronger oscillations.

The pump stop and pressure decreasing in the DC, let the RI-DC check valves open at 131÷133 s in SPES3 and 187 s in IRIS and allow the natural circulation from riser to SG annuli at a lower level in the RV. The RI-DC check valve mass flows are shown in Fig.6. 50 and Fig.6. 51 for each SG (for SG-A in SPES3 it is the sum of mass flows through the check valves 161 and 164, for SG-B of mass flow through the check valves 162 and 165 and for SG-C of mass flow through the check valves 163 and 166; for IRIS, the mass flows are combined for a direct comparison with SPES3). The trend and value of the RI-DC check valve mass flow is strictly related to the core inlet flow, Fig.6. 49.

The fast RV depressurization, rapidly causes flashing of the primary circuit and void begins at the core outlet at 203 s in SPES3 and 189 s in IRIS, Fig.6. 52, Fig.6. 53. The low liquid fraction period in the core lasts until about 7000 s in IRIS and 6000 s in SPES3.

#### *LM-Signal: EHRS-C, ADS Stage-I and EBT actuation*

The LM-Signal (LOCA mitigation) occurs at 182.22 s in SPES3 and 176 s in IRIS when the low PRZ pressure set-point (11.72e6 Pa) is reached, Fig.6. 7.

The LM-signal actuates the EHRS-C in SPES3 and EHRS-2 and 4 in IRIS, opens the ADS stage-I, and opens the EBT actuation valves.

The SPES3 EHRS-C and the IRIS EHRS 2 and 4 are actuated by opening in 2 s the related isolation valves. The peak flow rate of 0.421 kg/s is reached at 188 s in SPES3 while the IRIS peak of 0.585 kg/s is reached at 194 s. After the peak, a quite steady natural circulation flow of about 0.3 kg/s is reached in SPES3 between 700 s and 10000 s, while in IRIS the mass flow decreases until about 2000 s showing later strong oscillations around 0.2 kg/s until about 15000 s, Fig.6. 37, Fig.6. 38. The SPES3 mass flow is higher than IRIS in the long term and less oscillating, Fig.6. 38.

Power removed by SPES3 EHRS-C and IRIS EHRS 2 and 4 is shown in Fig.6. 39 and Fig.6. 40. The SPES3 EHRS-C peak of removed power occurs at 362 s with a value of 687 kW, while the IRIS EHRS 2 and 4

power peak occurs at 325 s with a value of 677 kW. The average power removed by the SPES3 EHRS-C in the long term is 21.9 kW, while that removed by IRIS EHRS 2 and 4 is 20.9 kW.

The Stage-I of the ADS trains are actuated on LM-signal (182.22 s in SPES3 and 176 s in IRIS) both in SPES3 and IRIS. The SPES3 mtrvlv 153 on the Single Train (ST) and 143 on the Double Train (DT) are fully open in 10 s and so do the three IRIS ADS train valves. The ADS Stage-I mass flows are shown in Fig.6. 12 and Fig.6. 13. For a direct comparison between SPES3 and IRIS, two of the IRS trains are condensed in one. SPES3 and IRIS show similar trends. Both IRIS and SPES3 show a two-peak trend flow, with the first SPES3 peak of 1.324 kg/s at 190 s and the second peak of 1.541 kg/s at 275 s and the first IRIS peak of 1.305 kg/s at 188 s and the second peak of 2.010 kg/s at 245 s.

When the ADS intervene, the PRZ is empty in SPES3 and almost empty in IRIS, Fig.6. 45, and the ADS flow peak is due to steam flowing toward the QT. At the ADS intervention, water is sucked upwards and the PRZ level increases. The second ADS mass flow peak is caused by an increasing liquid void fraction at the PRZ top that decreases when the PRZ empties.

The ADS integral flow is shown in Fig.6. 54 and mass exited from the RV through the ADS in IRIS is about 1.3 times that exited from SPES3. This justifies the difference in the RV mass trend observed in the early 1500 to 5000 s, Fig.6. 56. After the RV and containment pressure equalization and inversion (1830 s in IRIS and 2260 s in SPES3), Fig.6. 9, the differential pressure in SPES3 is sufficient to push back water into the RV through the ADS Stage-I pipe between 2500 s and 3650 s, Fig.6. 12. This does not occur in IRIS.

The LM-signal triggers the EBT actuation. Both in SPES3 and IRIS, the EBT actuation valves are fully open in 15 s. The EBT injection mass flows are shown in Fig.6. 57 and Fig.6. 58 and they are similar in SPES3 and IRIS until about 2000 s. The EBT injection into the broken DVI is initially about 14 times larger than injection into the intact DVI, due to the presence of the break. In SPES3, the EBT injection continues until both EBTs are empty, while in IRIS the intact loop EBT interrupts its injection between 2270 s and 4000 s and between 6400 s and 25800 s to completely empty at 28500 s, Fig.6. 60, Fig.6. 61. The trend of injection is related to the RV mass that in IRIS increases more than in SPES3 thanks to the stronger LGMS injection, Fig.6. 56, Fig.6. 68.

Soon after the EBT actuation, a liquid circulation from the RV toward the EBT starts at the EBT to RV connections, Fig.6. 59, then, after such connection is uncovered, steam replaces water contained in the EBT top lines and tanks. The SPES3 broken loop EBT is empty at 481 s while the corresponding IRIS EBT is empty at 620 s. The SPES3 intact loop EBT is empty at 3130 s while IRIS's one at 28500 s, Fig.6. 60, Fig.6. 61.

The EBT actuation is responsible for the mass flow through the break line, containment side, starting at 187 s in SPES3 and at 194 s in IRIS, Fig.6. 1. The EBT injected mass enters the RV through the intact DVI, while a reverse flow occurs through the broken DVI towards the break, Fig.6. 62, Fig.6. 63. Such reverse flow lasts until the RV and containment pressures equalize, Fig.6. 9, Fig.6. 10. After that, the DVI mass flow in SPES3 and IRIS is driven by the differential pressure between RV and containment and by the amount of water in one or the other side of the plant.

### *RV saturation*

The RV mass decreases due to the loss of mass from the break, Fig.6. 56. The fast RV depressurization leads to reach the saturation conditions (core inlet T = core outlet T) at 333 s in SPES3 and 242 s in IRIS. A two-phase mixture occurs in the core, Fig.6. 52, but the natural circulation through the RI-DC check valves allows to remove the decay heat and a temperature difference establishes again between core inlet and outlet when the core is under liquid single-phase, after 6000 s in SPES3 and 7000 s in IRIS. The inlet and outlet core temperatures are shown in Fig.6. 64 and Fig.6. 65. The IRIS core temperatures establish at a higher value than SPES3, correspondingly to the PRZ pressure.

The core heater rod temperatures are shown in Fig.6. 66, Fig.6. 67. Notwithstanding the core liquid void fraction decrease, the rod surface temperatures never overcome the maximum steady state temperature. Corresponding to the fluid temperature, even the heater rod temperatures stabilize at a higher value in IRIS than SPES3.

#### *Low DP RV-Containment signal, LGMS and RC to DVI valve actuation*

The containment pressure peak of 0.880 MPa occurs at 2130 s in SPES3 and of 0.936 MPa at 1405 s in IRIS, Fig.6. 4.

The “Low DP RV-Containment” signal set point of 50 kPa is reached at 2154.7 s in SPES3 and 1624 s in IRIS.

The combination of LM-signal AND Low DP RV-Containment signal actuates the LGMSs and opens the valves on the lines connecting the RC to the DVIs.

The SPES3 and IRIS LGMS isolation valves are fully open in 2 s as well as the RC to DVI line isolation valves.

The LGMS injection is related both to gravity and to the LGMS air space pressurization (through PSS to LGMS balance lines) by non-condensable gas entering the PSS from the DW. The broken loop LGMS injection into the DVI starts at 2154.7 s in SPES3 and 1624 in IRIS, while the intact loop LGMS injection into the DVI starts at 2240 s in SPES3 and 1730 in IRIS. The LGMS injection mass flow is shown in Fig.6. 68. Consequently to the LGMS injection into the broken DVI, a mass flow from the DEG break line restarts around 2200 s and lasts until the LGMS is empty, Fig.6. 2, Fig.6. 3.

Fig.6. 68 shows that a difference exists between the IRIS and SPES3 LGMS injection trend. The SPES3 mass flow is stronger than IRIS in the first phase of injection (~0.14 kg/s in SPES3 and ~0.09 kg/s in IRIS) and then it decreases to about one fourth of its value until the LGMS are empty. In IRIS, the injection starts and then the mass flow decreases gradually until the LGMS are empty, Fig.6. 69. The reason is the different pressurization of LGMS with respect to DVI due to the emptying of the PSS vent pipes in SPES3 and non-emptying of the same pipe in IRIS (see section *Steam dumping into PSS*), Fig.6. 70, Fig.6. 71.

#### *Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV*

The RV and containment pressure equalize at 2260 s in SPES3 and 1830 s in IRIS, Fig.6. 9. After this, the loss of mass through the break, RV side, depends on the periods when the RV pressure is higher than the containment pressure, Fig.6. 2, Fig.6. 3, Fig.6. 9, Fig.6. 10.

After the peak, the containment pressure decreases for steam condensation on the containment wall and for LGMS injection. After the RV and containment pressure are coupled, pressures decrease due to the EHRS heat removal from the primary side, Fig.6. 39. At 2440 s in SPES3 and 1690 s in IRIS, the DW pressure decreases below the PSS pressure, Fig.6. 23. When the differential pressure between PSS and DW is sufficient to overcome the total hydrostatic head of the PSS vent pipes plus extension, a reverse flow starts from the PSS to the DW through the vent lines, lasting between 2430 s and 4100 s in IRIS and 3260 s to 4330 s in SPES3, Fig.6. 14.

The RC level, initially increased for break and ADS mass flow collection, rapidly increases in correspondence of the PSS injection up to the complete fill-up at 4220 s in SPES3 and 21654 s in IRIS (11 m level from bottom in SPES3 and 11.75 m in IRIS), Fig.6. 26.

When the RC level is above the DVI connection (3940 s in SPES3 and 3871 s in IRIS) and the containment pressure overcomes the RV pressure, water enters the RV through the RC to DVI connections, Fig.6. 72, Fig.6. 73. The mass injected from RC to DVI is shown in Fig.6. 74. It is larger in SPES3 than IRIS because in SPES3 the injection occurs soon after the RC to DVI valves are open, instead in IRIS it begins only around

50000 s, Fig.6. 72, when the containment pressure is higher than the RV pressure, Fig.6. 9. Anyway, the total mass injected at the end of the transient is similar in SPES3 and IRIS.

The QT, initially empty, is partially filled-up by the ADS discharge in SPES3, while in IRIS it is completely filled-up, Fig.6. 75. The later SPES3 fill-up, around 10000 s, is related to the rapid increase of the DW level after the RC fill-up, Fig.6. 26, Fig.6. 27.

#### *Low LGMS mass signal: ADS Stage-II actuation*

The intact loop LGMS low mass signal is reached at 15825.33 s in SPES3 (LGMS-A) when mass reaches 198 kg (20% of 1 m<sup>3</sup> water at 48.9 °C) and at 20500 s in IRIS (LGMS-2) when the tank is practically empty. The broken loop signal is reached at 21569 s in SPES3 (LGMS-B) and 20860 s in IRIS (LGMS-1), Fig.6. 69.

The reaching of both LGMS low mass signals actuates the ADS Stage-II valves, fully open in 10 s both in SPES3 and IRIS, to allow steam circulation between RV and DW in the upper part of the plant and enhance condensation on the SG tubes in the long term of the transient, Fig.6. 76, Fig.6. 77. According to the pressure difference between DW and RV, Fig.6. 11, a little mass flow is observed in IRIS, instead SPES3 shows oscillations around zero, as DW and RV pressure are very similar.

The SPES3 RWST-A/B begins to heat-up at 91 s (after the EHRS-A and B actuation at 37 s) while IRIS RWST-1 begins to heat up only at 265 s contemporarily to RWST-2 (after EHRS-2 and 4 actuation at 176 s). The SPES3 RWST-C begins to heat-up at 214 s (after the EHRS-C actuation at 182.22 s). In SPES3, water reaches the maximum temperature of 94 °C around 800 00 s and stabilizes at such value until the end of the transient. In IRIS temperature reaches the saturation at the end of the transient (102 °C), Fig.6. 78.

The RWST mass is shown in Fig.6. 79 and pressure in Fig.6. 80. The trend of mass is different in SPES3 and IRIS RWST, with SPES3 mass decrease larger than IRIS one, notwithstanding SPES3 RWSTs are not in saturation conditions. The reason for this behavior of SPES3 RWST is related to the RWST model connected at the top with a time dependent volume with constant pressure and temperature dry air ( $P = 0.1013$  MPa, 20 °C) and with the same junction area as the RWST area. Very little water oscillations due to local boiling at lower level in the pool (EHRS HX zone) cause air transfer, forth and back, to the top control volume, Fig.6. 81. Oscillations are observed also in IRIS, but with lower amplitude. Air entering the RWST from the top control volume removes heat from the pool (preventing reaching of saturation) and removes mass when water solutes in the dry air. The global mass lost through the RWST upper junction is shown in Fig.6. 82.

Power transferred from the EHRS to RWST is shown in Fig.6. 83 and Fig.6. 84. SPES3 RWST power is higher than IRIS one in the early 10000 s, but they are more similar in the last part of the transient. In the long term, total power transferred to the RWST in IRIS is 41.2 kW while total power in SPES3 is 44.9 kW. So, the lower heat removal in IRIS and the higher core power ( power to fluid 59.9 kW in IRIS, 45.9 kW in SPES3 – difference probably due to heat release from structures) cause the IRIS RV and containment pressurization in the long term and this possibly explains the difference between the plants.

The SPES3 and IRIS containment pressure is still affected by the DW heat structures, larger in SPES3 than IRIS, even if the DW volume and thickness reduction and metal structure preheating reduce the differences with respect to the initial case. Power transfer to the DW structures is present until a thermal equilibrium is reached on the walls, Fig.6. 85, Fig.6. 86, Fig.6. 87, Fig.6. 88. At the peak, the SPES3 power (1.2 MW) is about 11 times the IRIS power (0.112 MW) transferred to the DW structures showing the influence of the SPES3 larger heat transfer surface. This delays the SPES3 pressure rise that anyway is not so far from IRIS one, Fig.6. 4.

Fig.6. 87 and Fig.6. 88 show the SPES3 and IRIS DW wall temperatures at the inner and outer surface. In SPES3, inside temperatures are indicated with label 01 and outside ones with label 13. Moreover, temperatures are taken at various axial levels in the DW (lower 01, intermediate 07, and upper 17). In IRIS, TA is the inside temperature and TB the outside one with heat structure 01 for the lower shell, 02 for the

concrete and 03 for the upper shell. The SPES3 DW is thermally insulated with the environment and the outer surface temperature is almost constant during the transient, while IRIS is not insulated and the inner and outer surface temperatures are very similar. Starting from different heat structure initial temperature (48.9 °C in IRIS and 84°C in SPES3), the IRIS DW temperatures increase up to similar values around 2000 s, then the IRIS DW temperature decrease more rapidly due to heat losses to the environment and to pressure in the containment, Fig.6. 87, Fig.6. 88, Fig.6. 5.

### 6.1.2 Primary to secondary to RWST heat transfer

A general agreement between SPES3-127 and IRIS HT5g sequence of events has come out of the transient analysis, but the different trend of the containment pressure in the long term needs a deeper investigation of phenomena that may cause it.

The heat transfer at the SG and at the EHRS has been investigated with particular attention to the part of the transient after 40000 s.

A sort of “global heat transfer coefficient” ( $h * S$ ) has been estimated for the Primary to Secondary side and for the EHRS to RWST heat transfer according to the following process and compared in SPES3 and IRIS.

#### Primary to Secondary circuit

The primary side saturation temperature has been obtained versus pressurizer pressure

$P (PRZ) \Rightarrow T_{sat} (P PRZ);$

The secondary side saturation temperature has been obtained versus steam generator pressure

$P (SG) \Rightarrow T_{sat} (PSG);$

The temperature difference between primary and secondary side has been obtained as difference of the above saturation temperatures

$DT1 = T (PRZ-SG);$

A global heat transfer coefficient has been obtained by the ratio between the SG total power and the above temperature difference

$SG \text{ tot power} / DT1 = h * S (SG) \quad \text{heat transfer coefficient} * \text{Surface}$

#### EHRS to RWST

The EHRS saturation temperature has been obtained versus EHRS inlet pressure

$P (EHRS) \Rightarrow T_{sat} (P EHRS);$

The RWST temperature is directly available

$T RWST;$

The temperature difference between EHRS and RWST has been obtained as difference of the above temperatures

$DT2 = T (EHRS-RWST);$

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$EHRS \text{ tot power} / DT2 = h * S (EHRS) \quad \text{heat transfer coefficient} * \text{Surface}$



### Primary to RWST (global heat transfer)

The temperature difference between primary and RWST is obtained from the variables described above:

$$DT3 = T (PRZ-RWST)$$

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$$EHRS \text{ tot power} / DT3 = h * S (\text{Global}) \quad \text{heat transfer coefficient} * \text{Surface}$$

Comparing SPES3 (blu curves) and IRIS (red curves) an opposite operation is observed, in particular:

- at SG, in SPES3 there is higher DT and lower  $h*S$  than in IRIS, Fig.6. 89 and Fig.6. 90;
- at EHRS, in SPES3 there is lower DT and higher  $h*S$  than in IRIS, Fig.6. 91 and Fig.6. 92;
- Globally in SPES3 there is a higher DT and the same  $h * S$  as in IRIS, Fig.6. 93 and Fig.6. 94, that indicates a higher removed power in SPES3 than IRIS.

In order to understand the reasons of the opposite heat transfer modes between SPES3 and IRIS, a comparison of the geometry and heat transfer parameters is performed at the SG and EHRS RELAP5 models. Tab.6. 3 and Tab.6. 4 show the differences, in particular:

#### 1) at the SG

- in SPES3 there is no correction on the DTh nor on the FF (DTh is a geometrical parameter used by RELAP5 to calculate the heat transfer coefficient; FF is the Fouling Factor, a multiplying factor to reduce or increase the heat transfer coefficient);
- in IRIS corrections are present on both of them;
- the left coordinate is different due to fouling simulation in IRIS SG tubes with diameter reduction.

#### 2) at the EHRS

- in SPES3 there is a correction only on the FF (calibrated on the PERSEO experimental data by means of the Cathare code);
- in IRIS there is a correction only on the DTh;
- different heat transfer correlations (101-default in SPES3 and 110-vertical bundle without crossflow in IRIS) are used at the right boundary, but for SPES3, the FF have been calibrated with 101 correlation on PERSEO data.

### 6.1.3 Case conclusions

The analysis of the DVI DEG break transient by the comparison of the SPES3-127 and IRIS HT5g cases has shown a general agreement in the sequence of events and occurring phenomena from both the qualitative and quantitative point of view, confirming that all design and model updates described in Chapter 5 have improved the simulation. Anyway a difference in the containment pressure trend is present in the second part of the transient, when the SPES3 decreases and IRIS increases due to an unbalance between core power and power rejected to the RWST.

The different RWST water temperature trend, differences in the heat transfer mode at the SG and EHRS, differences on some RELAP5 model geometric and heat transfer parameters at SGs and EHRSs are identified as the more likely causes of the different containment pressure trend between SPES3-127 and IRIS HT5g.

The investigation of such items is described in the next chapters.

**Tab.6. 1 – SPES3-127 and IRIS HT5g steady state conditions**

| <b>SPES3-127</b>         | <b>Primary/Core</b>             | <b>SG-A</b>       | <b>SG-B</b>       | <b>SG-C</b>       | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWSTAB</b> | <b>RWSTC</b> |
|--------------------------|---------------------------------|-------------------|-------------------|-------------------|---------------|-----------|-----------|---------------|-----------|----------------|---------------|--------------|
| Pressure (MPa)           | 15.5 (PRZ)<br>0.104 (pump head) | 5.83 (out)        | 5.83 (out)        | 5.88 (out)        | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013        | 0.1013       |
| Tin (°C)                 | 292.1                           | 223.9             | 223.9             | 223.9             | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20            | 20           |
| Tout (°C)                | 330                             | 322.3             | 320.5             | 320.1             |               |           |           |               |           |                |               |              |
| DT (°C)                  | 37.9                            | 99                | 96.6              | 96.2              |               |           |           |               |           |                |               |              |
| Superheating (°C)        |                                 | 48.6 (Tsat 273.7) | 46.8 (Tsat 273.7) | 45.9 (Tsat 274.2) |               |           |           |               |           |                |               |              |
| Mass flow (kg/s)         | 45.58<br>(2.14 in by-pass)      | 1.25              | 1.25              | 2.5               |               |           |           |               |           |                |               |              |
| Power (MW)               | 10                              | 2.5               | 2.5               | 5                 |               |           |           |               |           |                |               |              |
| Level (m)<br>-collapsed- | 1.94 (PRZ)                      | 1.58              | 1.78              | 1.81              | 3.14 full     | empty     | empty     | 3.80          | empty     | 2.26           | 6.97          | 6.97         |
| Mass (kg)                | 3290 (RV)                       |                   |                   |                   | 127           |           |           | 1480          |           | 884            | 11888         | 11888        |

| <b>IRIS HT5g</b>         | <b>Primary/Core</b>             | <b>SG 1</b>        | <b>SG 2</b>        | <b>SG 3</b>        | <b>SG 4</b>        | <b>SG 5</b>        | <b>SG 6</b>        | <b>SG 7</b>        | <b>SG 8</b>        | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWST1</b> | <b>RWST2</b> |
|--------------------------|---------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|---------------|-----------|-----------|---------------|-----------|----------------|--------------|--------------|
| Pressure (MPa)           | 15.5 (PRZ)<br>0.128 (pump head) | 5.81 (out)         | 5.79 (out)         | 5.79 (out)         | 5.78 (out)         | 5.78 (out)         | 5.79 (out)         | 5.79 (out)         | 5.81 (out)         | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013       | 0.1013       |
| Tin (°C)                 | 292                             | 223.9              | 223.9              | 223.9              | 223.9              | 223.9              | 223.9              | 223.9              | 223.9              | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20           | 20           |
| Tout (°C)                | 330                             | 318.18             | 316.19             | 318.39             | 316.52             | 315.49             | 318.47             | 316.19             | 318.18             |               |           |           |               |           |                |              |              |
| DT (°C)                  | 38                              | 94.28              | 92.29              | 94.49              | 92.62              | 91.59              | 94.57              | 92.29              | 94.28              |               |           |           |               |           |                |              |              |
| Superheating (°C)        |                                 | 44.68 (Tsat 273.5) | 42.99 (Tsat 273.2) | 45.19 (Tsat 273.2) | 43.42 (Tsat 273.1) | 42.39 (Tsat 273.1) | 45.37 (Tsat 273.2) | 43.09 (Tsat 273.2) | 44.68 (Tsat 273.5) |               |           |           |               |           |                |              |              |
| Mass flow (kg/s)         | 45.08<br>(2.13 in by-pass)      | 0.628              | 0.628              | 0.628              | 0.628              | 0.628              | 0.628              | 0.628              | 0.628              |               |           |           |               |           |                |              |              |
| Power (MW)               | 10                              | 1.24               | 1.26               | 1.24               | 1.26               | 1.26               | 1.24               | 1.26               | 1.24               |               |           |           |               |           |                |              |              |
| Level (m)<br>-collapsed- | 2.02 (PRZ)                      | 2.00               | 2.05               | 1.99               | 2.04               | 2.04               | 1.99               | 2.05               | 2.00               | 3.14 full     | empty     | empty     | 3.00          | empty     | 2.668          | 9.125        | 9.125        |
| Mass (kg)                | 3240 (RV)                       |                    |                    |                    |                    |                    |                    |                    |                    | 127           |           |           | 1483          |           | 989            | 11966        | 11966        |

Tab.6. 2 – SPES3-127 and IRIS HT5g list of the main events

| DVI-B DEG break 2 inch equivalent                                                        |                                                         | SPES3-127      |                                        |                                                      | IRIS-HT5g |                          |                                                                |
|------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------|----------------------------------------|------------------------------------------------------|-----------|--------------------------|----------------------------------------------------------------|
| N.                                                                                       | Phases and events                                       | Time (s)       | Quantity                               | Notes                                                | Time (s)  | Quantity                 | Notes                                                          |
| <b>Break</b>                                                                             |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 1                                                                                        | Break initiation                                        | 0              |                                        | break valves stroke 2 s                              | 0         |                          | Instantaneous stroke 0.02 s delay                              |
| 2                                                                                        | Break flow peak (Containment side)                      | 1              | 0.688 kg/s                             | Break flow = 0 kg/s at 11 s                          | 0.03      | 0.50 kg/s                | Break flow = 0 kg/s at 1.1 s                                   |
| 3                                                                                        | Break flow peak (RV side)                               | 2              | 1.33 kg/s                              |                                                      | 0.1       | 1.35 kg/s                |                                                                |
| <b>Blowdown, RV depressurization, containment pressurization. Steam dumping into PSS</b> |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 4                                                                                        | Steam-air mixture begins to flow from DW to PSS         | 15             |                                        |                                                      | 23        |                          | 0 to 10 s water empties the vent pipe and moves into the PSS   |
| <b>S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation</b>         |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 5                                                                                        | High Containment pressure signal                        | 31.39          | 1.7e5 Pa                               | S-signal. Set-point for safety analyses              | 30        | 1.7e5 Pa                 | S-signal. Set-point for safety analyses                        |
| 6                                                                                        | SCRAM begins                                            | 31.39          |                                        |                                                      | 30        |                          |                                                                |
| 7                                                                                        | MFIV-A,B,C closure start                                | 31.39          |                                        | MFIV-A,B,C stroke 5 s                                | 30        |                          | MFIV-1,2,3,4 stroke 5 s                                        |
| 8                                                                                        | MSIV-A-B-C closure start                                | 31.39          |                                        | MSIV-A,B,C stroke 5 s.                               | 30        |                          | MSIV-1,2,3,4 stroke 5 s.                                       |
| 9                                                                                        | EHRS-A and B opening start (EHRS 1 and 3 in IRIS)       | 31.39          |                                        | EHRS-A,B IV stroke 2 s.                              | 40        |                          | EHRS-1,3 IV stroke 2 s. S-signal + 10 s delay                  |
| 10                                                                                       | EHRS-A and B peak mass flow                             | 37             | 0.215 kg/s                             |                                                      | 44        | 0.285 kg/s               |                                                                |
| 11                                                                                       | High SG pressure signal                                 | 45.59          | 9e6 Pa                                 |                                                      | 43        | 9e6 Pa                   |                                                                |
| 12                                                                                       | SG-A high pressure reached                              | 45.59          |                                        |                                                      | 43        |                          |                                                                |
| 13                                                                                       | SG-B high pressure reached                              | 46.36          |                                        |                                                      | 43        |                          |                                                                |
| 14                                                                                       | SG-C high pressure reached                              | 46.55          |                                        |                                                      | 43        |                          |                                                                |
| 15                                                                                       | RWST-A/B begins to heat-up                              | 91             |                                        |                                                      | 265       |                          | Same time as RWST-2.                                           |
| 16                                                                                       | EHRS-A power peak                                       | 244            | 348 kW                                 |                                                      | 160       | 352 kW                   | EHRS-1                                                         |
| 17                                                                                       | EHRS-B power peak                                       | 244            | 348 kW                                 |                                                      | 160       | 354 kW                   | EHRS-3                                                         |
| <b>Pump coastdown and primary circulation through RI-DC check valves</b>                 |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 18                                                                                       | Low PRZ water level signal                              | 98.22          | 1.189 m                                |                                                      | 130       | 1.189 m                  |                                                                |
| 19                                                                                       | RCP coastdown starts                                    | 113.22         |                                        | Low PRZ level signal + 15 s delay                    | 145       |                          | Low PRZ level signal + 15 s delay                              |
| 20                                                                                       | Secondary loop pressure peak                            | 64<br>65<br>70 | 105e5 Pa A<br>108e5 Pa B<br>112e5 Pa C |                                                      | 56        | 111.0e5 Pa<br>110.0e5 Pa | SG-1 to 4<br>SG-5 to 8                                         |
| 21                                                                                       | Natural circulation begins through shroud valves        | 131, 133       |                                        | SG-A,B 131 s, SG-C 133 s                             | 187       |                          | SG-1+2, 5+6+7+8 187 s, SG-3+4 187 s                            |
| 22                                                                                       | Flashing begins at core outlet                          | 203            | voidf 110 (core)                       | <1                                                   | 189       | voidf 110 (core)         | <1                                                             |
| <b>LM-Signal: EHRS-C, ADS Stage-I and EBT actuation. RV saturation</b>                   |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 23                                                                                       | Low PRZ pressure signal                                 | 182.22         | 11.72e6 Pa                             | LM-Signal (High P cont + Low P PRZ)                  | 176       | 11.72e6 Pa               | LM-Signal (High P cont + Low P PRZ)                            |
| 24                                                                                       | EHRS-C opening start (EHRS 2 and 4 in IRIS)             | 182.22         |                                        | EHRS-C IV stroke 2 s.                                | 176       |                          | EHRS-2+4 IV stroke 2 s.                                        |
| 25                                                                                       | EHRS-C peak mass flow                                   | 188            | 0.421 kg/s                             |                                                      | 194       | 0.585 kg/s               | EHRS-2+4                                                       |
| 26                                                                                       | RWST-C begins to heat-up                                | 214            |                                        |                                                      | 265       |                          | Same time as RWST-1                                            |
| 27                                                                                       | EHRS-C power peak                                       | 362            | 687 kW                                 |                                                      | 325       | 677 kW                   |                                                                |
| 28                                                                                       | ADS Stage I start opening (3 trains)                    | 182.22         |                                        | ADS valve stroke 10 s                                | 176       |                          | ADS valve stroke 10 s                                          |
| 29                                                                                       | ADS Stage I first peak flow (3 trains)                  | 190            | 1.324 kg/s                             | ST 0.454 kg/s; DT 0.87 kg/s                          | 188       | 1.305 kg/s               | ST (1) 0.433 kg/s; DT (2+3) 0.872 kg/s                         |
| 30                                                                                       | ADS Stage I second peak flow (3 trains)                 | 275            | 1.541 kg/s                             | ST 0.501 kg/s; DT 1.04 kg/s. Due to liquid fraction. | 245       | 2.010 kg/s               | ST (1)0.678 kg/s; DT (2+3) 1.332 kg/s. Due to liquid fraction. |
| 31                                                                                       | EBT-A and B valve opening start                         | 180.22         |                                        | EBT valve stroke 15 s                                | 176       |                          | EBT valve stroke 15 s                                          |
| 32                                                                                       | Break flow peak (Containment side)                      | 201            | 0.703 kg/s                             | Due to EBT intervention                              | 208       | 0.636 kg/s               | Due to EBT intervention                                        |
| 33                                                                                       | EBT-RV connections uncovered                            | 220            |                                        |                                                      | 385       |                          |                                                                |
| 32                                                                                       | Natural circulation interrupted at SGs top              | 249            |                                        | Pump inlet uncovered (voidf 176-01 ~0)               | 285       |                          | Mass flow = 0 at SG top (mflowj 211-25 ~0)                     |
| 36                                                                                       | Core in saturation conditions                           | 333            |                                        |                                                      | 242       |                          |                                                                |
| 37                                                                                       | EBT-B empty (broken loop)                               | 481            |                                        | 481 s almost empty (620 s completely empty)          | 620       |                          |                                                                |
| <b>Low DP RV-Containment signal, LGMS and RC to DVI valve actuation</b>                  |                                                         |                |                                        |                                                      |           |                          |                                                                |
| 38                                                                                       | Containment pressure peak                               | 2130           | 8.80e5 Pa                              |                                                      | 1405      | 9.36e5 Pa                |                                                                |
| 39                                                                                       | Low DP RV-Containment                                   | 2154.7         | 50e3 Pa                                |                                                      | 1624      | 50e3 Pa                  |                                                                |
| 40                                                                                       | LGMSA/B valve opening start                             | 2154.7         |                                        | LM + low DP RV-cont . LGMS valve stroke 2 s.         | 1624      |                          | LM + low DP RV-cont . LGMS valve stroke 2 s.                   |
| 41                                                                                       | RC to DVI line valve opening                            | 2154.7         |                                        | RC to DVI valve stroke 2 s.                          | 1624      |                          | RC to DVI valve stroke 2 s.                                    |
| 42                                                                                       | LGMS-B starts to inject into RC through DVI broken loop | 2154.7         |                                        |                                                      | 1624      |                          | LGMS-1 broken loop                                             |
| 43                                                                                       | LGMS-A starts to inject into RV through DVI intact loop | 2240           |                                        |                                                      | 1730      |                          | LGMS-2 intact loop                                             |

....continues



....continued

|                                                                                                                         | DVI-B break 2 inch equivalent DEG               | SPES3-127   |                      |                                                         | IRIS-HT5g |           |                                                                                    |
|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|-------------|----------------------|---------------------------------------------------------|-----------|-----------|------------------------------------------------------------------------------------|
| N.                                                                                                                      | Phases and events                               | Time (s)    | Quantity             | Notes                                                   | Time (s)  | Quantity  | Notes                                                                              |
| <b>Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV</b> |                                                 |             |                      |                                                         |           |           |                                                                                    |
| 44                                                                                                                      | Containment and RV pressure equalization        | 2260        |                      |                                                         | 1830      |           |                                                                                    |
| 45                                                                                                                      | Mixture starts to flow from RC to DVI-A         | 2270        |                      |                                                         | -         |           | Negligible until 49116 s.                                                          |
| 46                                                                                                                      | DW pressure lower than PSS pressure             | 2440        |                      |                                                         | 1690      |           |                                                                                    |
| 47                                                                                                                      | EBT-A empty (intact loop)                       | 3130        |                      |                                                         | 28500     |           |                                                                                    |
| 48                                                                                                                      | Water starts to flow from PSS to DW             | 3260 - 3400 |                      | 3260 PSS A, 3400 B                                      | 2430      |           |                                                                                    |
| 49                                                                                                                      | Steam and gas mixture flows again from RV to QT | 3640        |                      | 3640 to 4260 s<br>(RV P > DW P)                         | 3190      |           | 3190 to 4320 s<br>(RV P > DW P)                                                    |
| 50                                                                                                                      | RC level at DVI elevation                       | 3940        |                      |                                                         | 3871      |           |                                                                                    |
| 51                                                                                                                      | RC full of water                                | 4220        |                      |                                                         | 21654     |           |                                                                                    |
| 52                                                                                                                      | QT fill-up starts from DW connection            | 10610       |                      |                                                         | -         |           | QT full at 2810 s for ADS Stage-I intervention                                     |
| <b>Low LGMS mass signal: ADS Stage-II actuation</b>                                                                     |                                                 |             |                      |                                                         |           |           |                                                                                    |
| 53                                                                                                                      | Low LGMS mass                                   | 15825.33    | 20% mass<br>(198 kg) | LGMS A (intact loop)                                    | 20500     | (10.7 kg) | LGMS-2 (intact loop)                                                               |
| 54                                                                                                                      |                                                 | 21569.43    | 20% mass<br>(198 kg) | LGMS B (broken loop)                                    | 20860     | (10.7 kg) | LGMS-1 (broken loop)                                                               |
| 55                                                                                                                      | ADS stage-II start opening                      | 21569.43    |                      | ADS stage II valve stroke 10 s.                         | 20860     |           | ADS stage II valve stroke 10 s.                                                    |
| 56                                                                                                                      | LGMS-A empty (intact loop)                      | 30990       |                      |                                                         | 21100     |           | LGMS-2 (intact loop) 10 kg residual mass 21000 to 34100 s. 37500 completely empty. |
| 56                                                                                                                      | LGMS-B empty (broken loop)                      | 40000       |                      | 18 kg at 40000 s. 10kg residual mass 50000 to 100000 s. | 22300     |           | LGMS-1 (broken loop).                                                              |
| 57                                                                                                                      | Flow from RC to RV (intact loop) start          | 28815       |                      |                                                         | 49116     |           |                                                                                    |
| <b>Long Term conditions</b>                                                                                             |                                                 |             |                      |                                                         |           |           |                                                                                    |
|                                                                                                                         | RWST-A/B power                                  | 70000       | 25.3                 | Aver. 70000 to 95000 s                                  | 70000     | 21.2      | Aver. 70000 to 95000 s                                                             |
|                                                                                                                         | RWST-A/B power                                  | 70000       | 24.2                 | Aver. 70000 to 95000 s                                  | 70000     | 21.3      | Aver. 70000 to 95000 s                                                             |
|                                                                                                                         | Core power                                      | 70000       | 51.4                 | Aver. 70000 to 95000 s                                  | 70000     | 55.5      | Aver. 70000 to 95000 s                                                             |
| 58                                                                                                                      | RWST-A/B temperature                            | 100000      | 94 °C                | 1e5 Pa pressure                                         | 100000    | 101.5 °C  | 1e5 Pa pressure RWST-1                                                             |
| 59                                                                                                                      | RWST-C temperature                              | 100000      | 94 °C                | 1e5 Pa pressure                                         | 100000    | 101.5 °C  | 1e5 Pa pressure RWST-2                                                             |
| 60                                                                                                                      | Core power                                      | 100000      | 45.9 kW              | Aver. 90000 to 95000 s                                  | 100000    | 53.9 kW   | Aver. 90000 to 95000 s                                                             |
| 61                                                                                                                      | EHRS-A power                                    | 100000      | 11.1 kW              | Aver. 90000 to 95000 s                                  | 100000    | 9.87 kW   | Aver. 90000 to 95000 s                                                             |
| 62                                                                                                                      | EHRS-B power                                    | 100000      | 11.9 kW              | Aver. 90000 to 95000 s                                  | 100000    | 10.4 kW   | Aver. 90000 to 95000 s                                                             |
| 63                                                                                                                      | EHRS-C power                                    | 100000      | 21.9 kW              | Aver. 90000 to 95000 s                                  | 100000    | 20.9 kW   | Aver. 90000 to 95000 s                                                             |

**Tab.6. 3 – SPES3-127 and IRIS HT5g SG RELAP5 model geometrical and heat transfer parameters**

## Steam Generator

## Left geometry

| *     | crdno    | Naxial | Nradialmeshp | Geomtype | StState | Leftcoord |
|-------|----------|--------|--------------|----------|---------|-----------|
| SPES3 | 12711000 | 48     | 6            | 2        | 1       | 0.007042  |
| IRIS  | 12711000 | 50     | 6            | 2        | 1       | 0.006542  |

## Right geometry

| *     | crdno    | Nointervals | Rightcoord |
|-------|----------|-------------|------------|
| SPES3 | 12711101 | 5           | 0.00873    |
| IRIS  | 12711101 | 1           | 0.007042   |
| IRIS  | 12711102 | 4           | 0.00873    |

## \* left boundary conditions

| *     | crdno    | Boundvol  | Incr  | BCtype | SACode | SAfactor[m] | Heatstr |
|-------|----------|-----------|-------|--------|--------|-------------|---------|
| SPES3 | 12711501 | 271010000 | 10000 | 1      | 1      |             |         |
| IRIS  | 12711501 | 271010000 | 10000 | 1      | 1      |             |         |

## \* right boundary conditions

| *     | crdno    | Boundvol  | Incr | BCtype | SACode | SAfactor[m] | Heatstr |
|-------|----------|-----------|------|--------|--------|-------------|---------|
| SPES3 | 12711601 | 211010000 | 0    | 134    | 1      |             |         |
| IRIS  | 12711601 | 211010000 | 0    | 134    | 1      |             |         |

## \* additional left boundary conditions

| *     | crdno    | Dth      | Hlf | Hlr | gslf | gslr | gKF | gKR | boilf | natcl   | PvsD | FF  | Hstr |
|-------|----------|----------|-----|-----|------|------|-----|-----|-------|---------|------|-----|------|
| SPES3 | 12711801 | 0.       | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 8.2     | 1.1  | 1.  | 48   |
| IRIS  | 12711801 | 0.014084 | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 0.01323 | 1.1  | 1.1 | 50   |

## \* additional right boundary conditions

| *     | crdno    | Dth    | Hlf | Hlr | gslf | gslr | gKF | gKR | boilf | natcl | PvsD  | FF | Hstr |
|-------|----------|--------|-----|-----|------|------|-----|-----|-------|-------|-------|----|------|
| SPES3 | 12711901 | 0.0    | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 8.2   | 1.317 | 1. | 48   |
| IRIS  | 12711901 | 0.0310 | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 7.9   | 1.317 | 1. | 50   |

**Tab.6. 4 – SPES3-127 and IRIS HT5g EHRS RELAP5 model geometrical and heat transfer parameters**

# EHRS

## Left geometry

| *     | crdno    | Naxial | Nradialmeshp | Geomtype | StState | Leftboundary |
|-------|----------|--------|--------------|----------|---------|--------------|
| SPES3 | 15581000 | 18     | 6            | 2        | 1       | 0.022352     |
| IRIS  | 15071000 | 10     | 5            | 2        | 1       | 0.022352     |

## Right geometry

| *     | crdno    | Nointervals | Rightcoord |
|-------|----------|-------------|------------|
| SPES3 | 15581101 | 5           | 0.02540    |
| IRIS  | 15071101 | 4           | 0.02540    |

## \* left boundary conditions

| *     | crdno    | Boundvol  | Incr  | BCtype | SACode | SAfactor[m] | Heatstr |
|-------|----------|-----------|-------|--------|--------|-------------|---------|
| SPES3 | 15581501 | 558010000 | 10000 | 101    | 1      |             |         |
| IRIS  | 15071501 | 507010000 | 10000 | 1      | 0      |             |         |

## \* right boundary conditions

| *     | crdno    | Boundvol  | Incr   | BCtype | SACode | SAfactor[m] | Heatstr |
|-------|----------|-----------|--------|--------|--------|-------------|---------|
| SPES3 | 15581601 | 520180000 | -10000 | 101    | 1      |             |         |
| IRIS  | 15071601 | 581110000 | -10000 | 110    | 0      |             |         |

## \* additional left boundary conditions

| *     | crdno    | Dth     | Hlf | Hlr | gslf | gslr | gKF | gKR | boilf | natcl | PvsD | FF    | Hstr |
|-------|----------|---------|-----|-----|------|------|-----|-----|-------|-------|------|-------|------|
| SPES3 | 15581801 | 0.0     | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 1.8   | 1.1  | 2.725 | 18   |
| IRIS  | 15071801 | 0.00028 | 0.9 | 0.9 | 0.   | 0.   | 0.  | 0.  | 1.    | 0.1   | 1.0  | 1.0   | 10   |

## \* additional right boundary conditions

| *     | crdno    | Dth     | Hlf | Hlr | gslf | gslr | gKF | gKR | boilf | natcl | PvsD | FF      | Hstr |
|-------|----------|---------|-----|-----|------|------|-----|-----|-------|-------|------|---------|------|
| SPES3 | 15581901 | 0.0     | 10. | 10. | 0.   | 0.   | 0.  | 0.  | 1.    | 1.8   | 1.1  | 3.54284 | 18   |
| IRIS  | 15071901 | 0.19300 | 0.9 | 0.9 | 0.   | 0.   | 0.  | 0.  | 1.    | 1.75  | 2.1  | 1.0     | 10   |

Fig.6. 1 – SPES3-127 and IRIS HT5g DVI break flow (window)

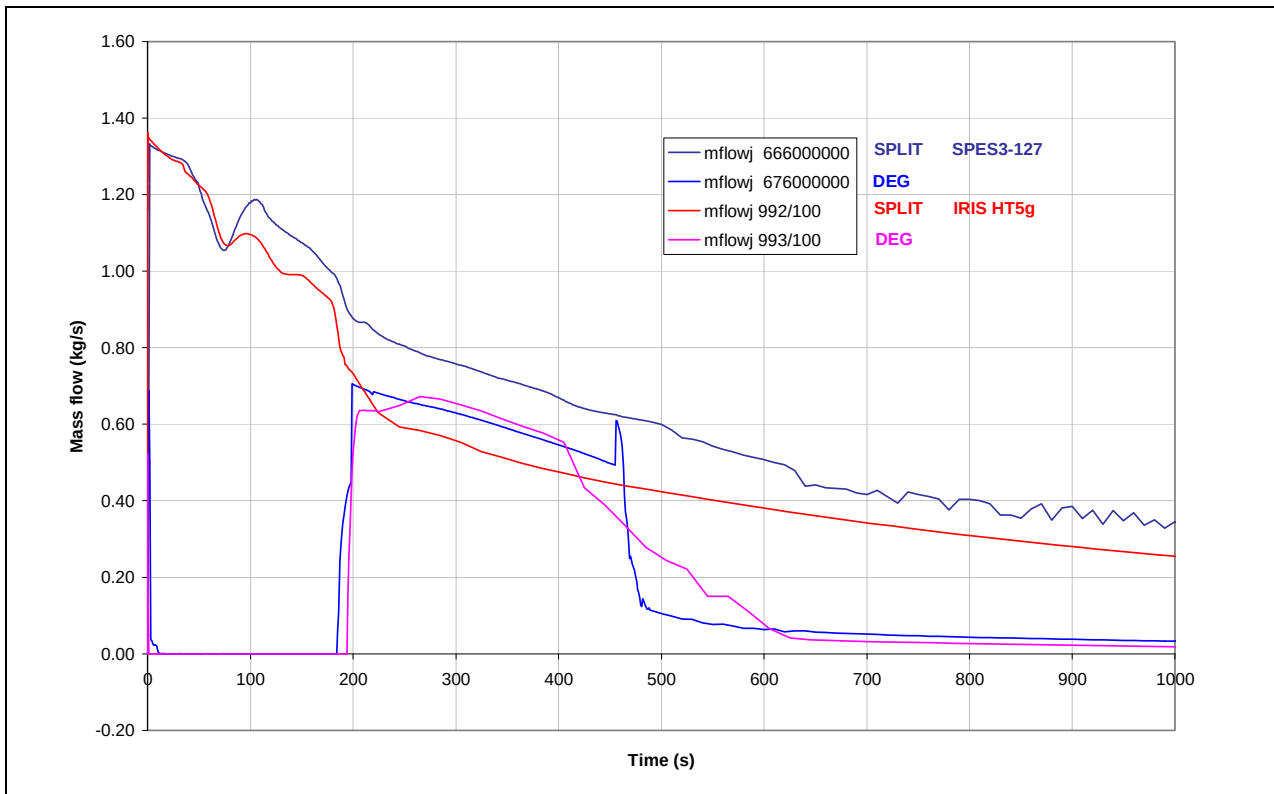
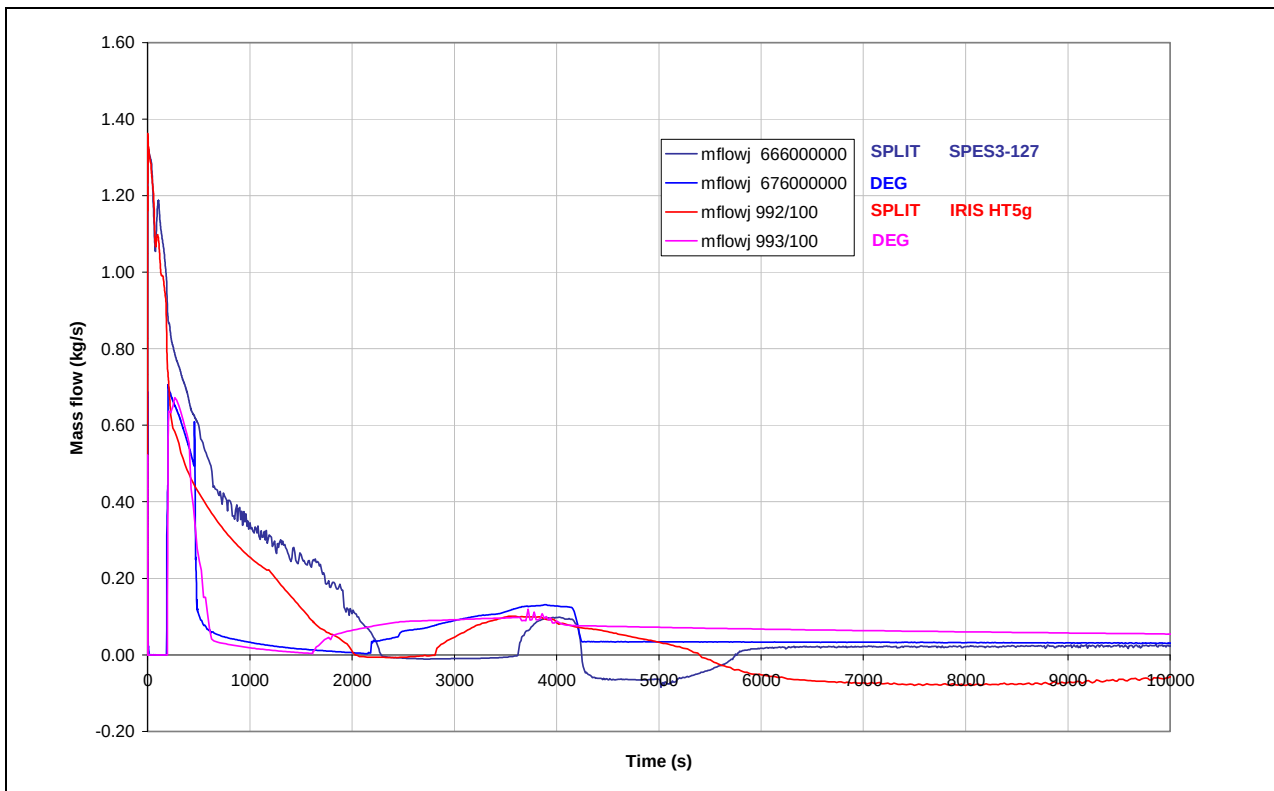
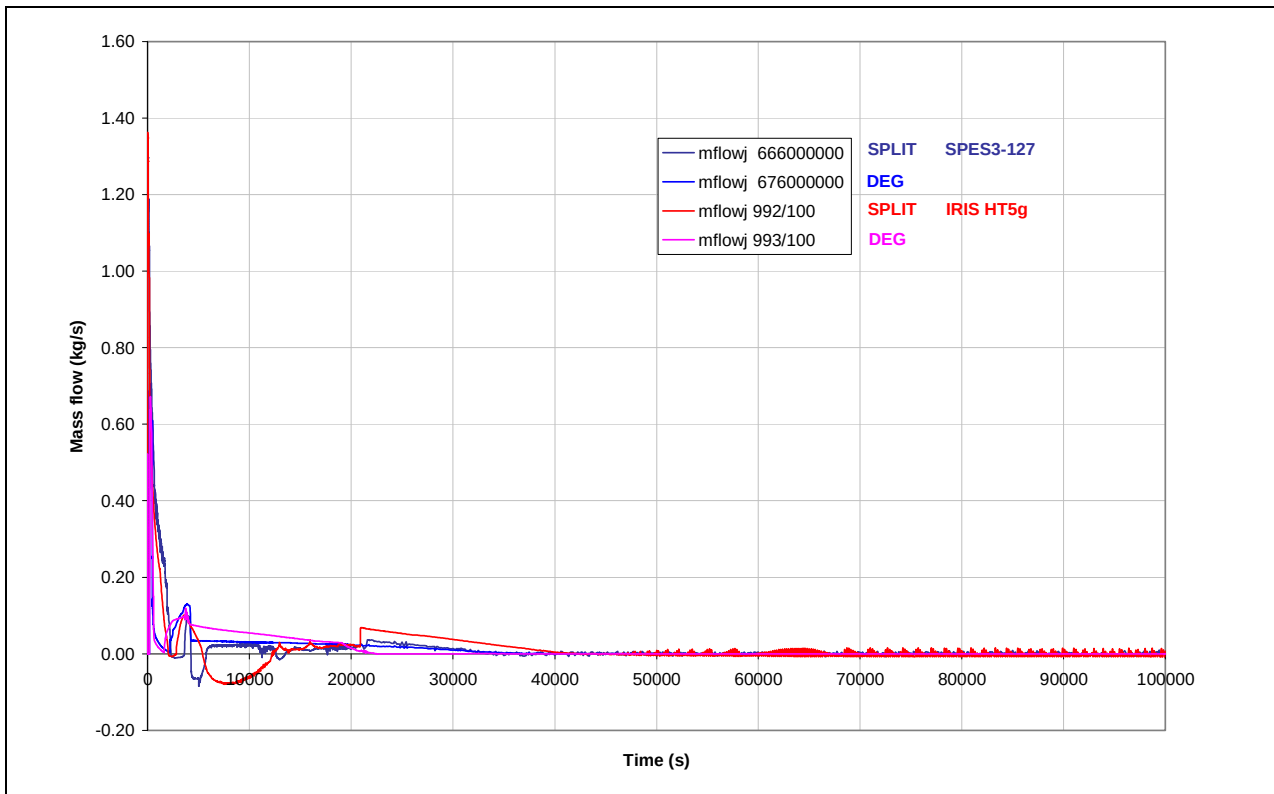


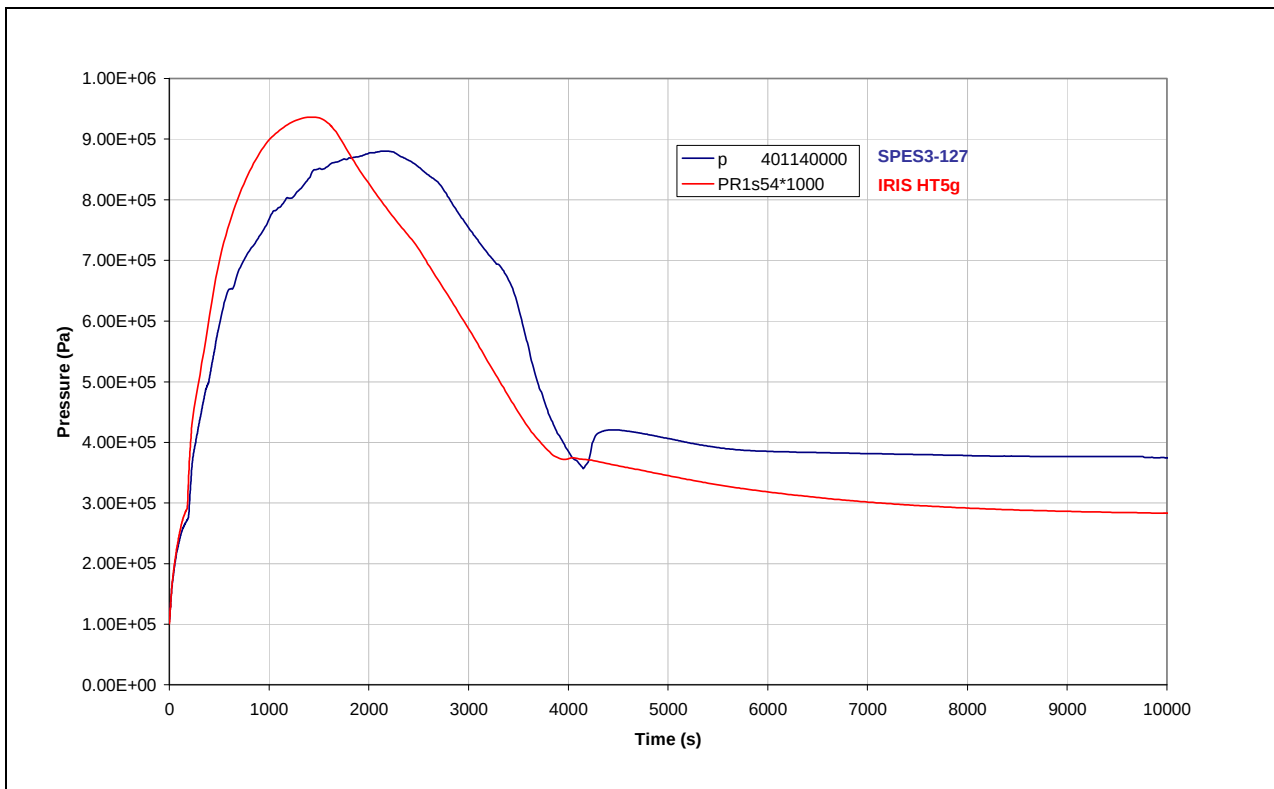
Fig.6. 2 – SPES3-127 and IRIS HT5g DVI break flow (window)



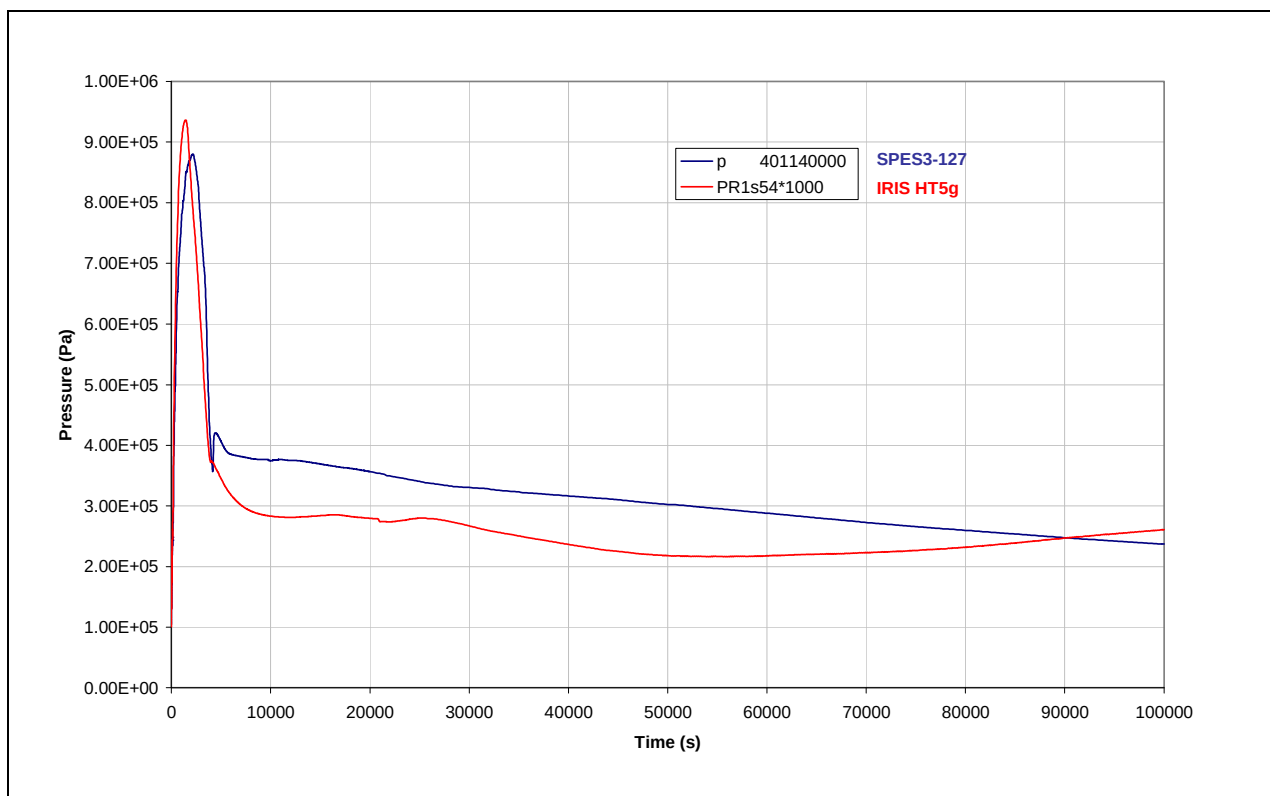
**Fig.6. 3 – SPES3-127 and IRIS HT5g DVI break flow**



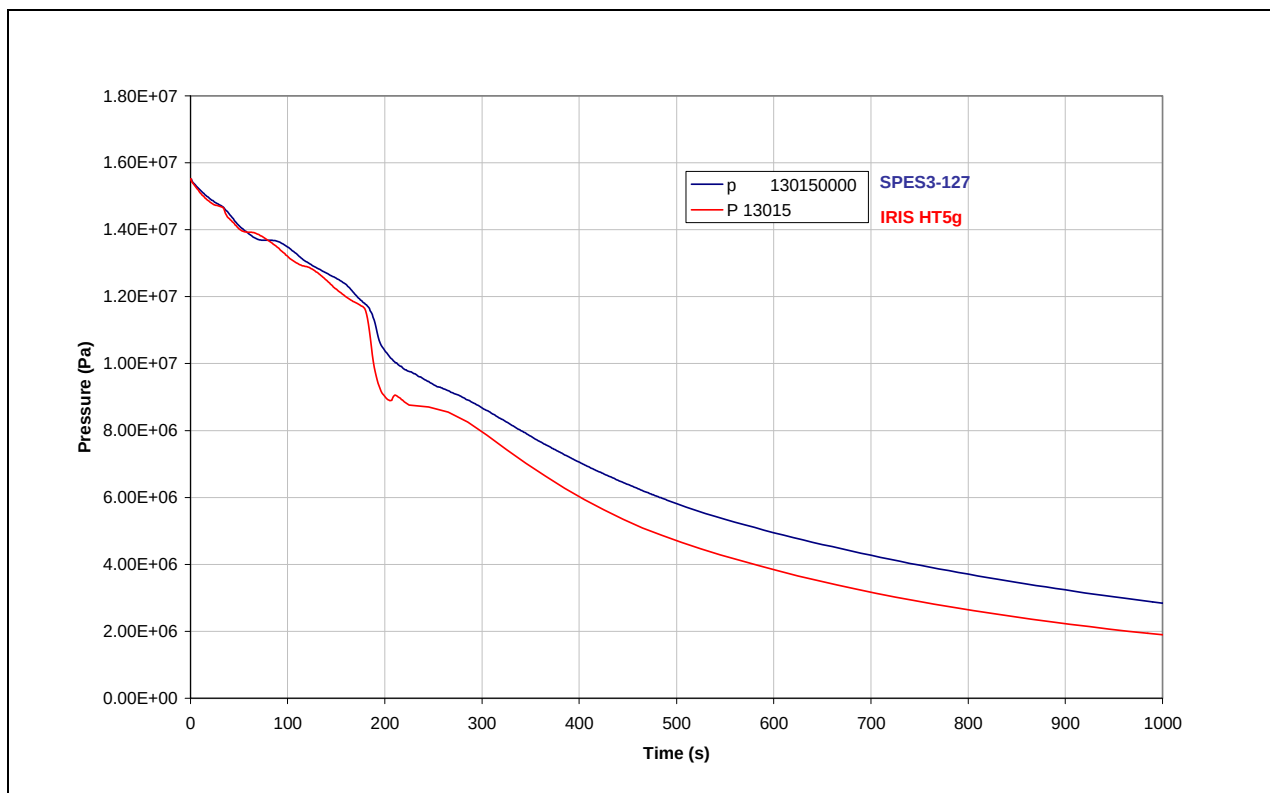
**Fig.6. 4 – SPES3-127 and IRIS HT5g DW pressure (window)**



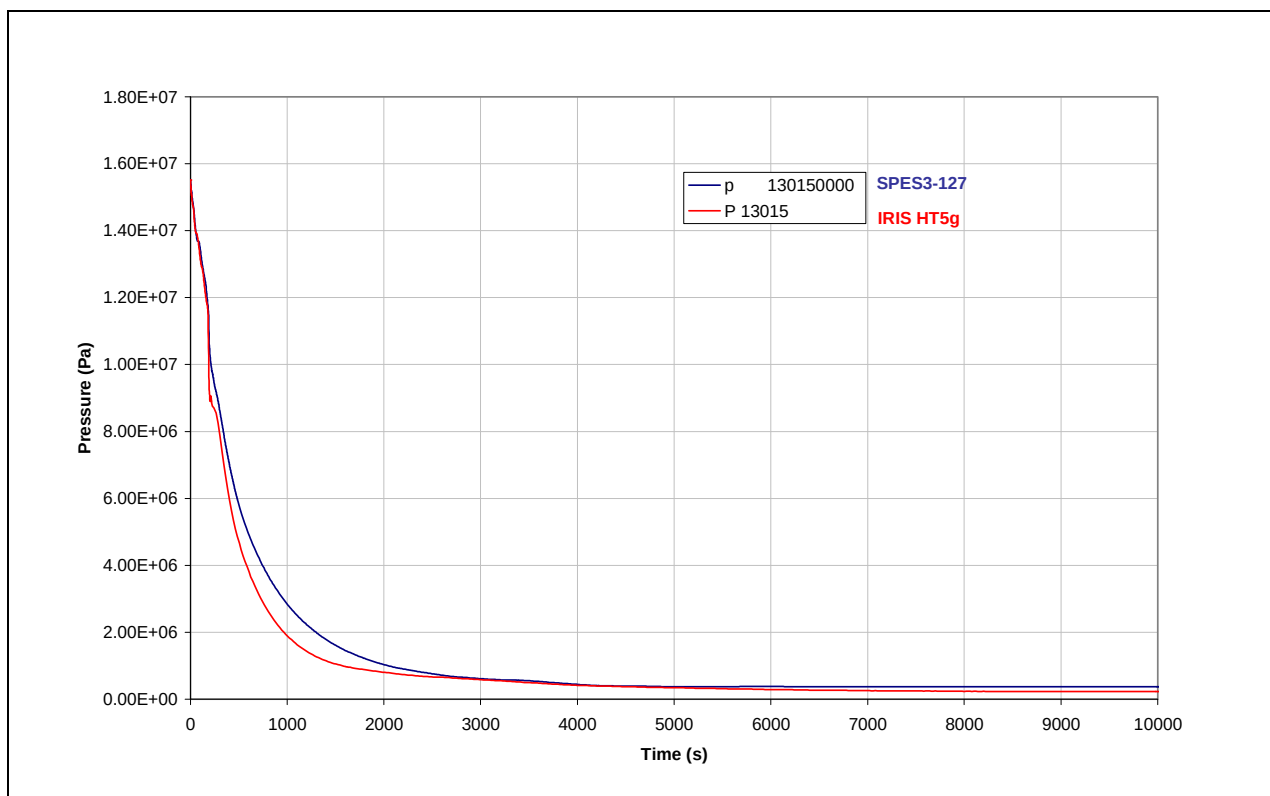
**Fig.6. 5 – SPES3-127 and IRIS HT5g DW pressure**



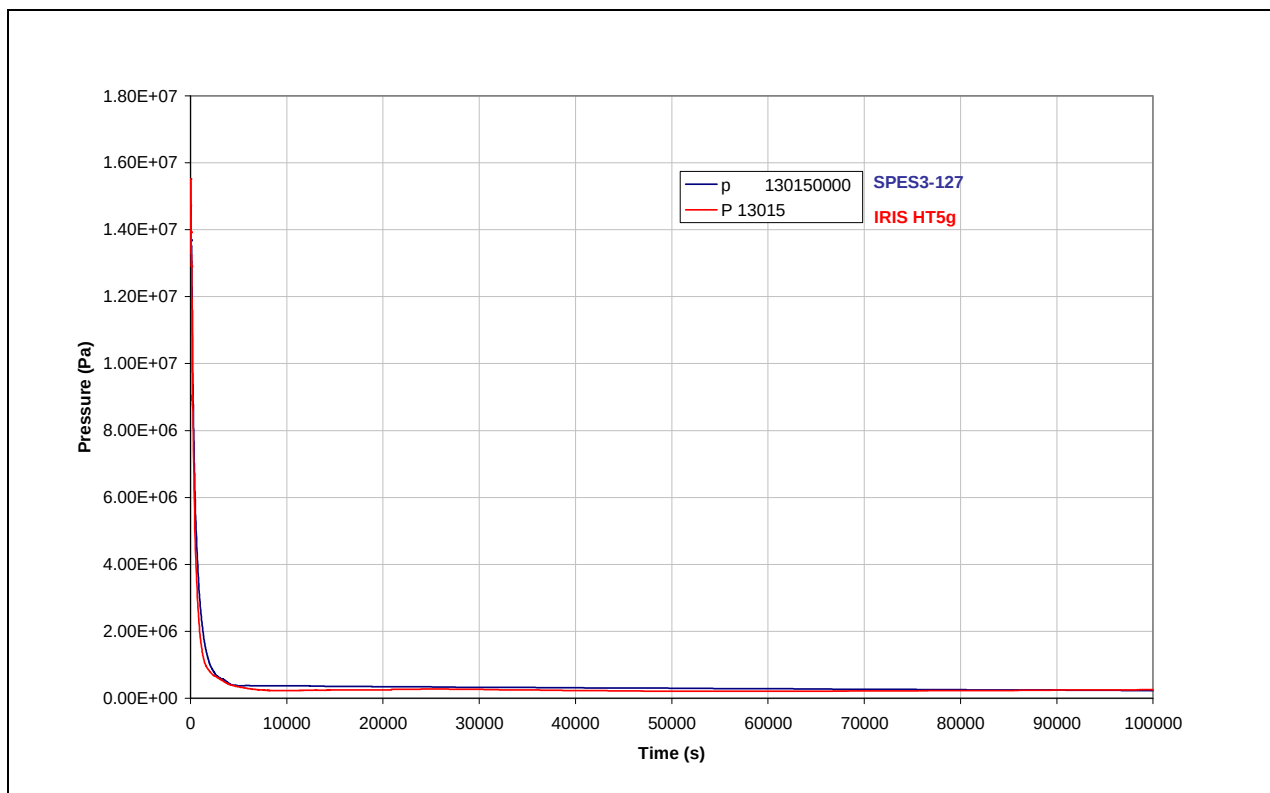
**Fig.6. 6 – SPES3-127 and IRIS HT5g PRZ pressure (window)**



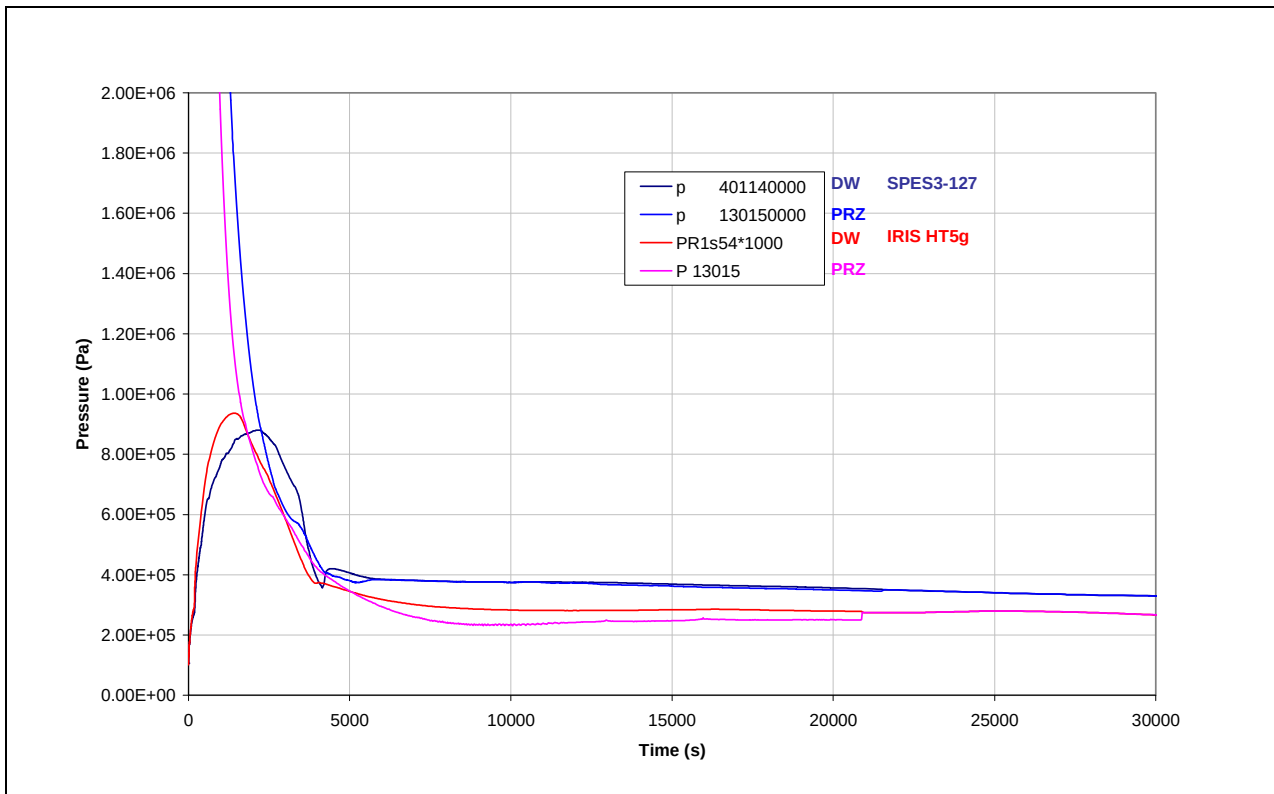
**Fig.6. 7 – SPES3-127 and IRIS HT5g PRZ pressure (window)**



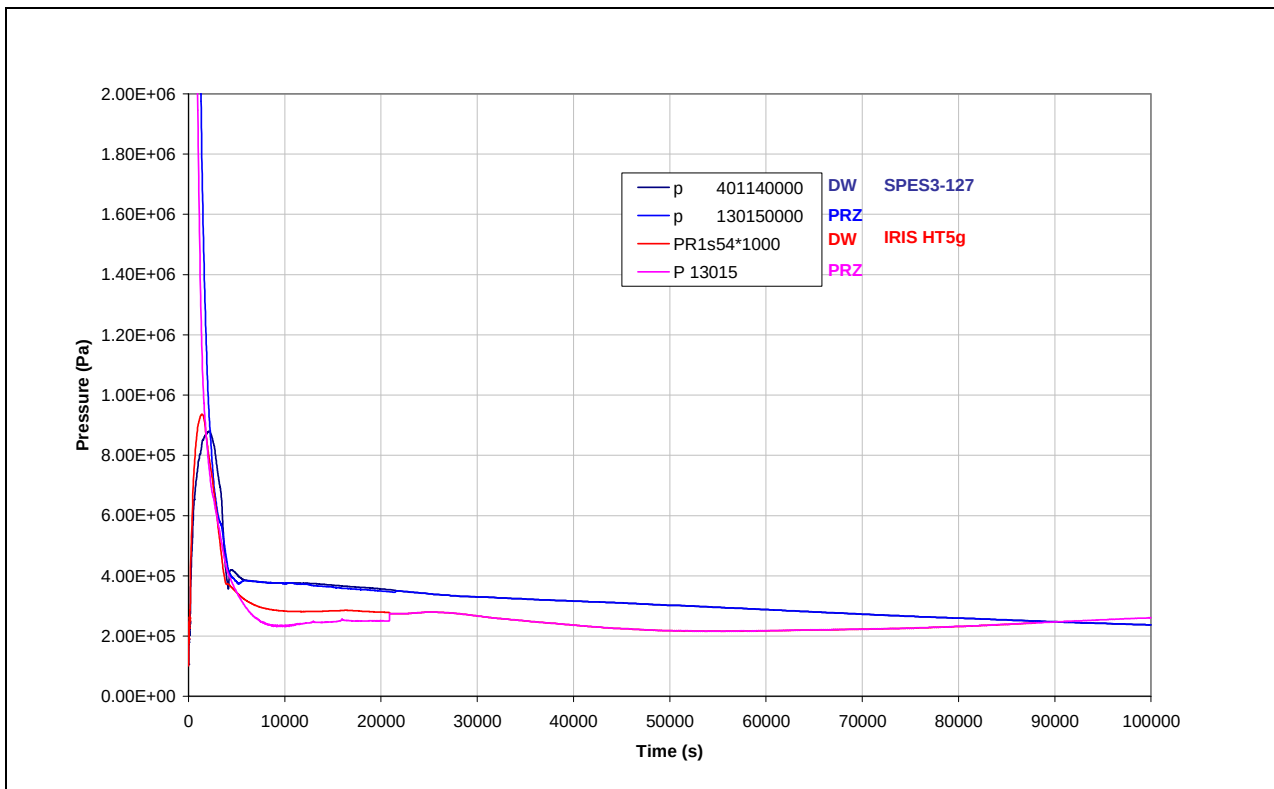
**Fig.6. 8 – SPES3-127 and IRIS HT5g PRZ pressure**



**Fig.6. 9 – SPES3-127 and IRIS HT5g PRZ and DW pressures (window)**

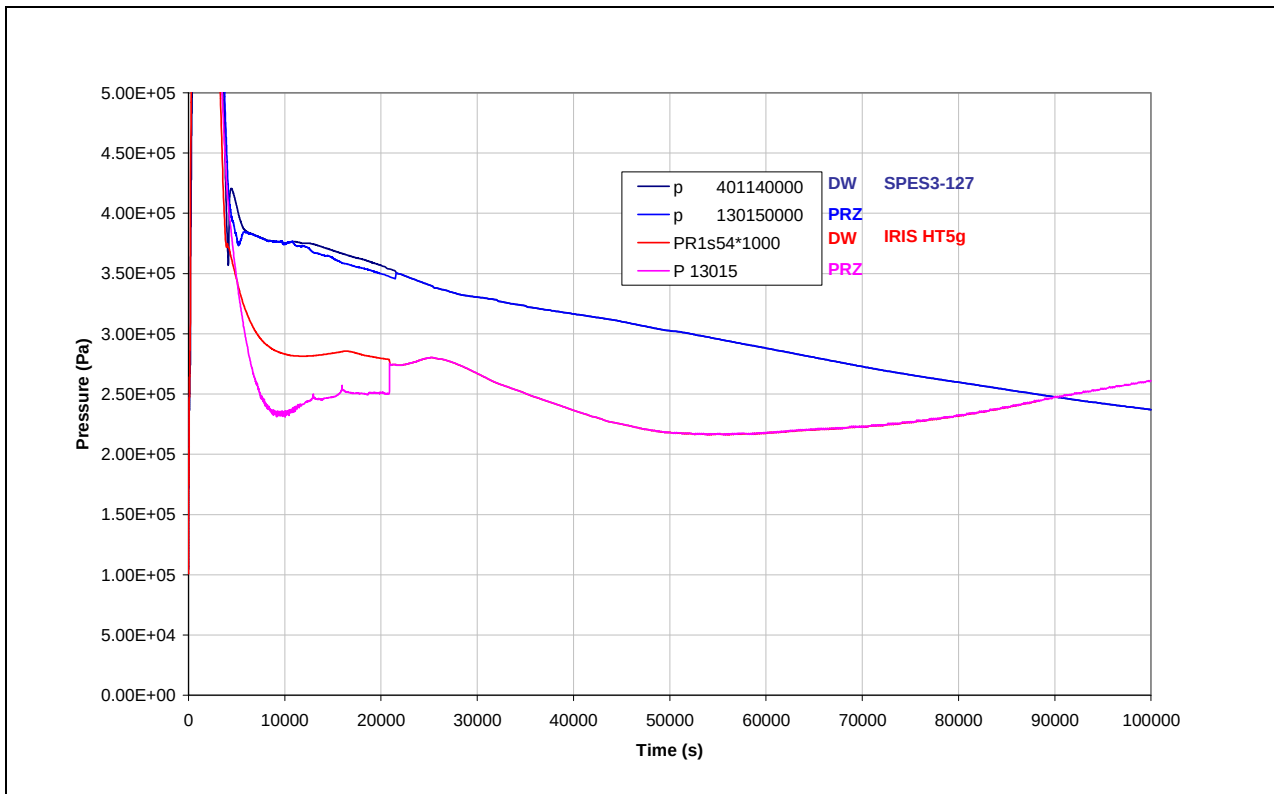


**Fig.6. 10 – SPES3-127 and IRIS HT5g PRZ and DW pressures**

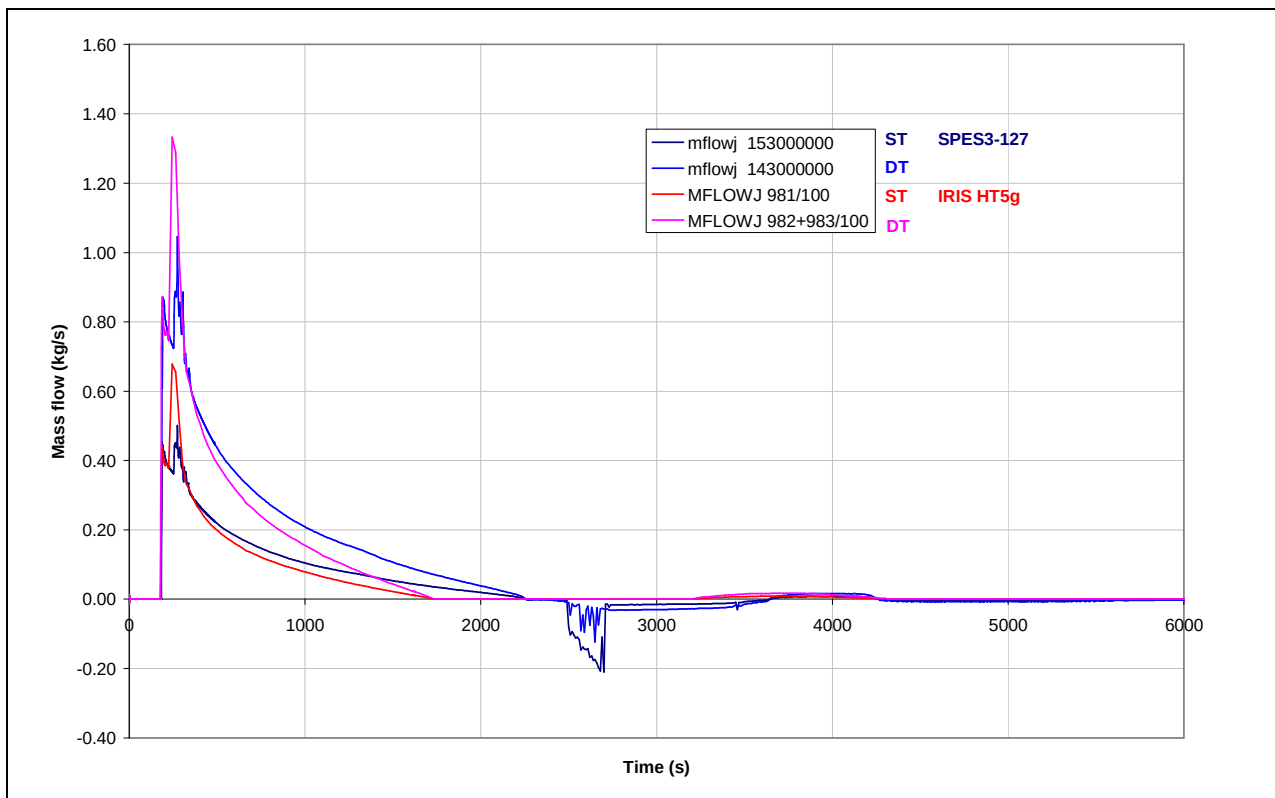




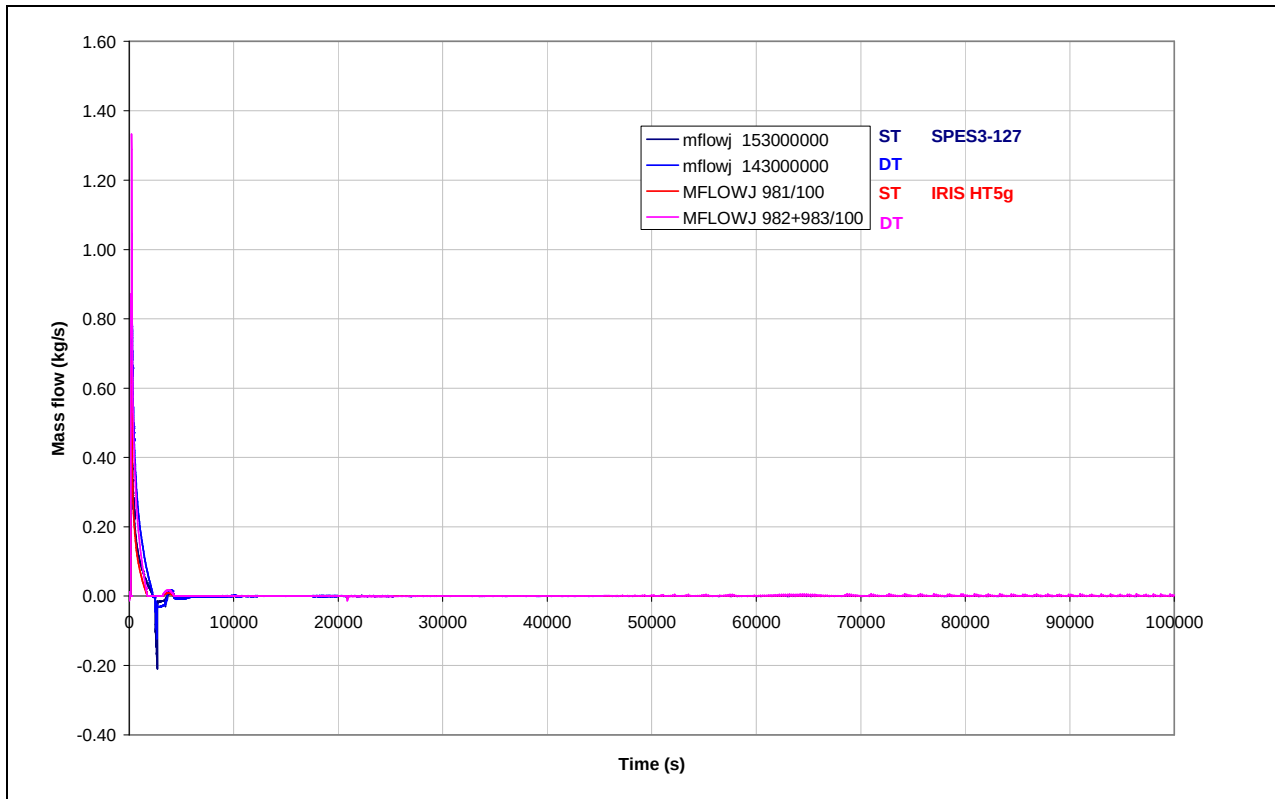
**Fig.6. 11 – SPES3-127 and IRIS HT5g PRZ and DW pressures (detail)**



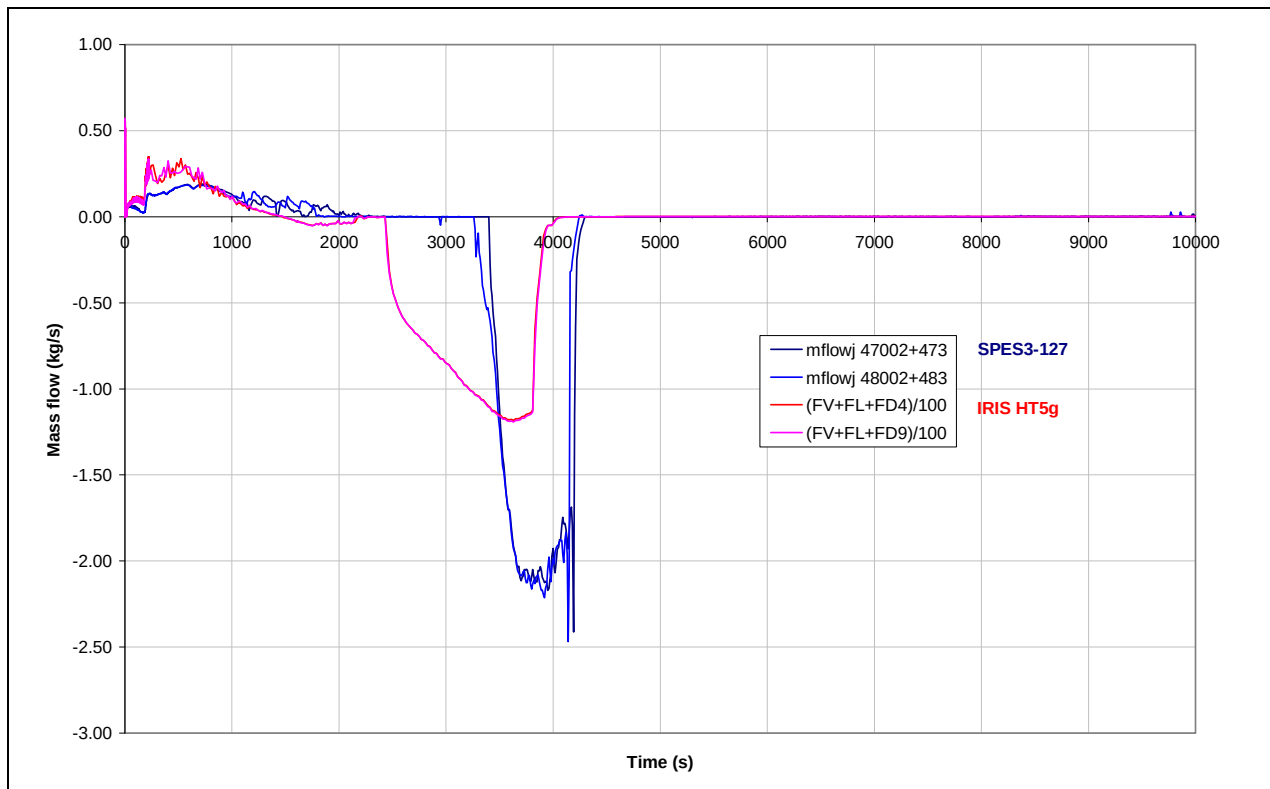
**Fig.6. 12 – SPES3-127 and IRIS HT5g ADS Stage-I mass flow (window)**



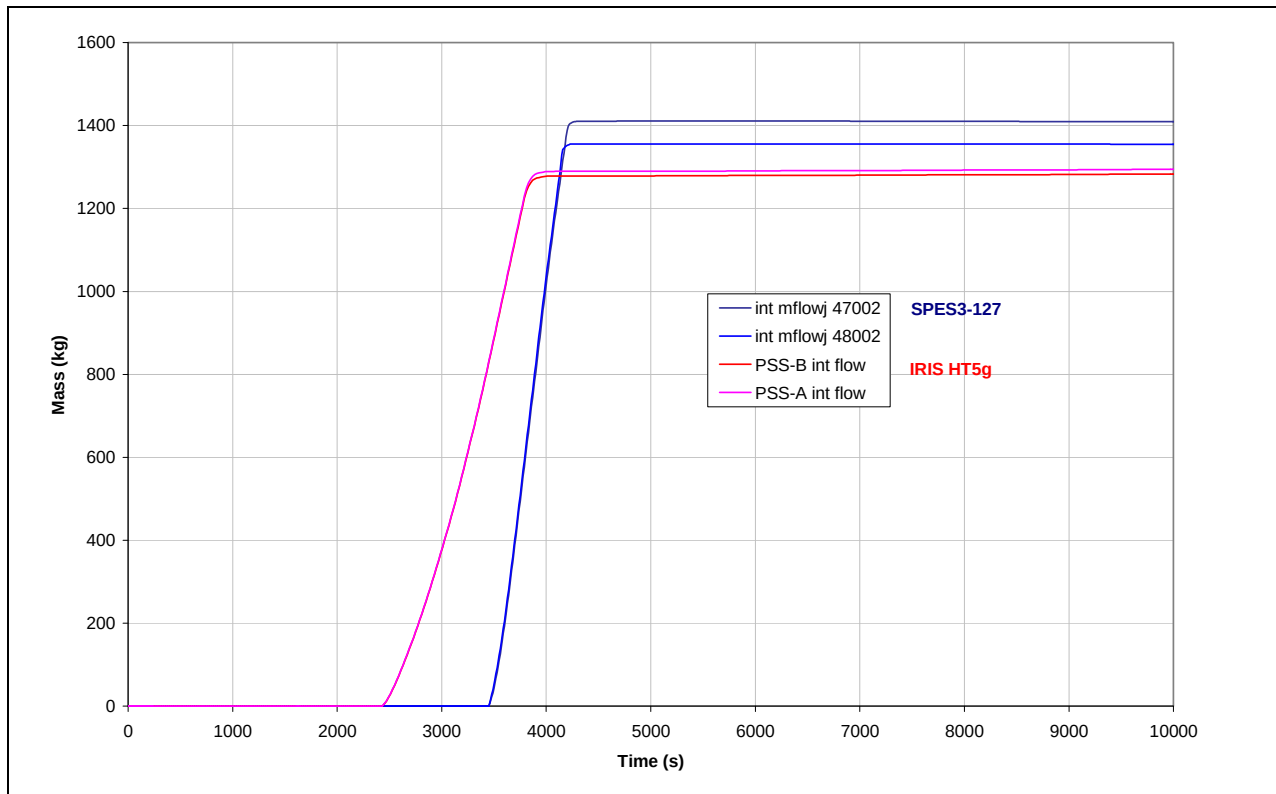
**Fig.6. 13 – SPES3-127 and IRIS HT5g ADS Stage-I mass flow**



**Fig.6. 14 – SPES3-127 and IRIS HT5g DW to PSS mass flow (window)**



**Fig.6. 15 – SPES3-127 and IRIS HT5g PSS to DW integral flow (window)**



**Fig.6. 16 – SPES3-127 and IRIS HT5g PSS level (window)**

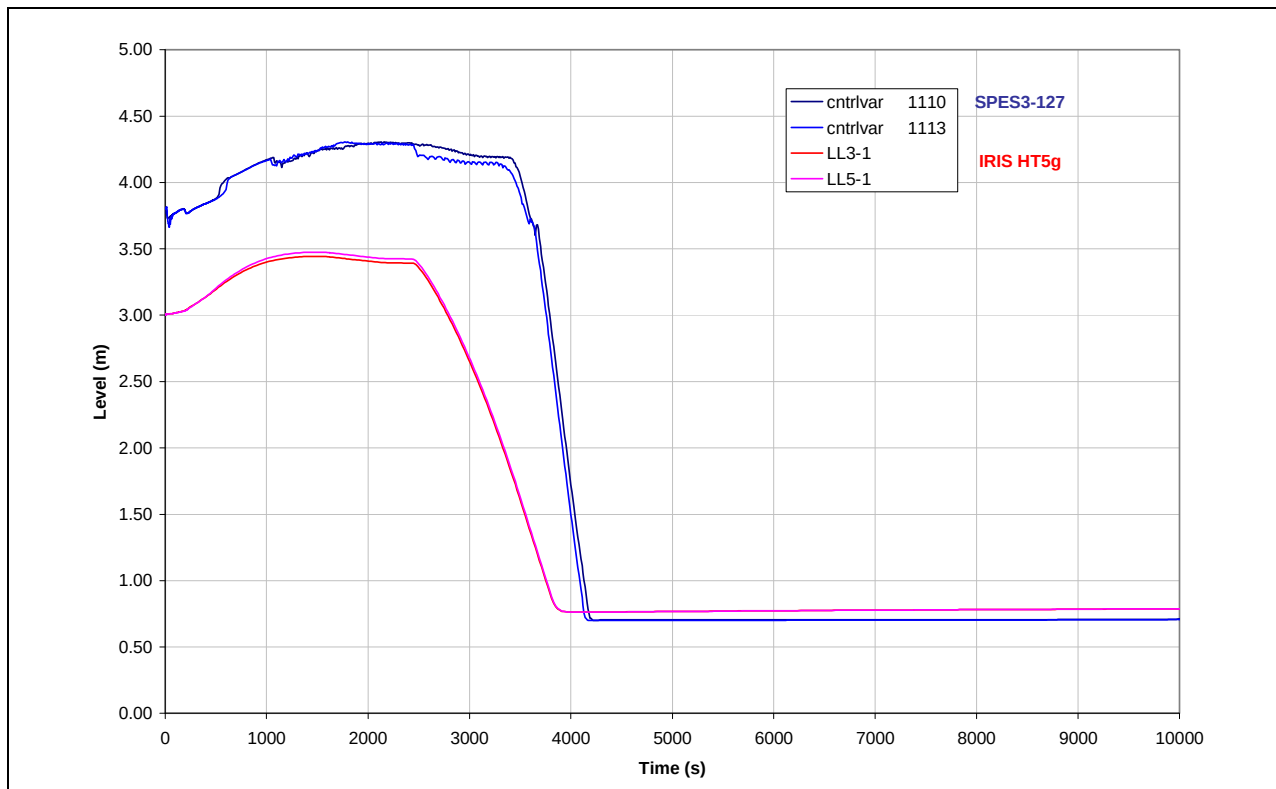


Fig.6. 17 – SPES3-127 and IRIS HT5g DW non-condensable gas quality (window)

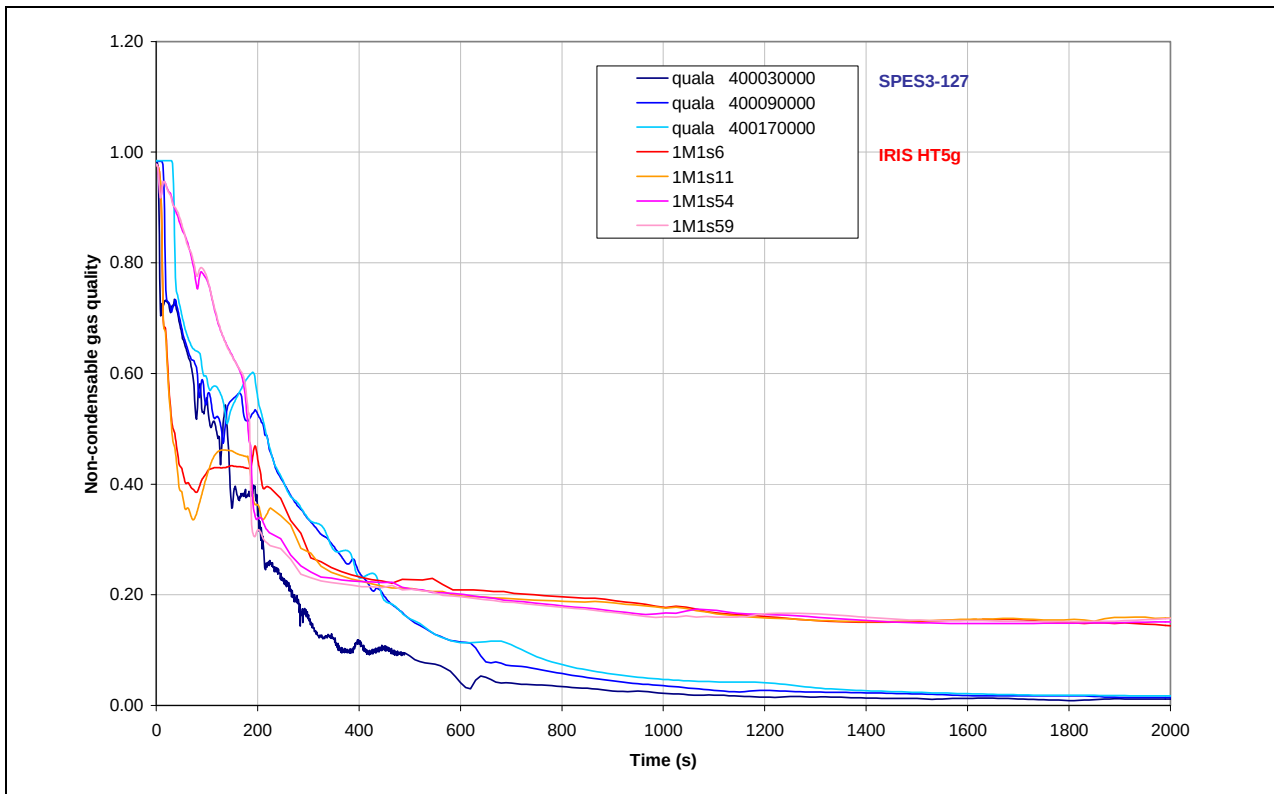
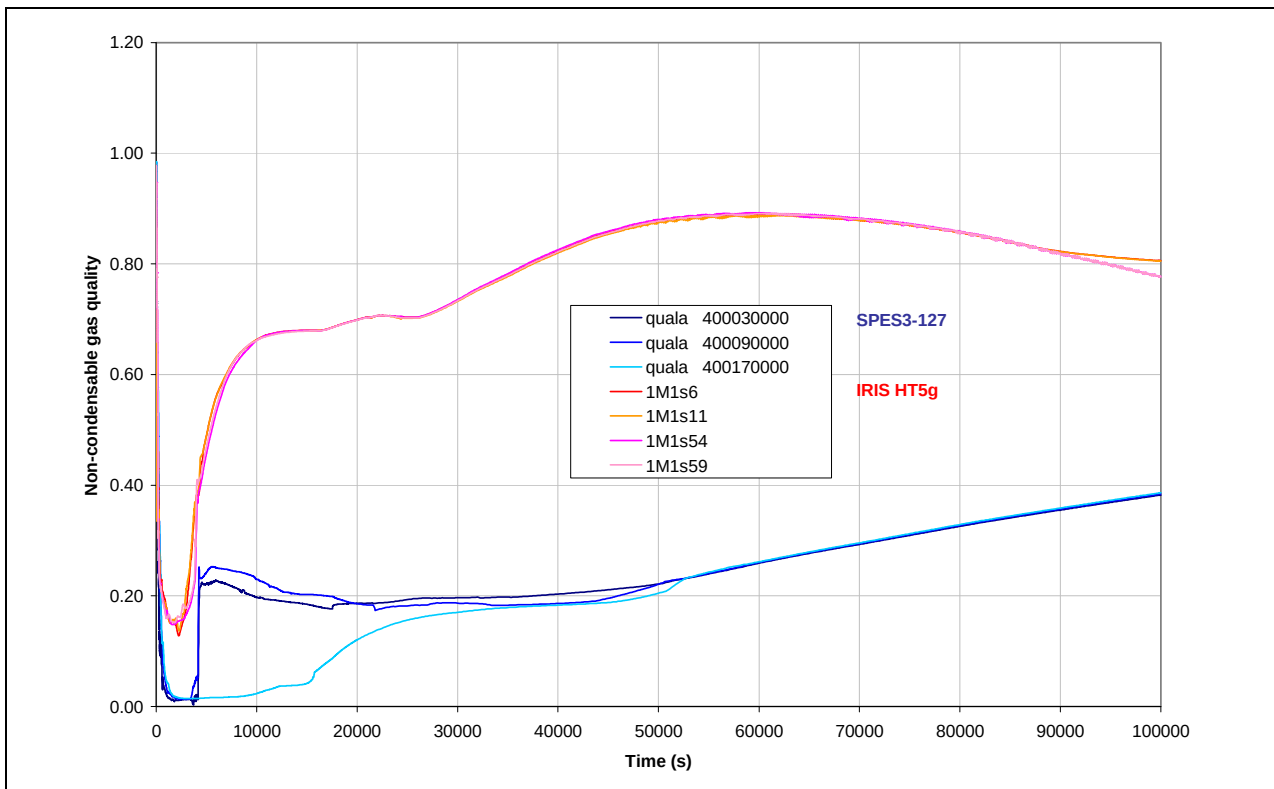
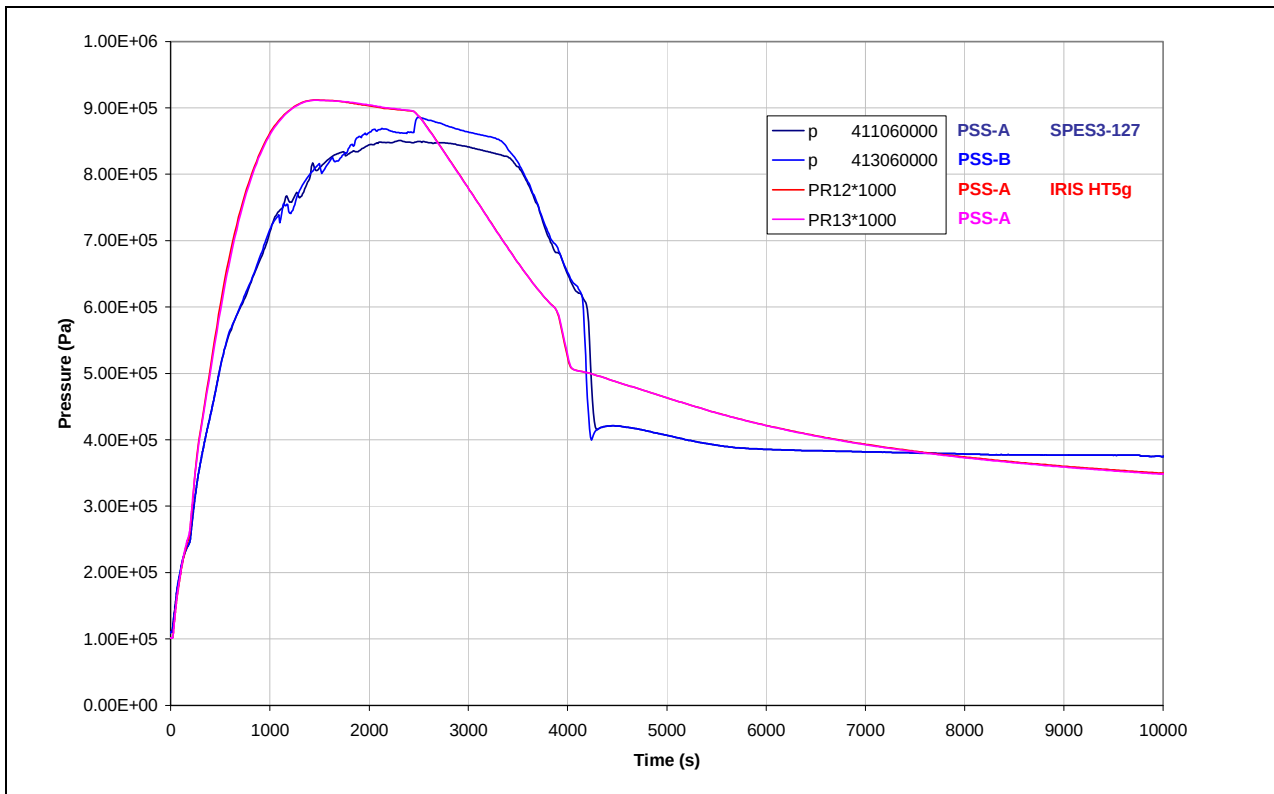


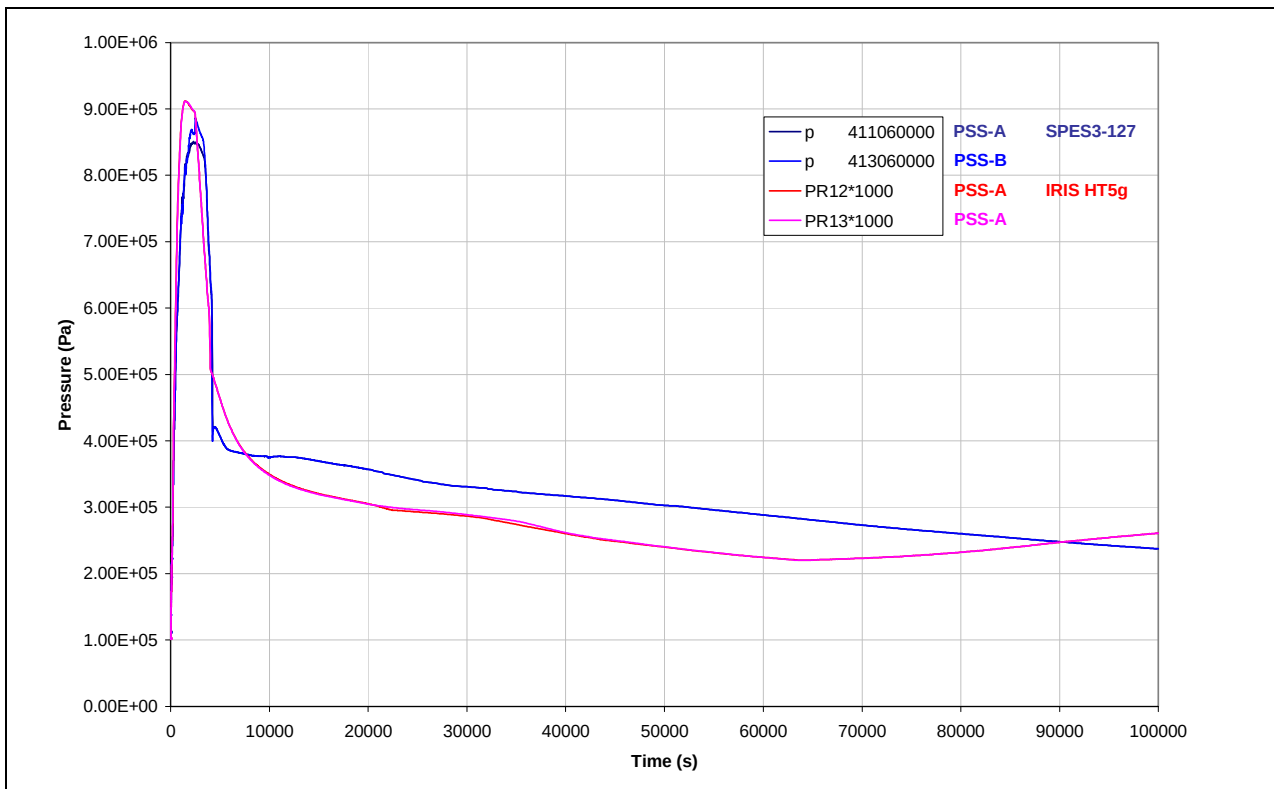
Fig.6. 18 – SPES3-127 and IRIS HT5g DW non-condensable gas quality



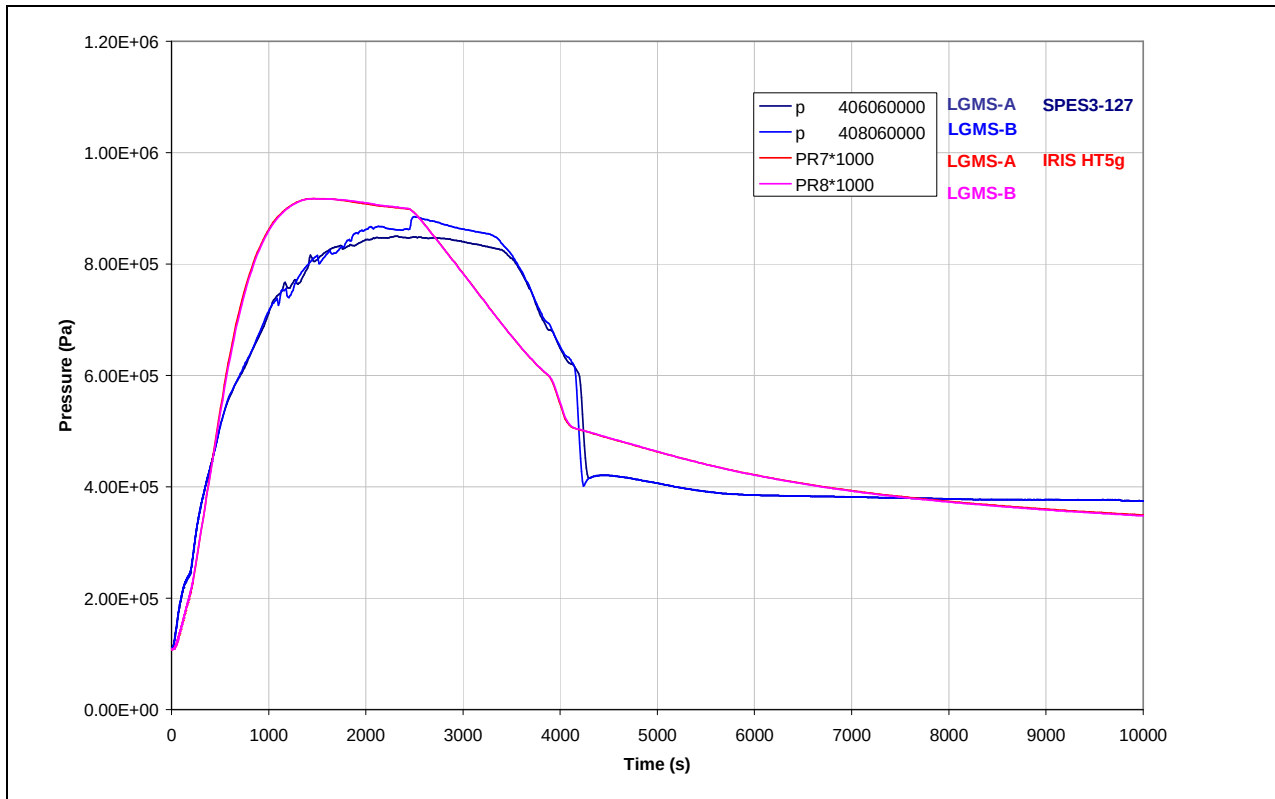
**Fig.6. 19 – SPES3-127 and IRIS HT5g PSS pressure (window)**



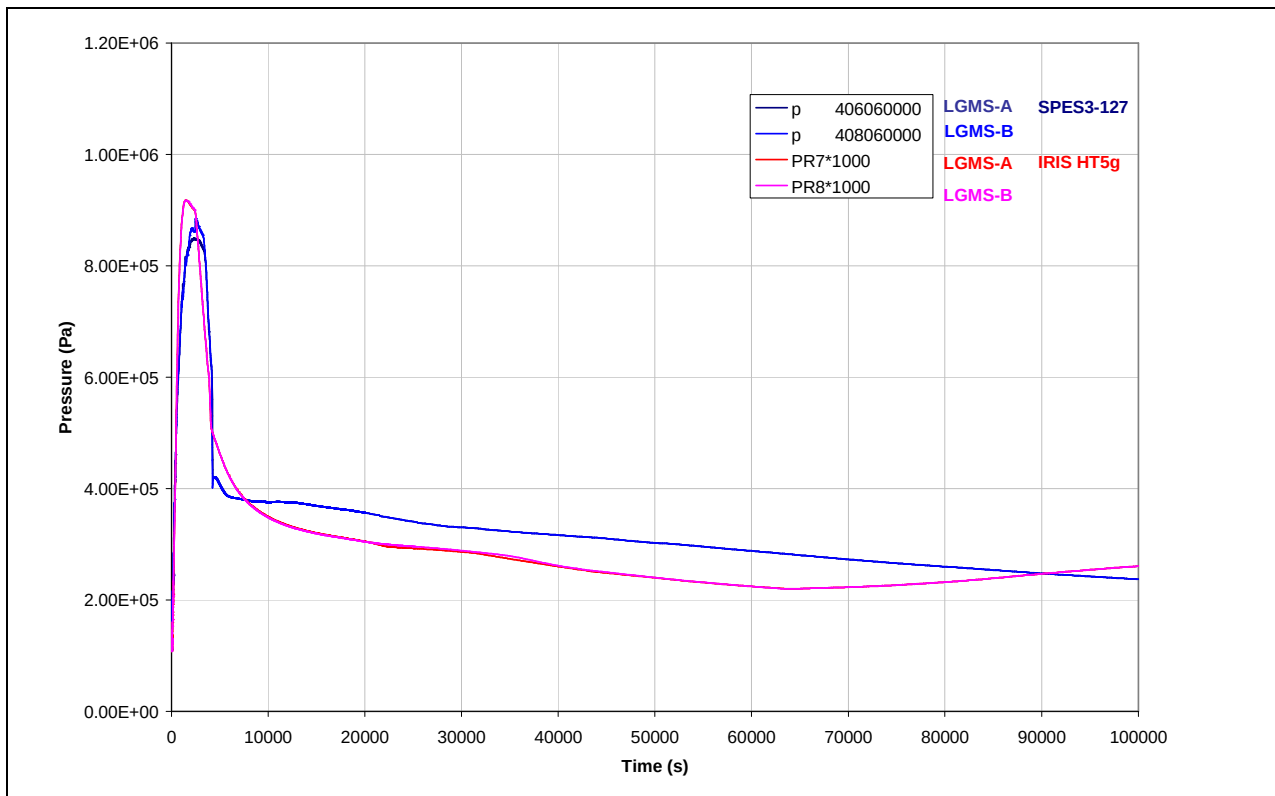
**Fig.6. 20 – SPES3-127 and IRIS HT5g PSS pressure**



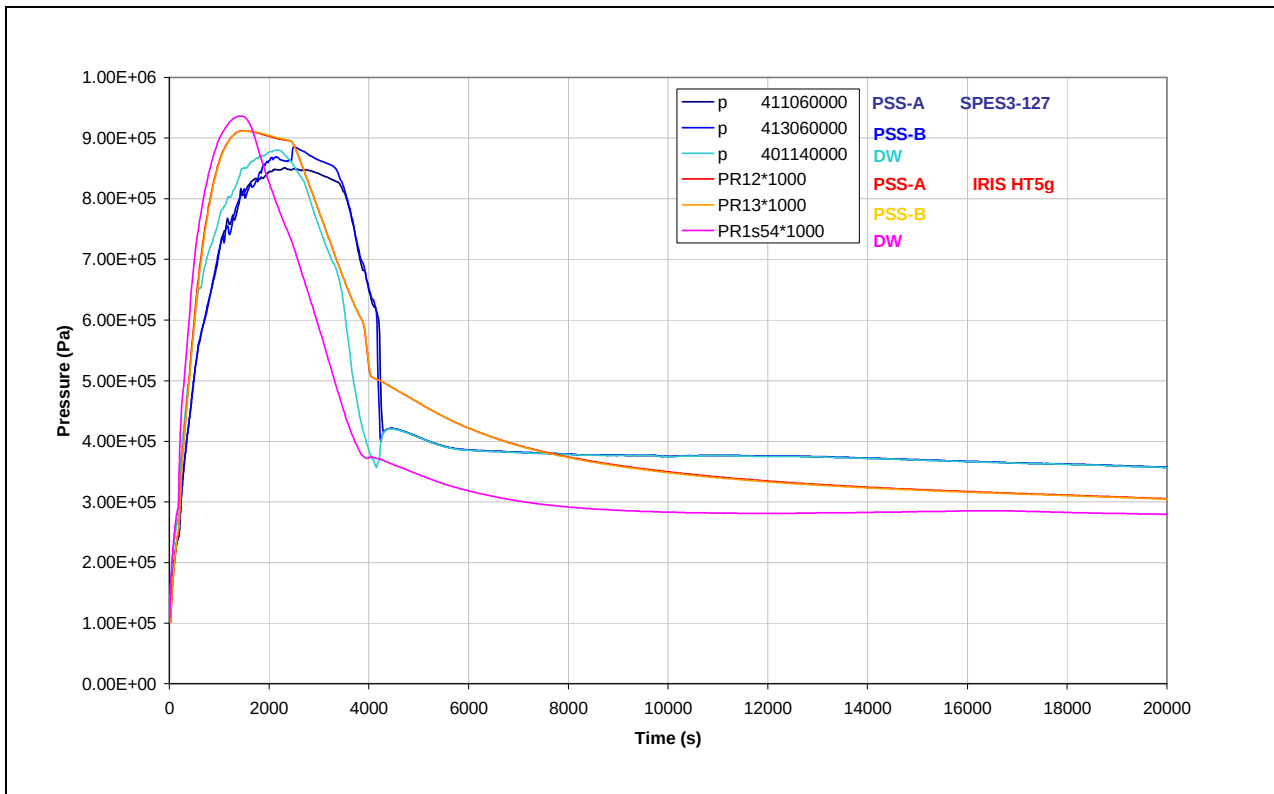
**Fig.6. 21 – SPES3-127 and IRIS HT5g LGMS pressure (window)**



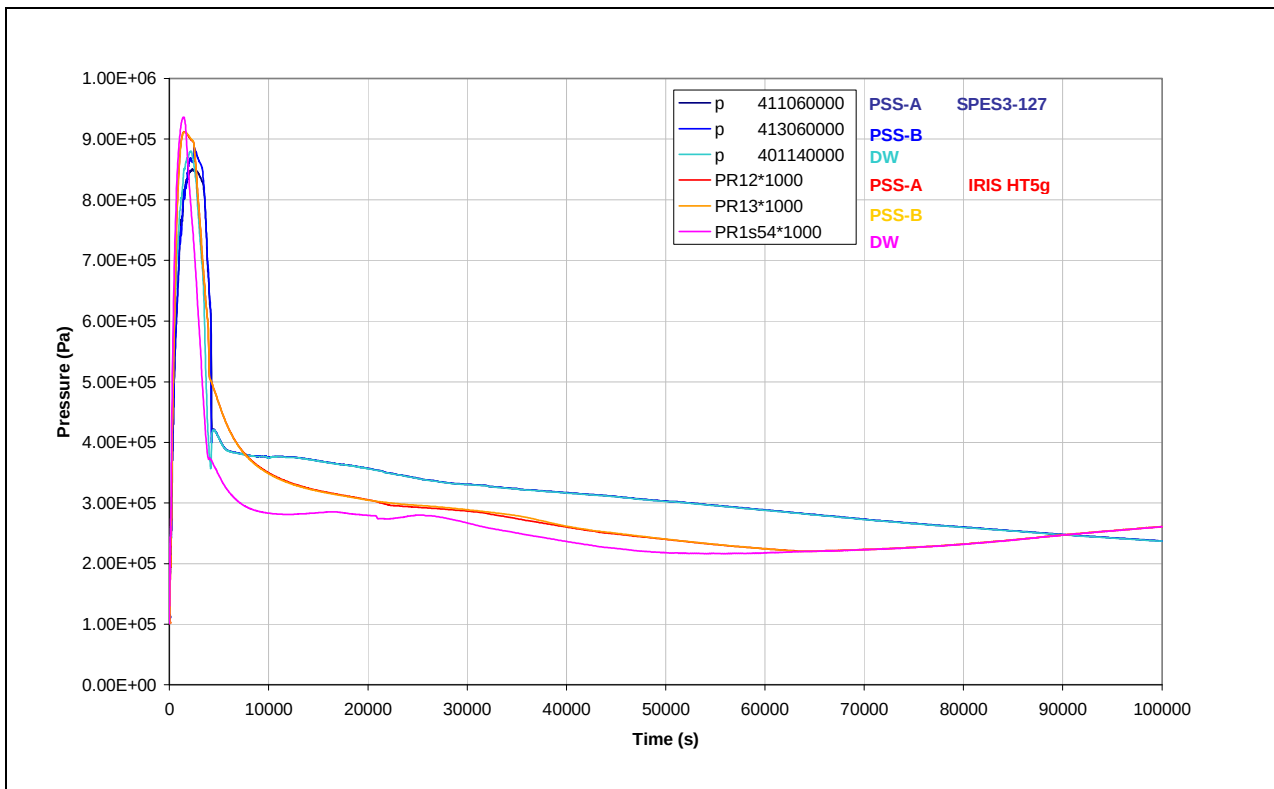
**Fig.6. 22 – SPES3-127 and IRIS HT5g LGMS pressure**



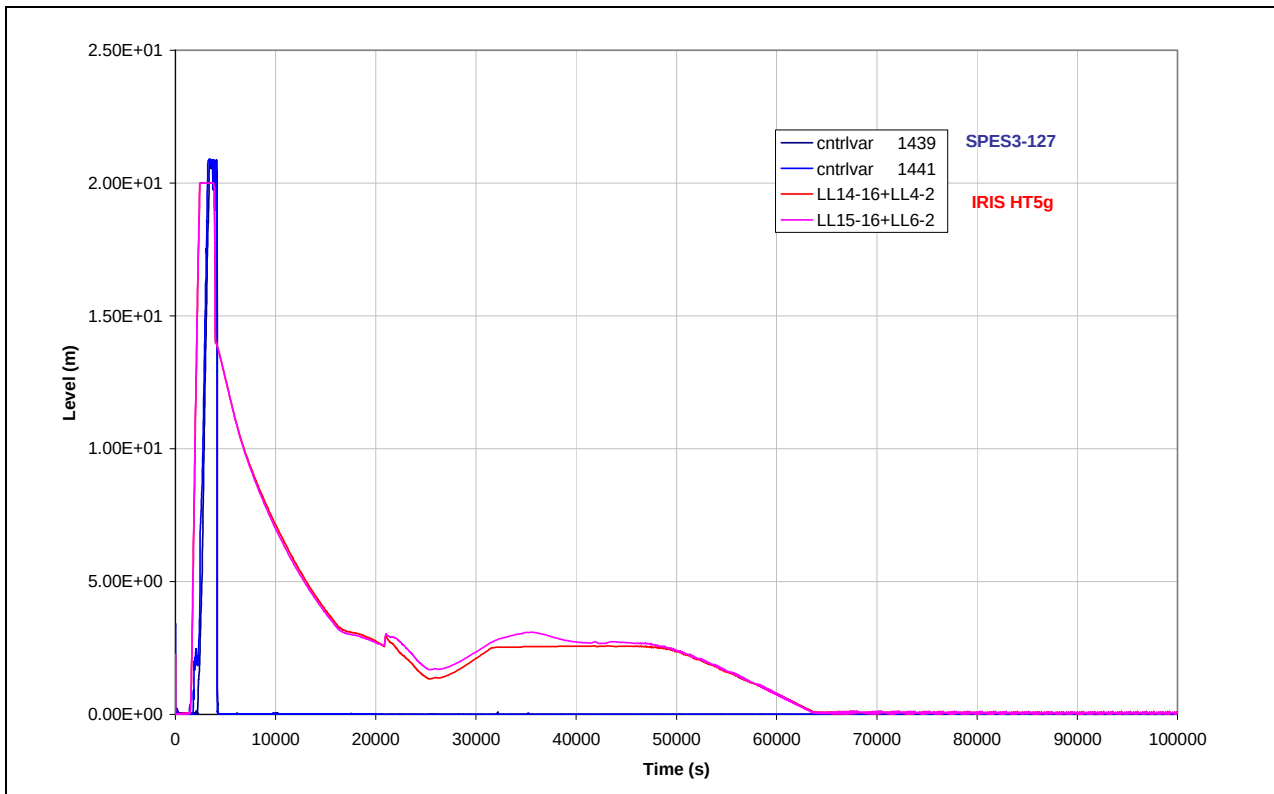
**Fig.6. 23 – SPES3-127 and IRIS HT5g DW and PSS pressure (window)**



**Fig.6. 24 – SPES3-127 and IRIS HT5g DW and PSS pressure**



**Fig.6. 25 – SPES3-127 and IRIS HT5g PSS to DW pipe level**



**Fig.6. 26 – SPES3-127 and IRIS HT5g RC level (window)**

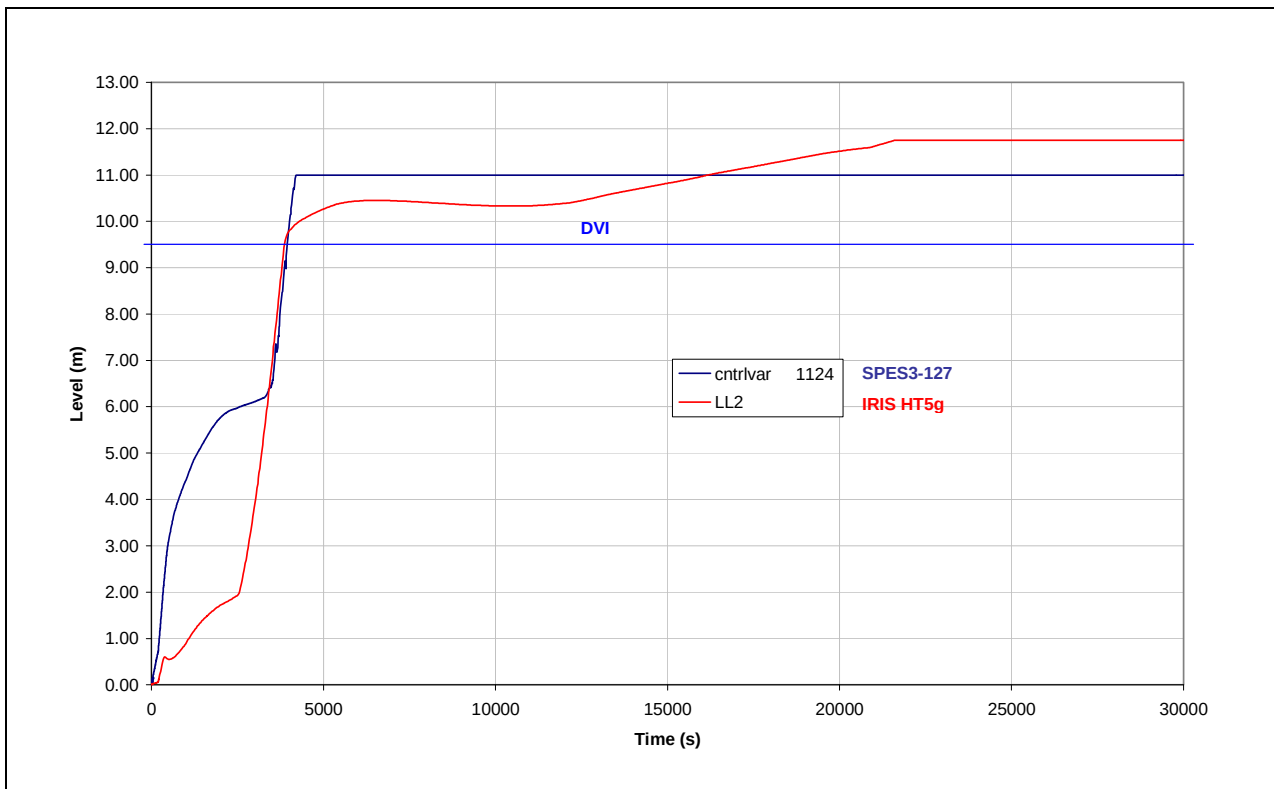




Fig.6. 27 – SPES3-127 and IRIS HT5g DW level

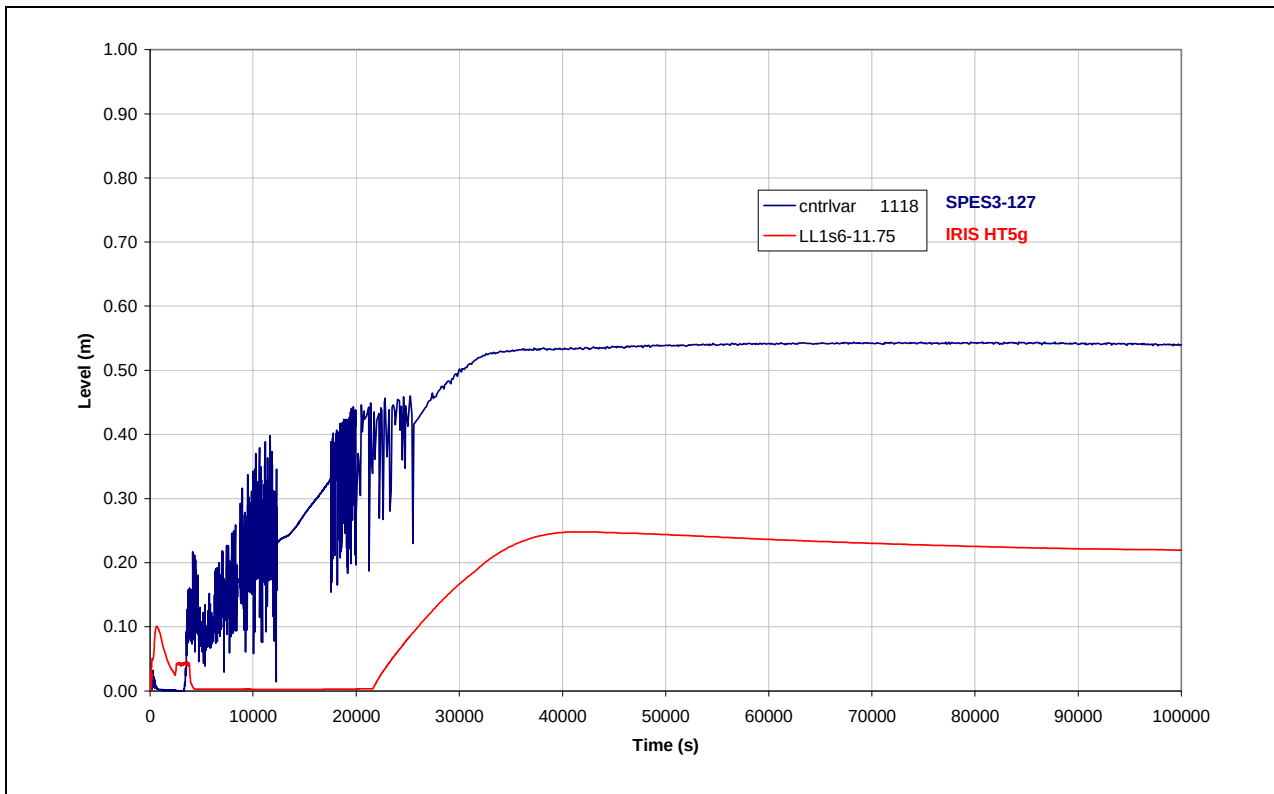


Fig.6. 28 – SPES3-127 and IRIS HT5g PSS liquid and gas temperature (window)

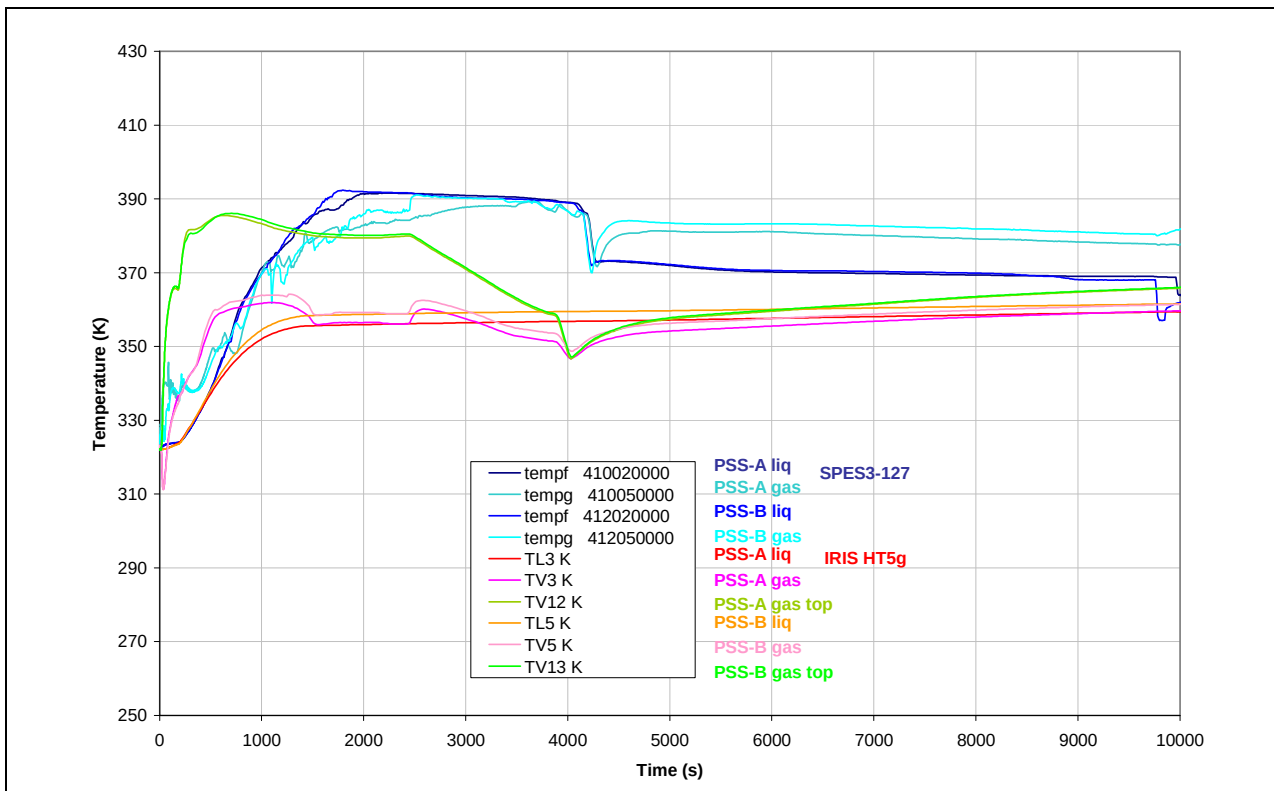


Fig.6. 29 – SPES3-127 and IRIS HT5g PSS liquid and gas temperature

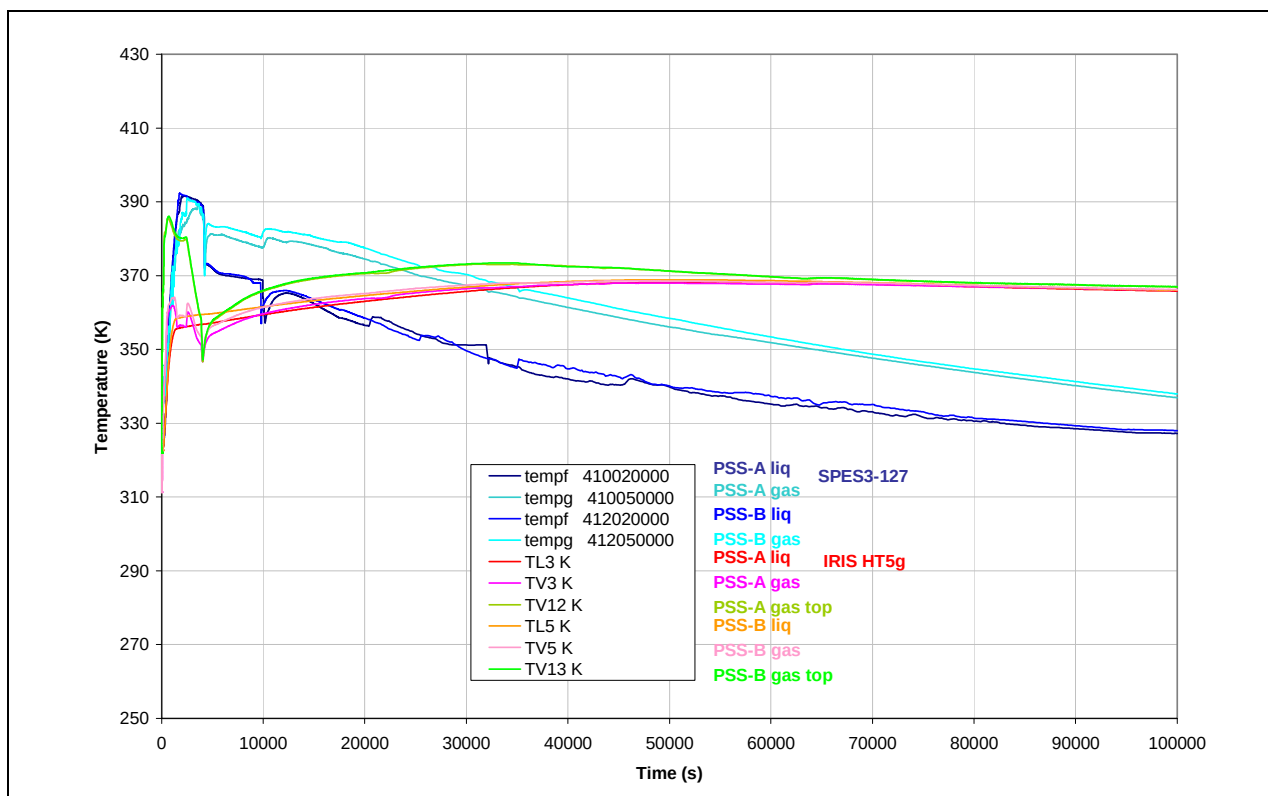
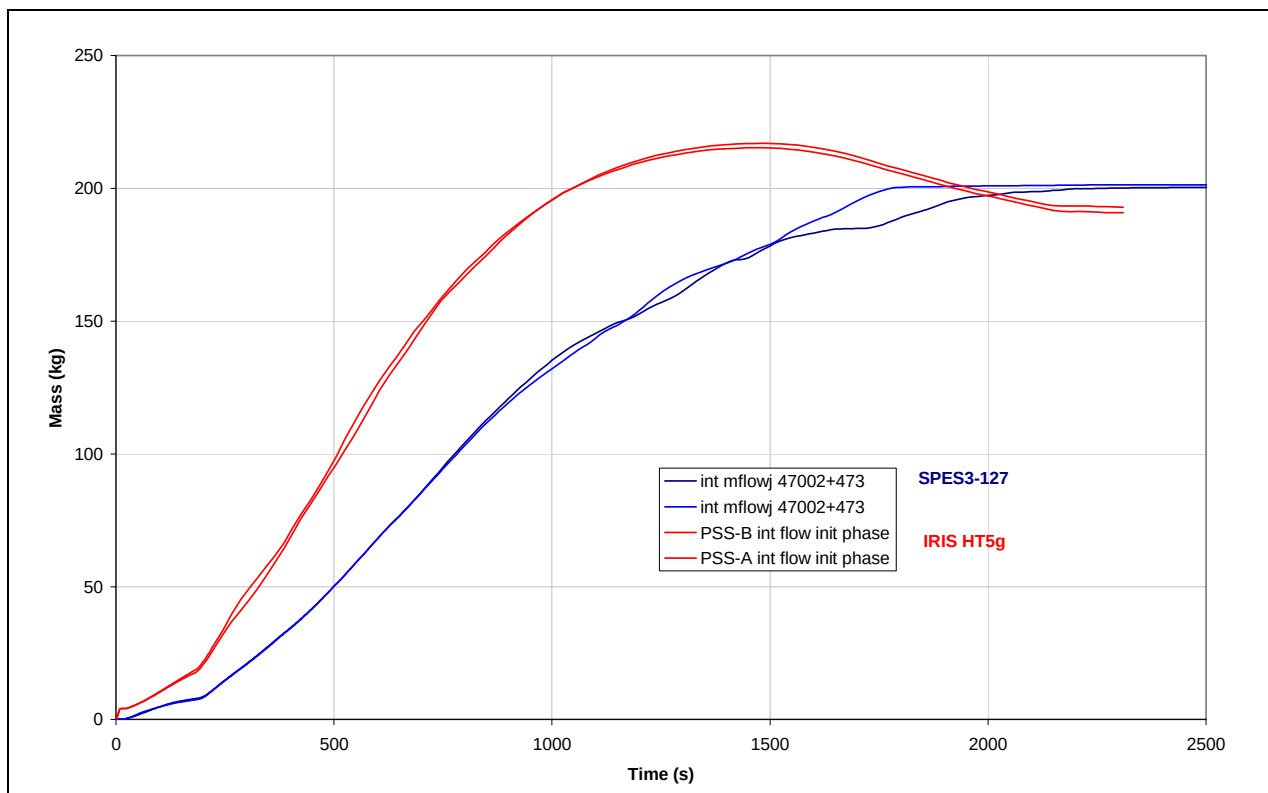
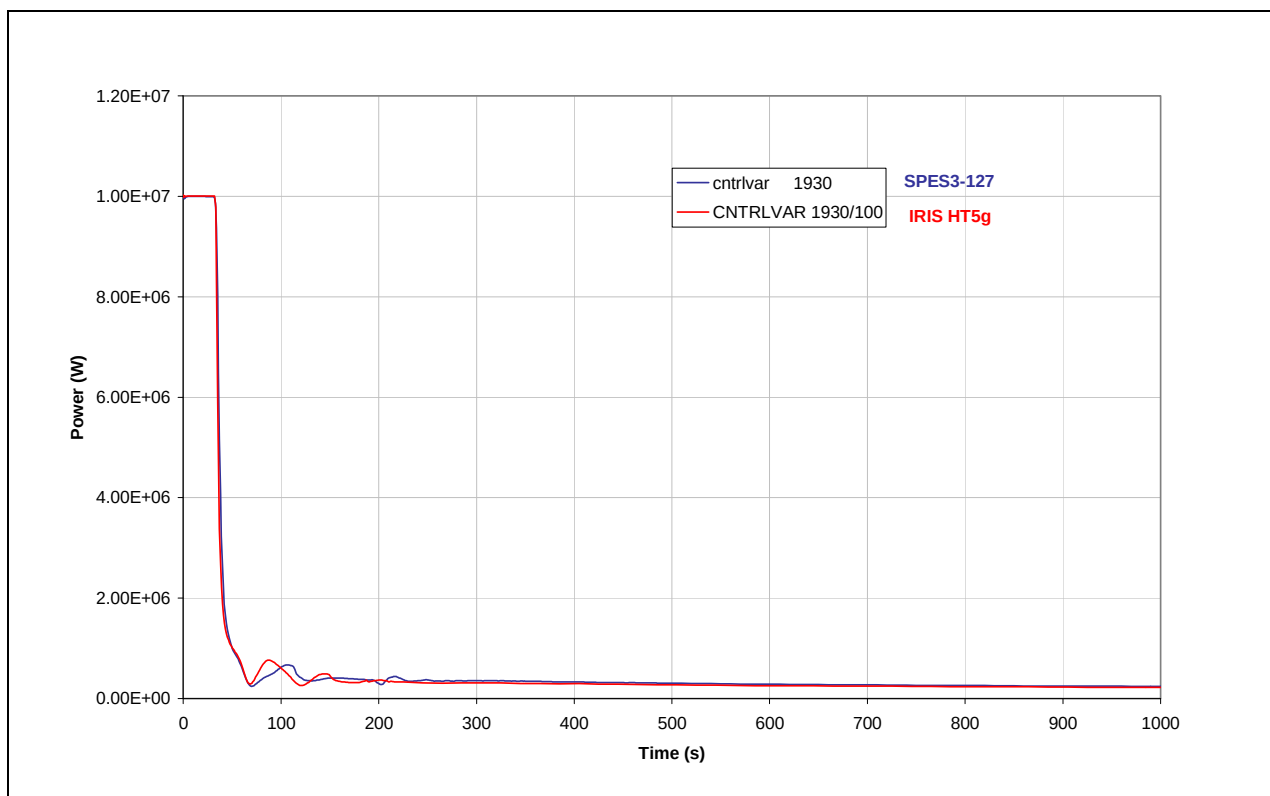


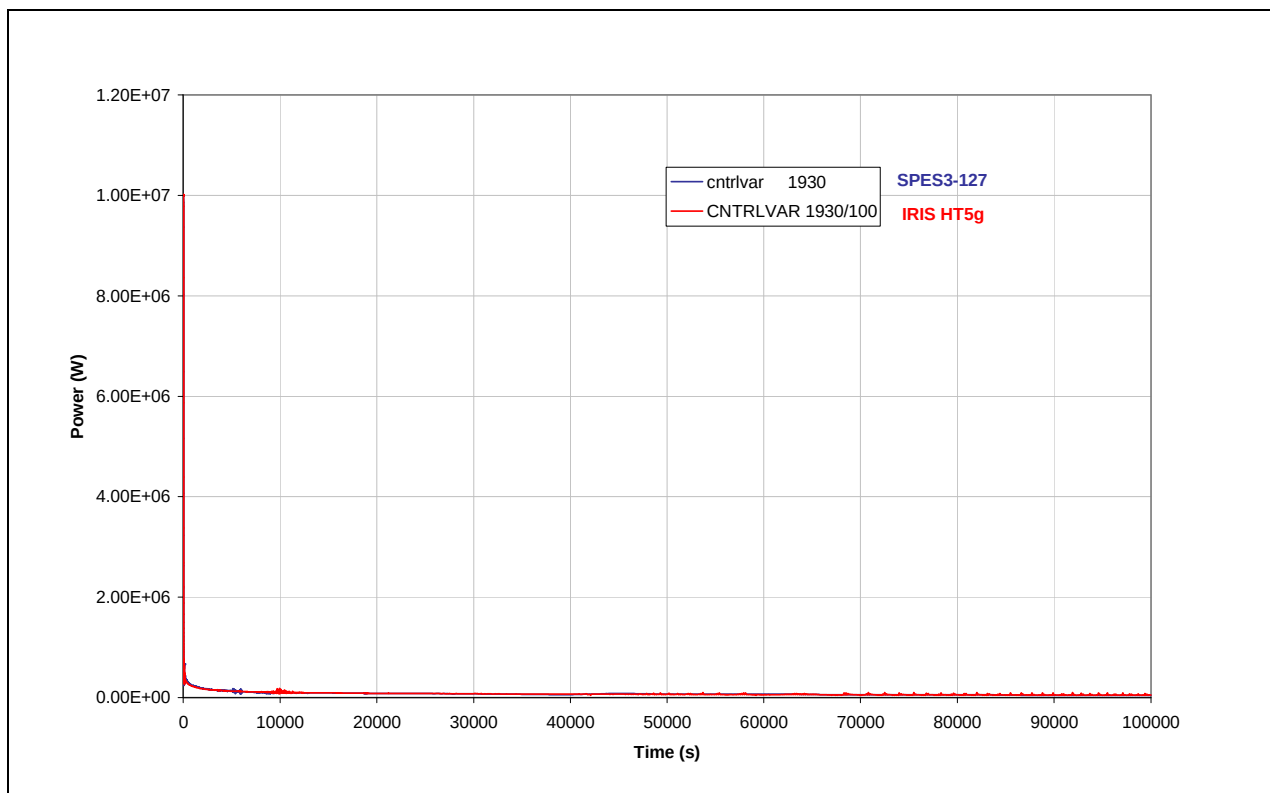
Fig.6. 30 – SPES3-127 and IRIS HT5g DW to PSS integral flow (first phase of injection)



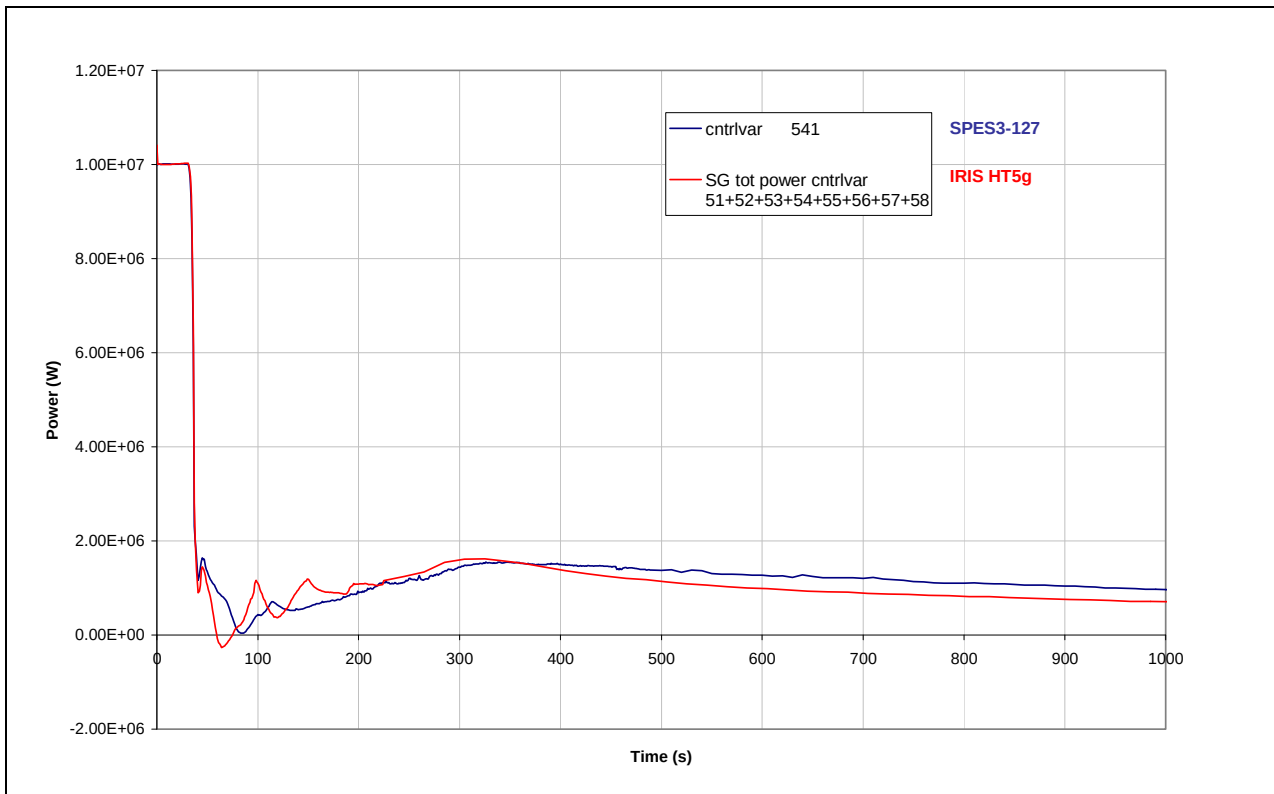
**Fig.6. 31 – SPES3-127 and IRIS HT5g core power (window)**



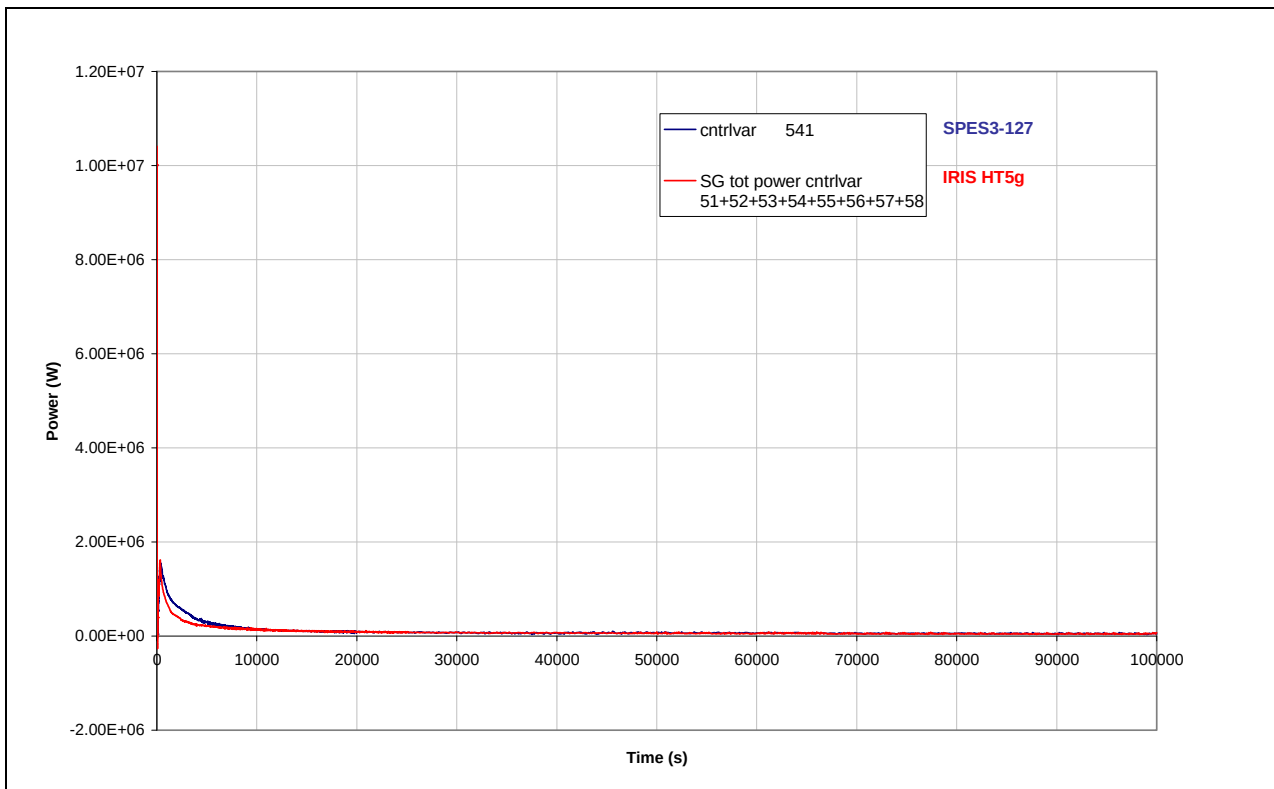
**Fig.6. 32 – SPES3-127 and IRIS HT5g core power**



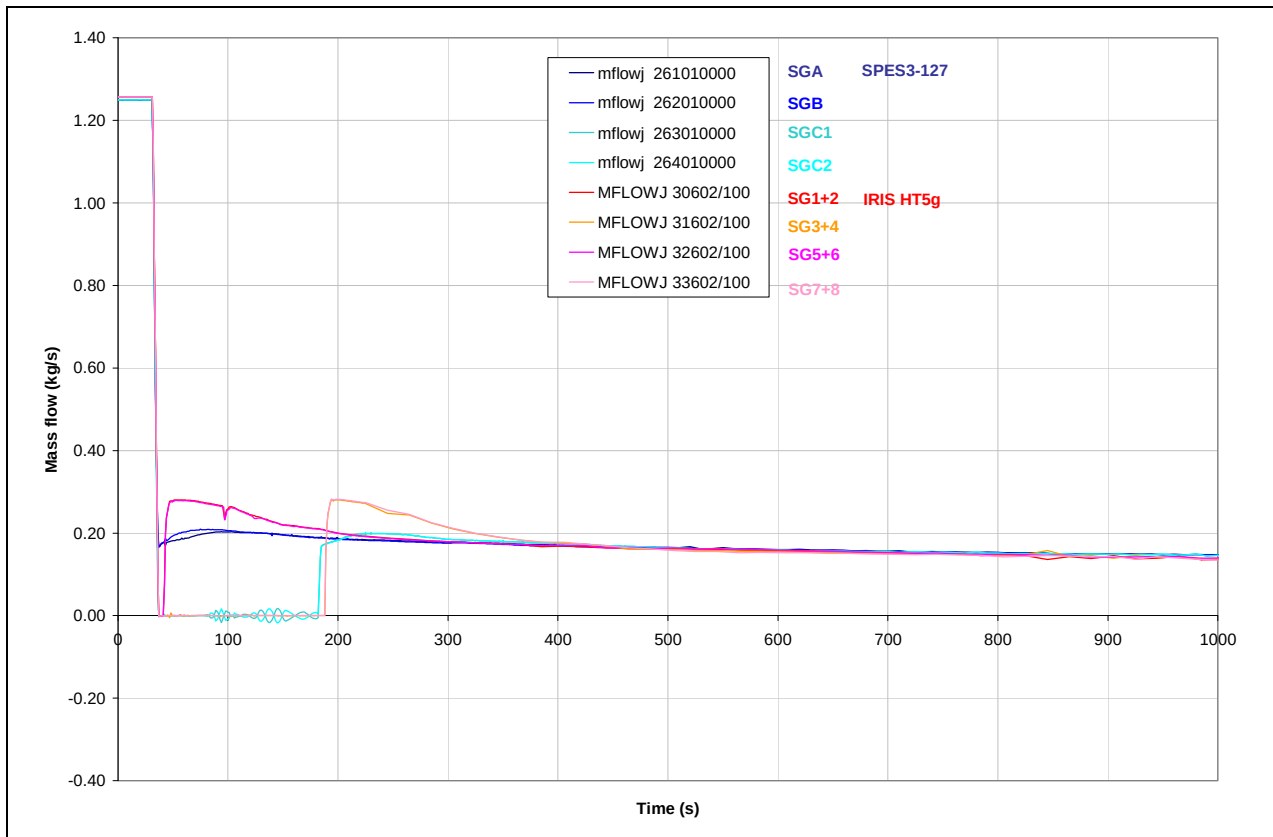
**Fig.6. 33 – SPES3-127 and IRIS HT5g SG power (window)**



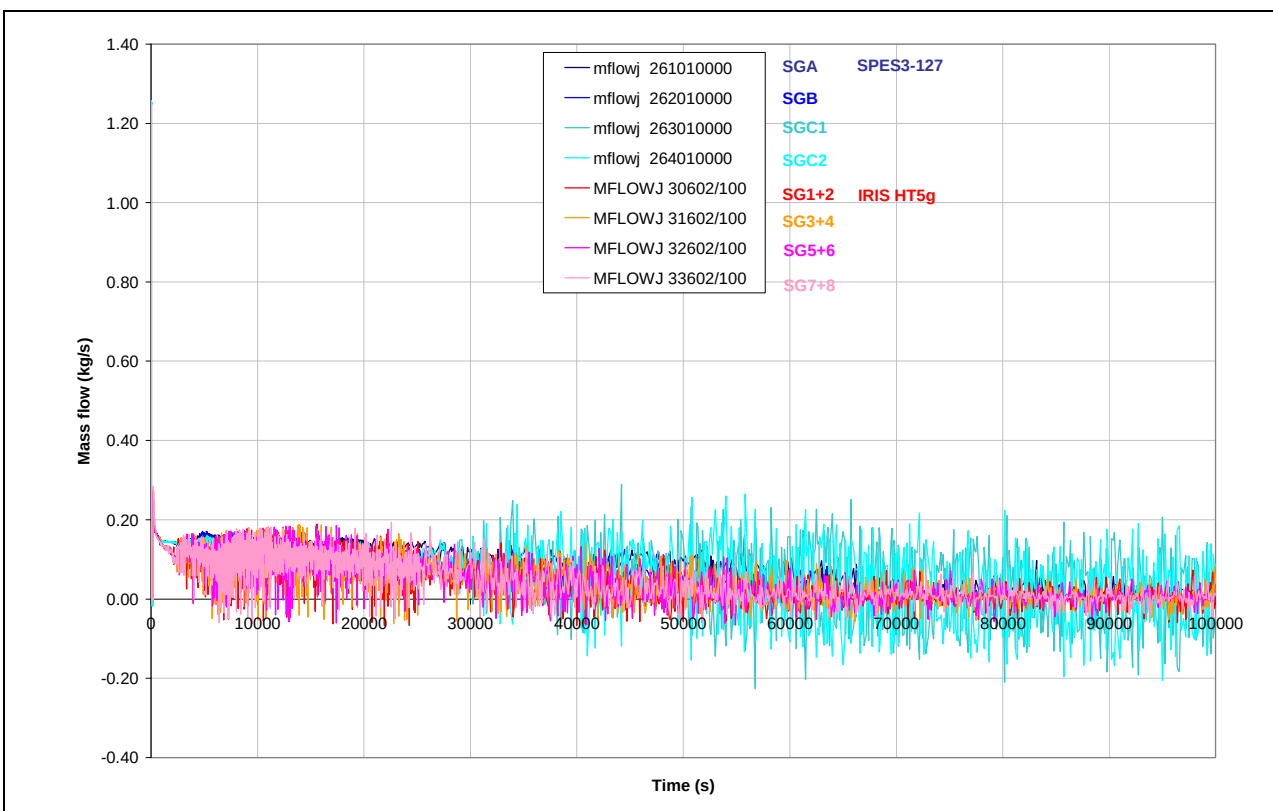
**Fig.6. 34 – SPES3-127 and IRIS HT5g SG power**



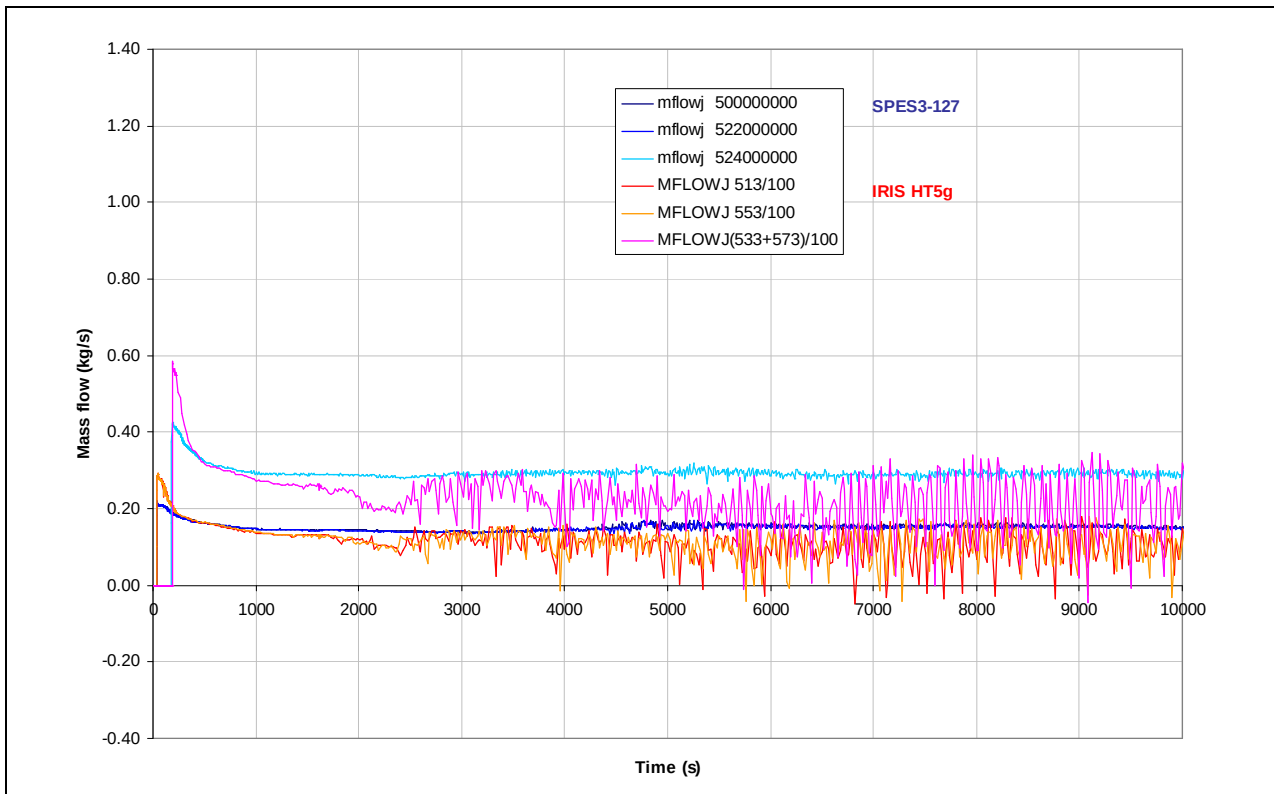
**Fig.6. 35 – SPES3-127 and IRIS HT5g SG ss mass flow (window)**



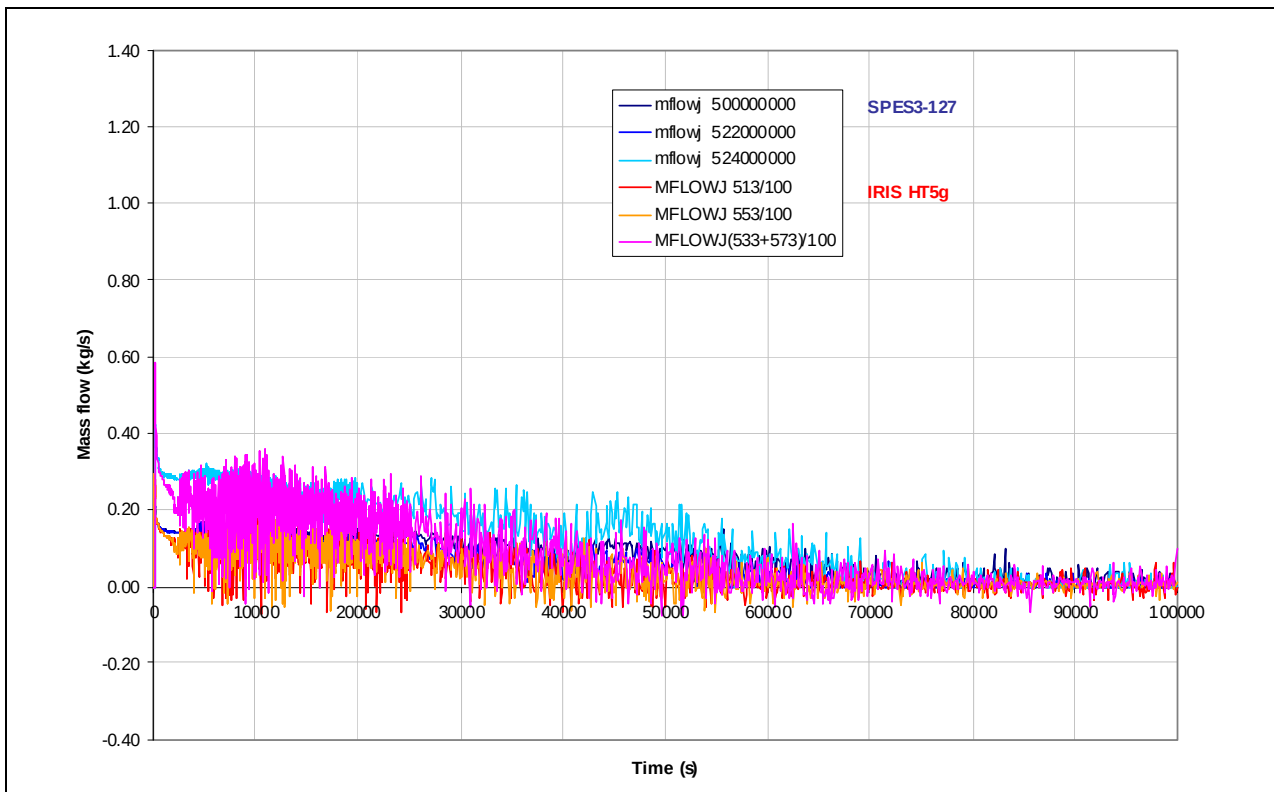
**Fig.6. 36 – SPES3-127 and IRIS HT5g SG ss mass flow**



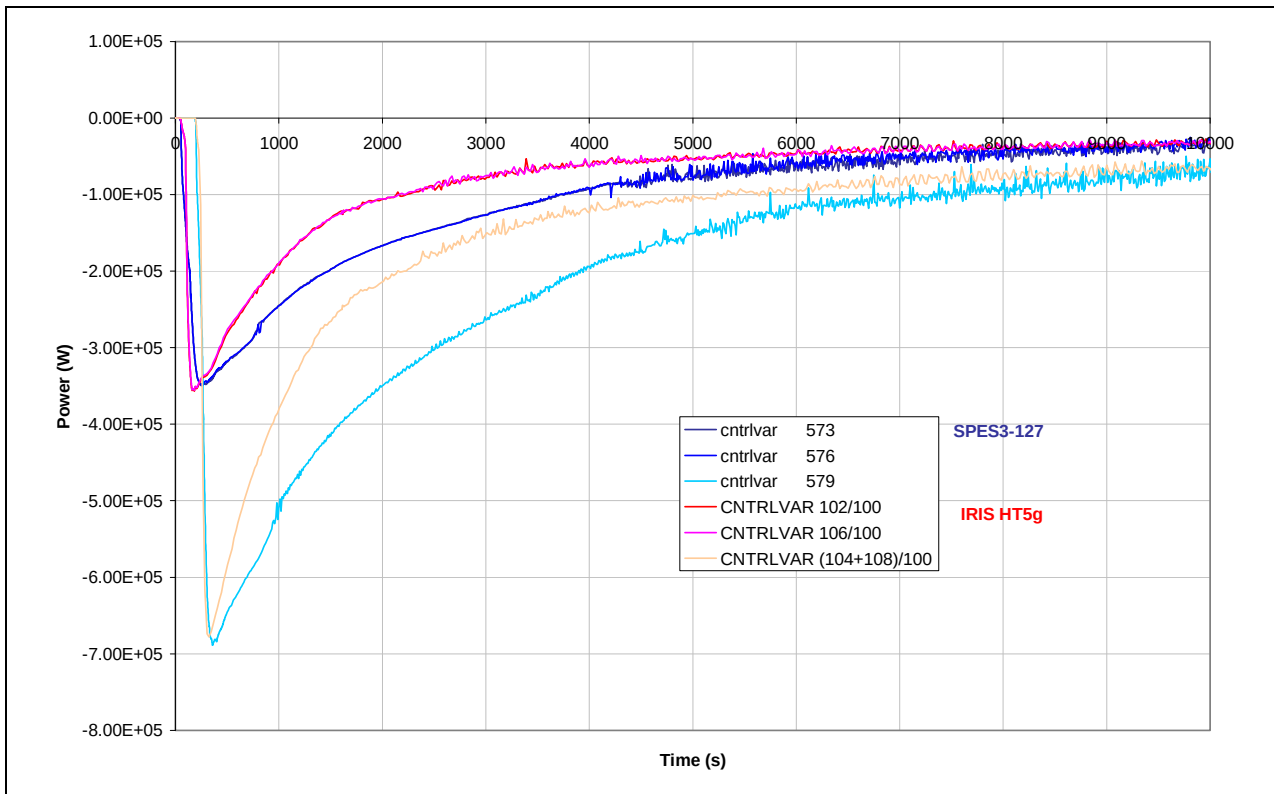
**Fig.6. 37 – SPES3-127 and IRIS HT5g EHRs cold leg mass flow (window)**



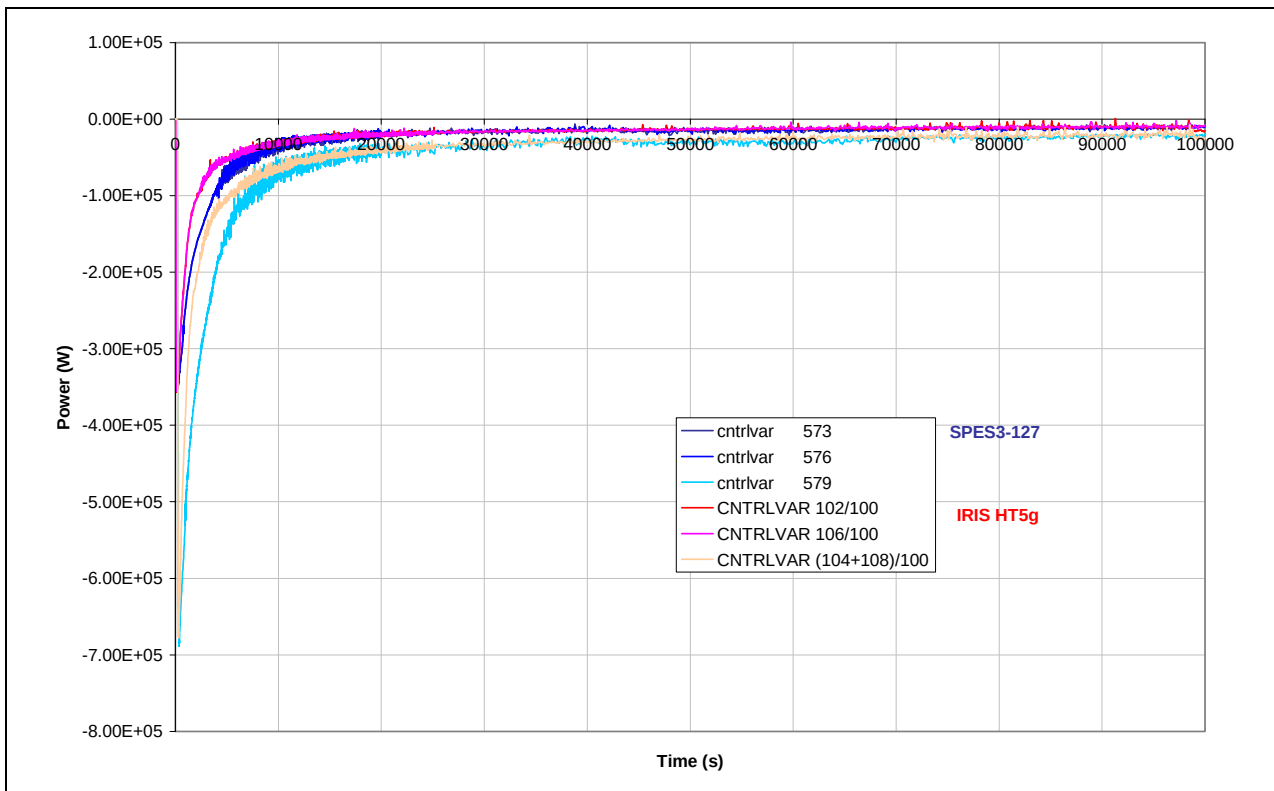
**Fig.6. 38 – SPES3-127 and IRIS HT5g EHRs cold leg mass flow**



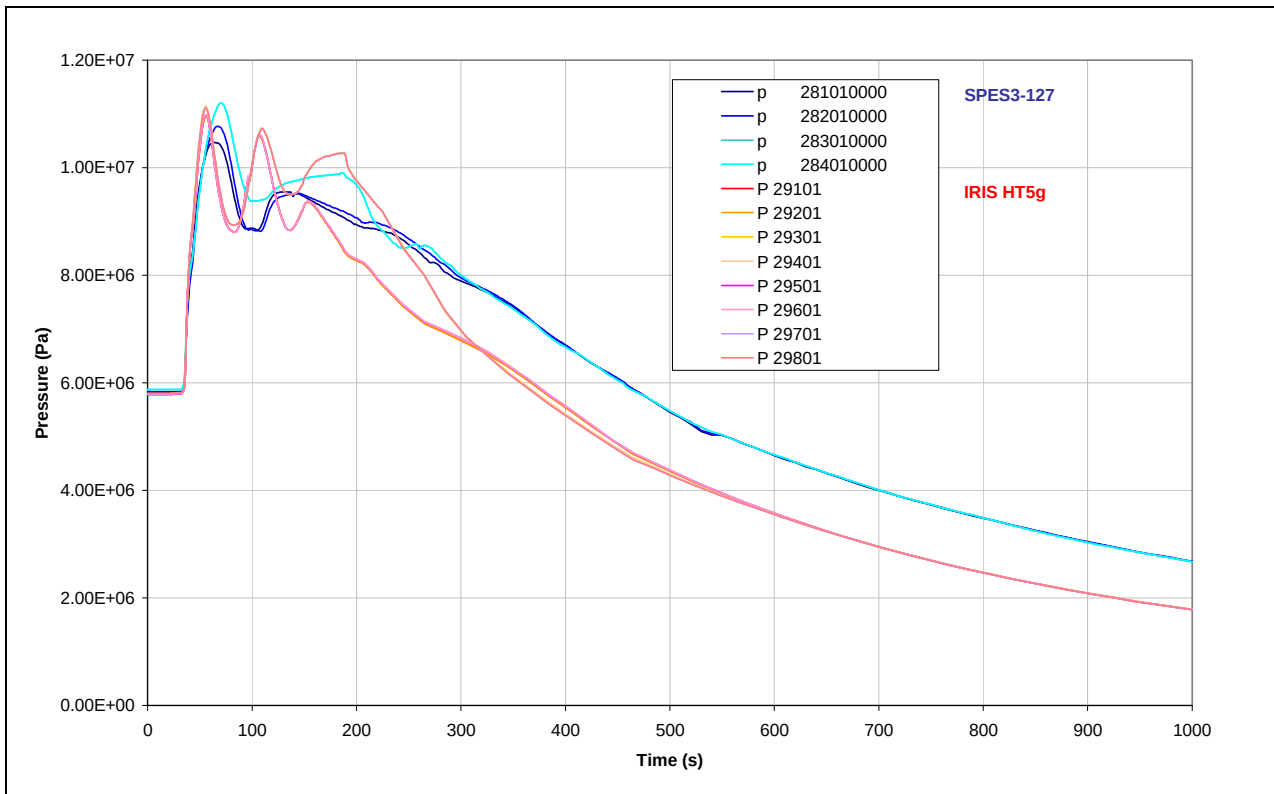
**Fig.6. 39 – SPES3-127 and IRIS HT5g EHRS power (window)**



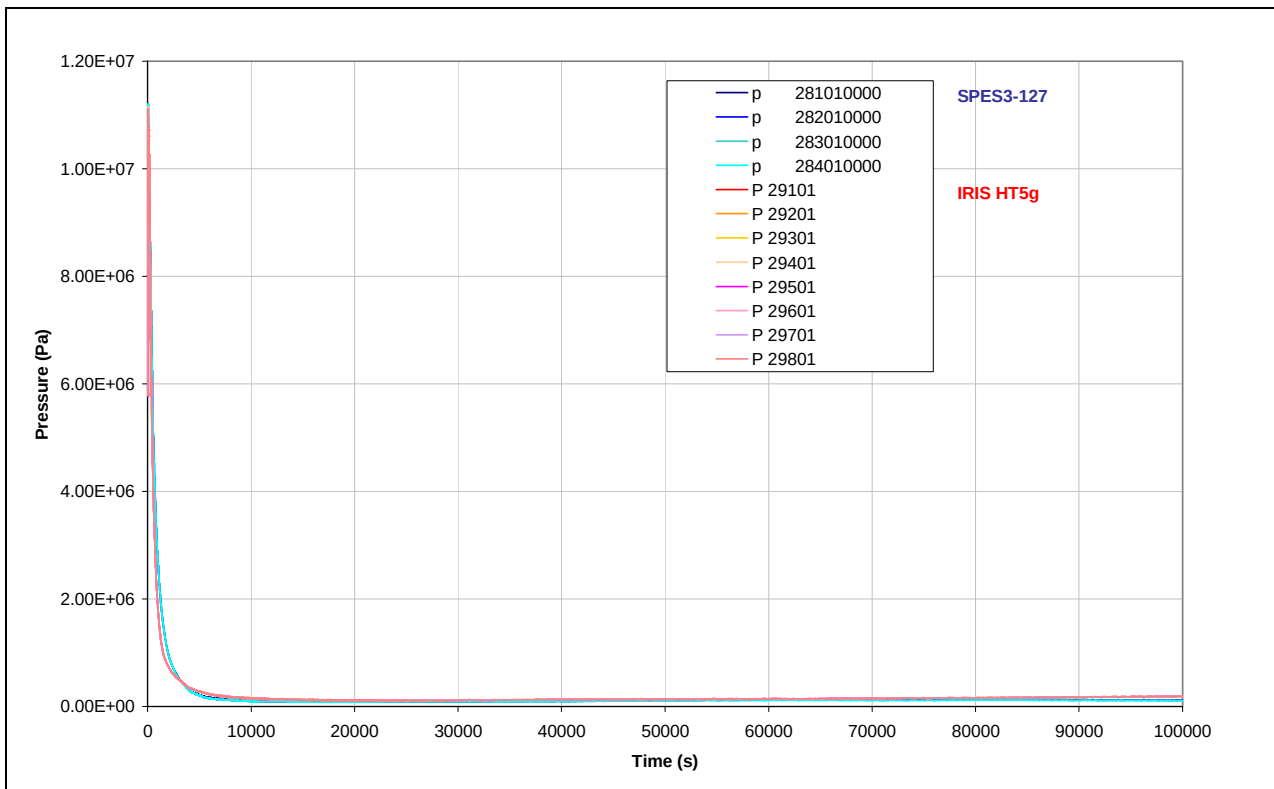
**Fig.6. 40 – SPES3-127 and IRIS HT5g EHRS power**



**Fig.6. 41 – SPES3-127 and IRIS HT5g SG ss outlet pressure (window)**

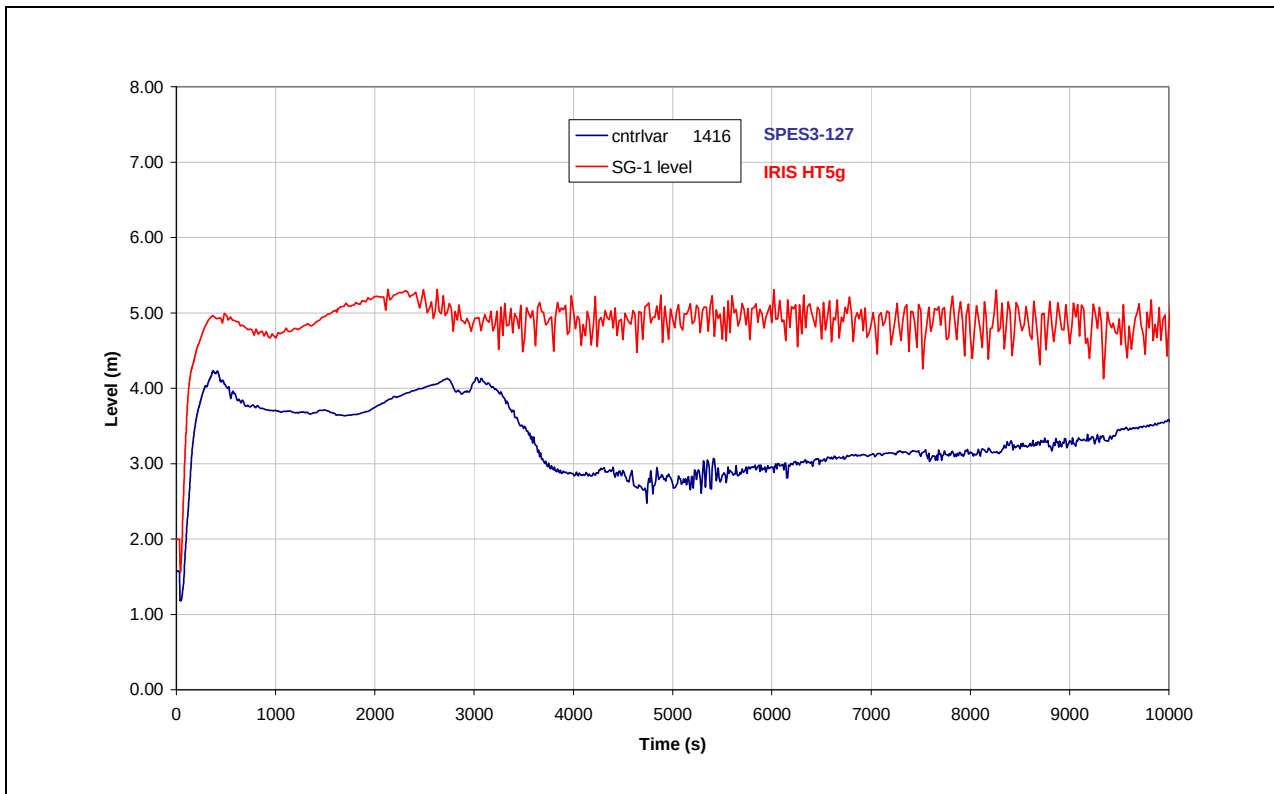


**Fig.6. 42 – SPES3-127 and IRIS HT5g SG ss outlet pressure**

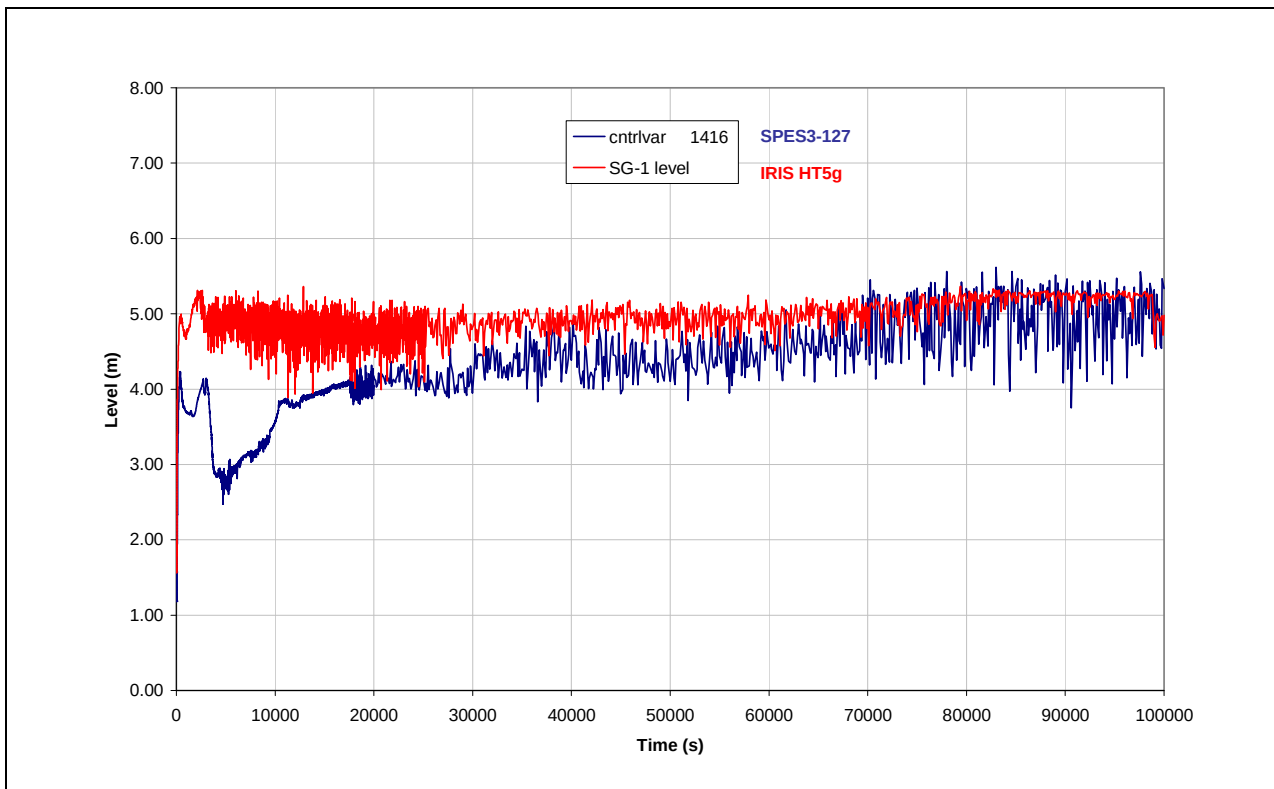




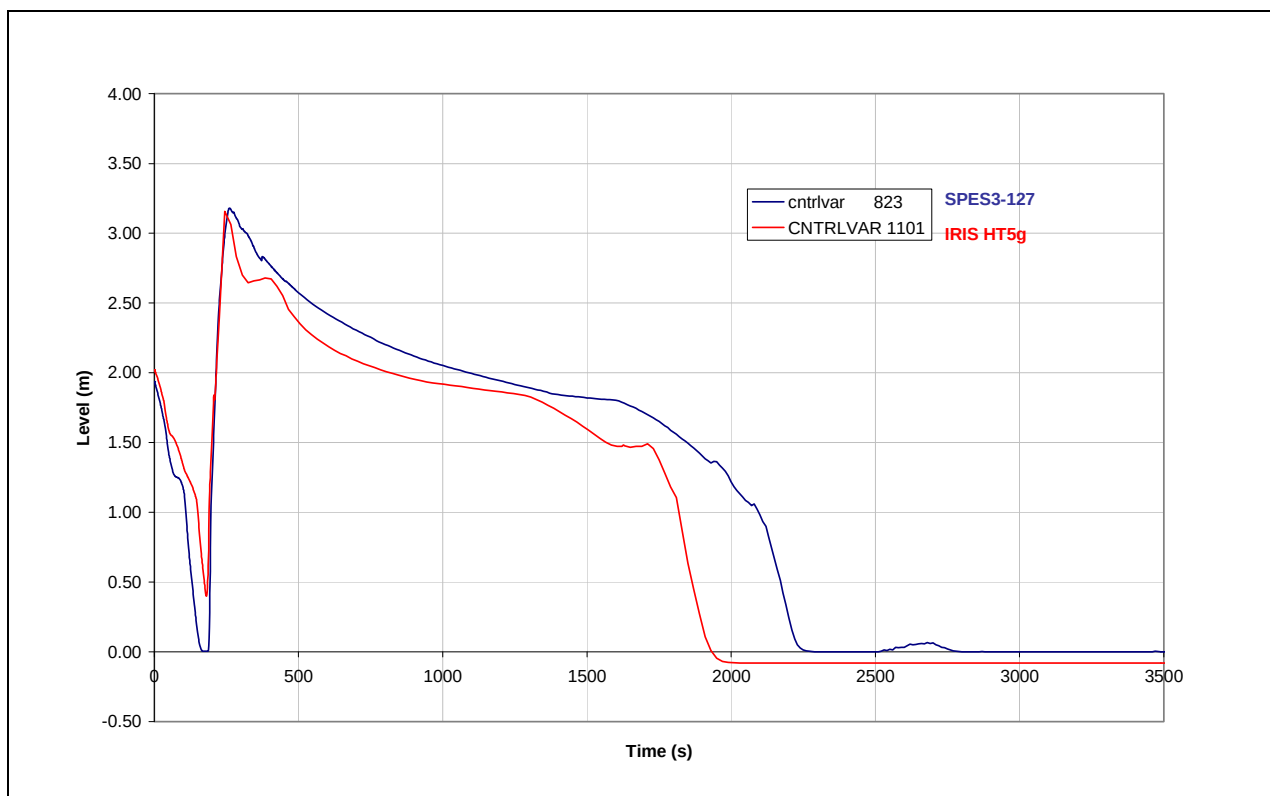
**Fig.6. 43 – SPES3-127 and IRIS HT5g SG-1ss collapsed level (window)**



**Fig.6. 44 – SPES3-127 and IRIS HT5g SG-1ss collapsed level**



**Fig.6. 45 – SPES3-127 and IRIS HT5g PRZ level**



**Fig.6. 46 – SPES3-127 and IRIS HT5g DVI break SPLIT integral flow**

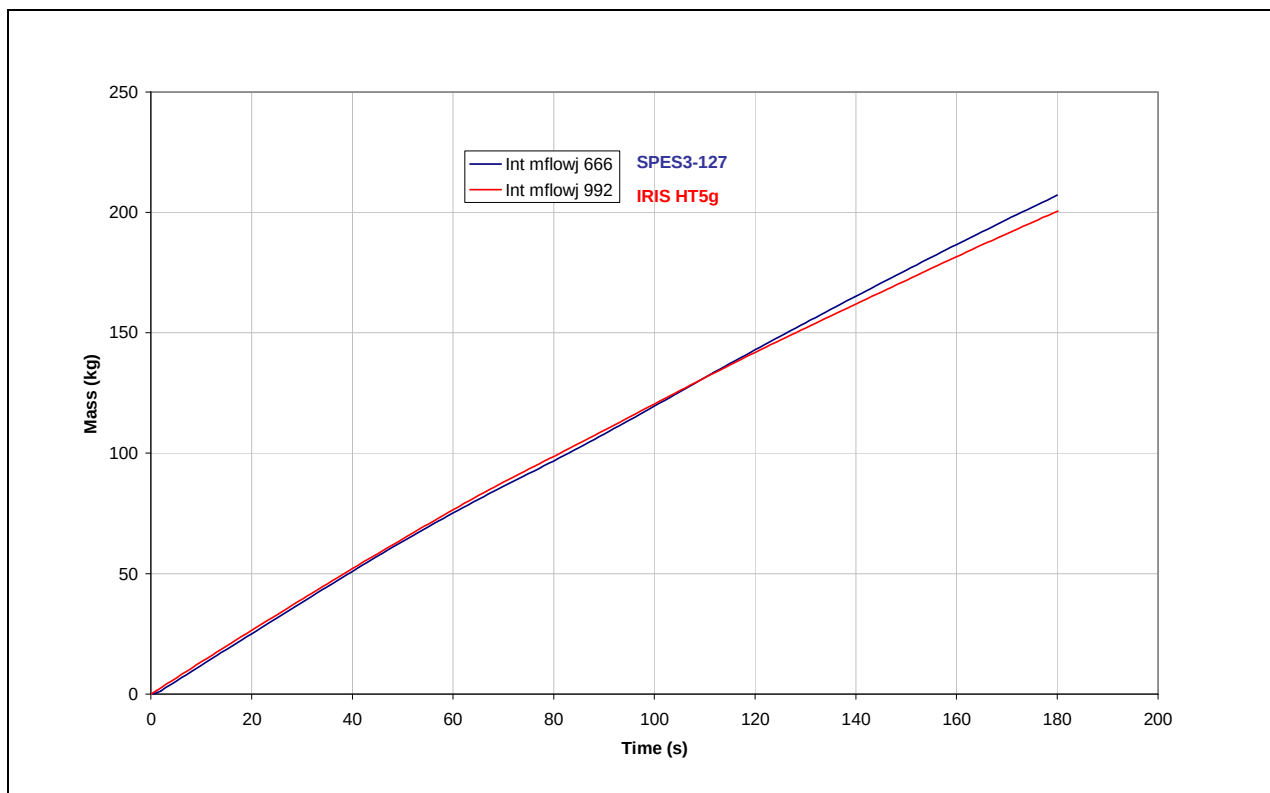


Fig.6. 47 – SPES3-127 and IRIS HT5g pump inlet liquid fraction

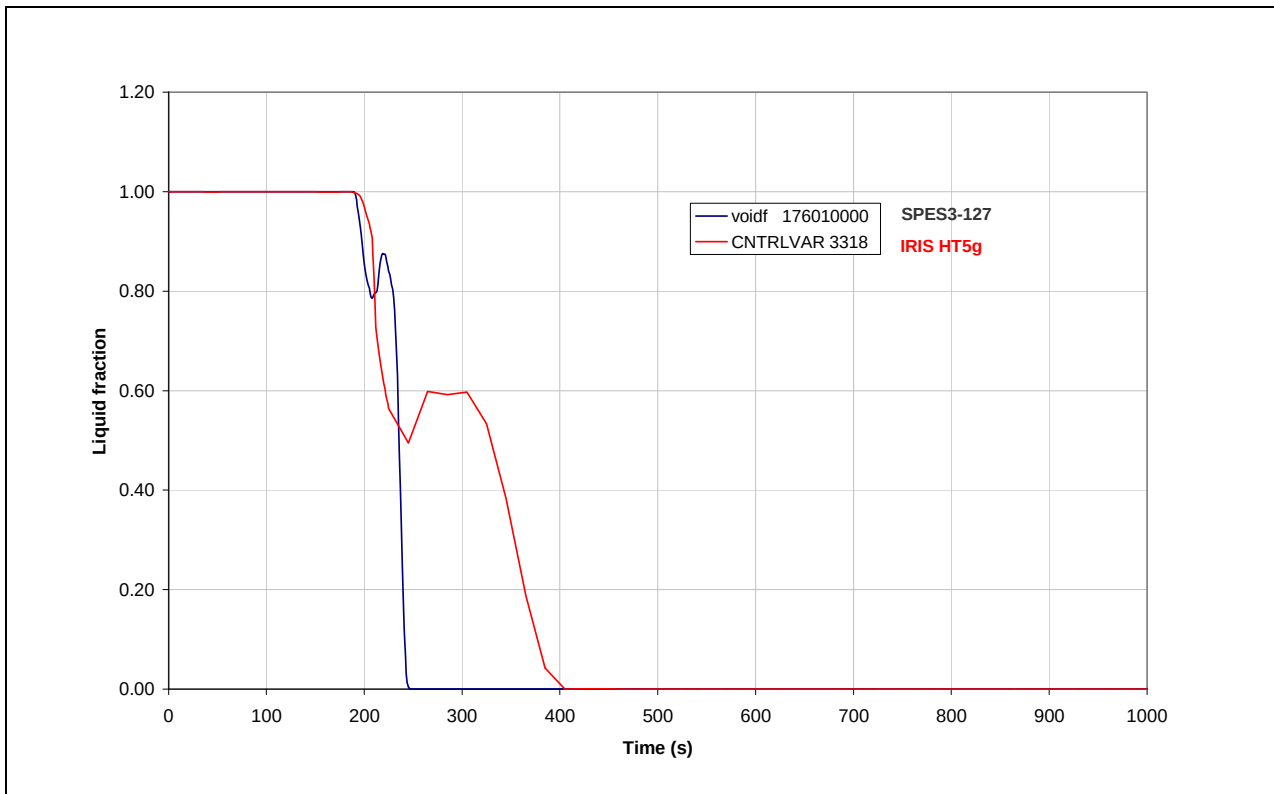


Fig.6. 48 – SPES3-127 and IRIS HT5g core outlet flow (window)

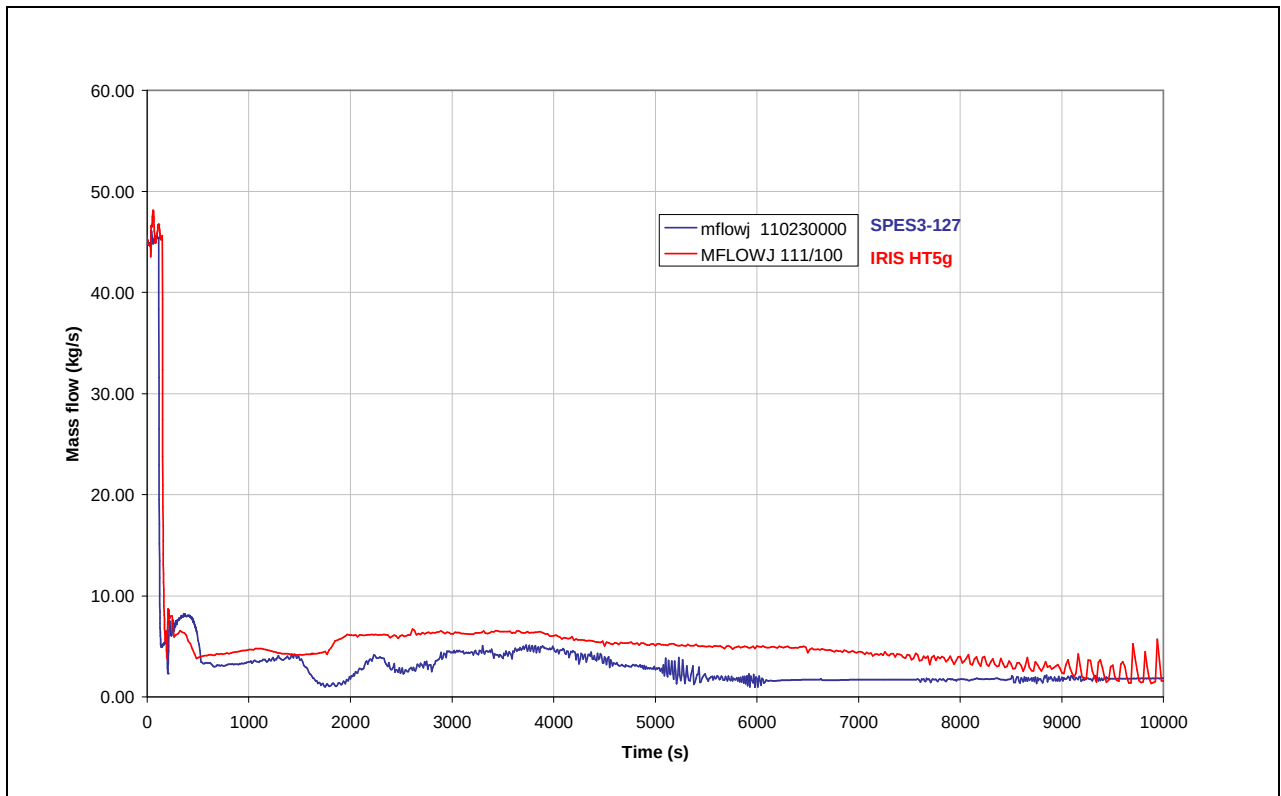


Fig.6. 49 – SPES3-127 and IRIS HT5g core outlet flow

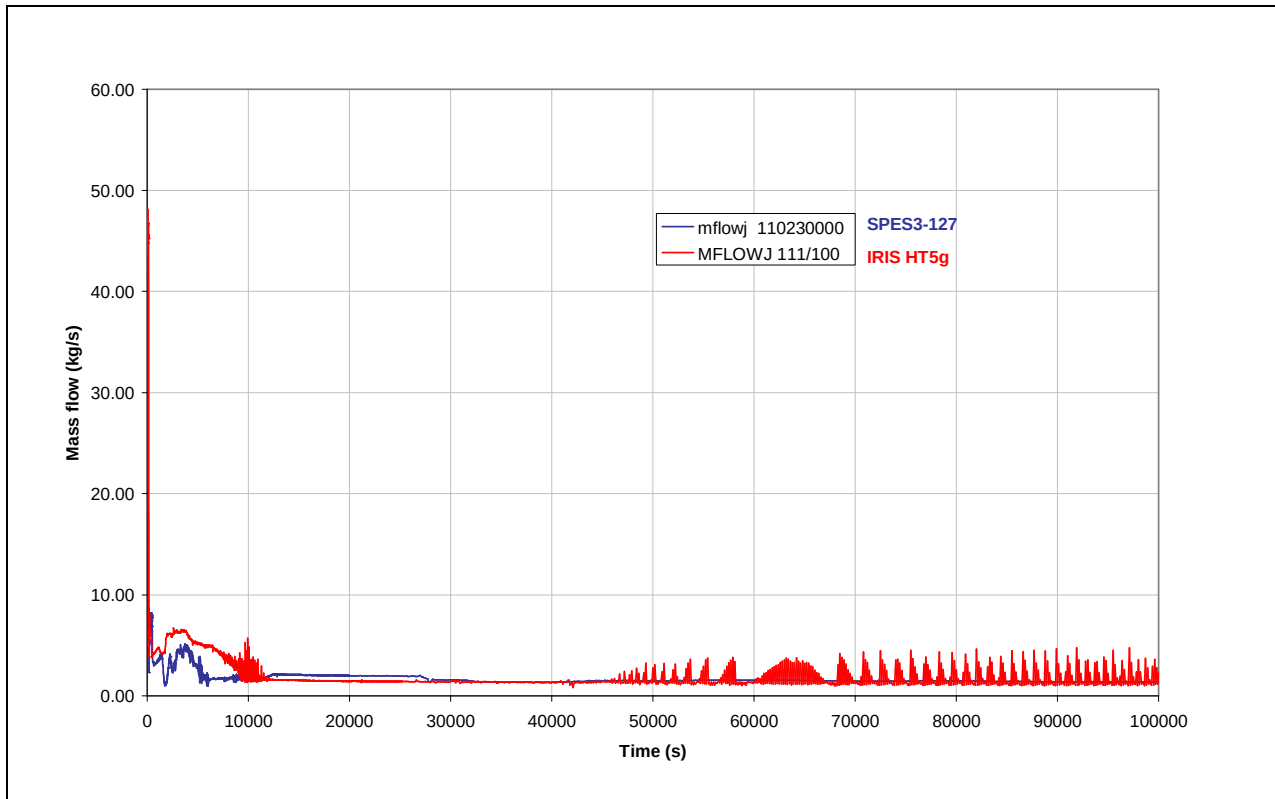


Fig.6. 50 – SPES3-127 and IRIS HT5g RI-DC check valve mass flow (window)

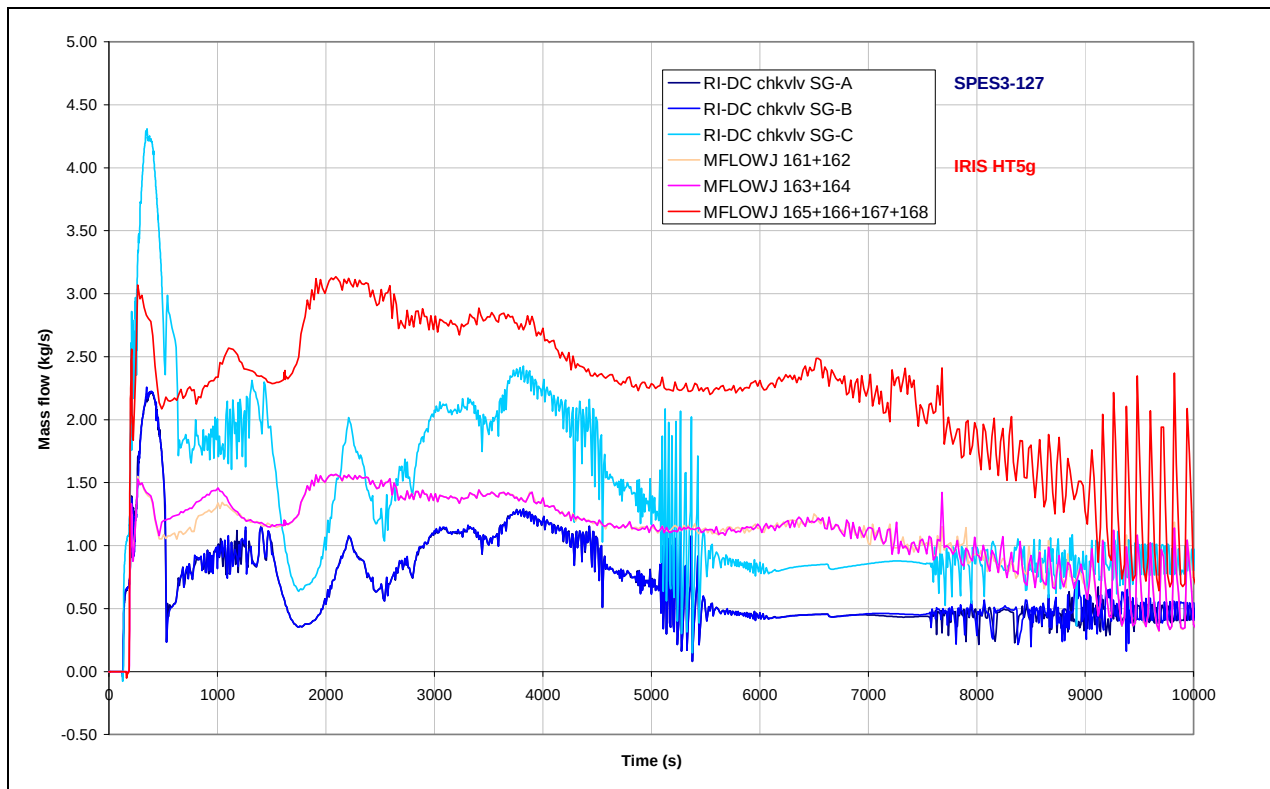


Fig.6. 51 – SPES3-127 and IRIS HT5g RI-DC check valve mass flow

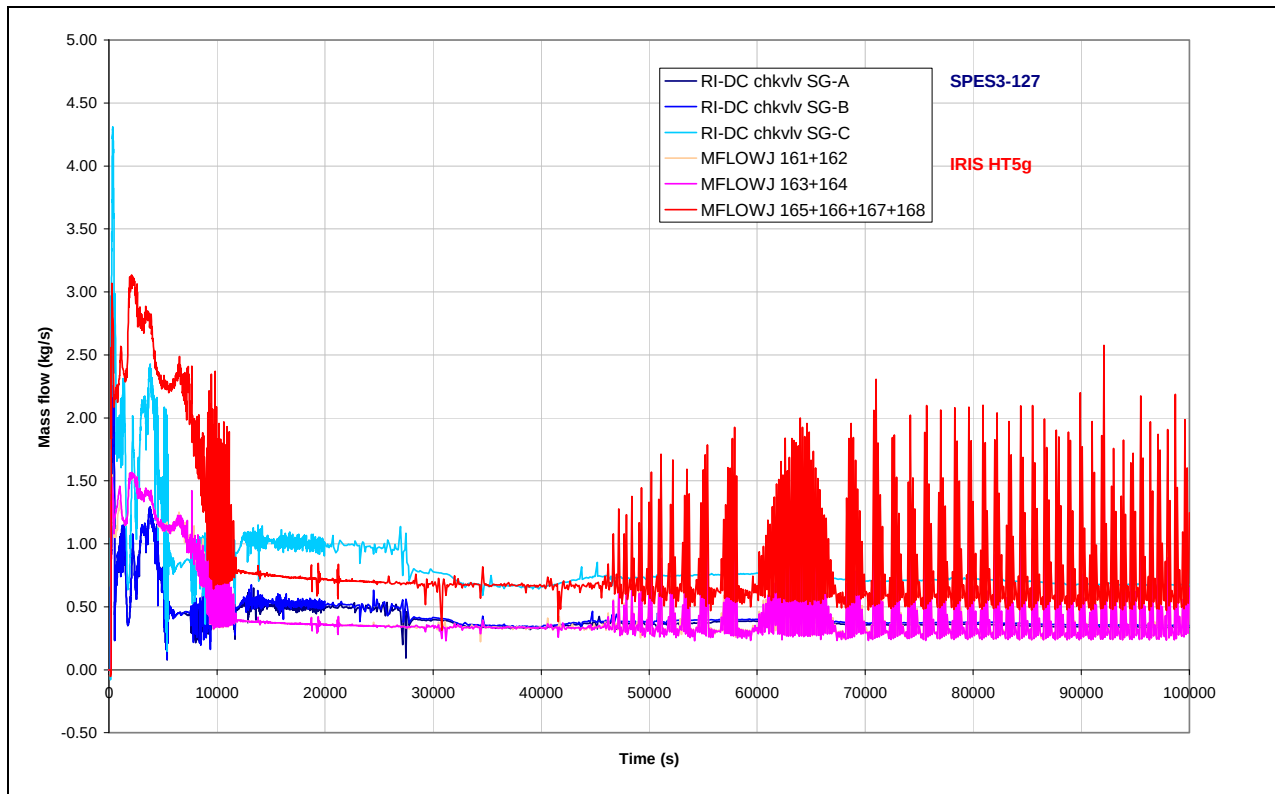


Fig.6. 52 – SPES3-127 and IRIS HT5g core liquid void fraction (window)

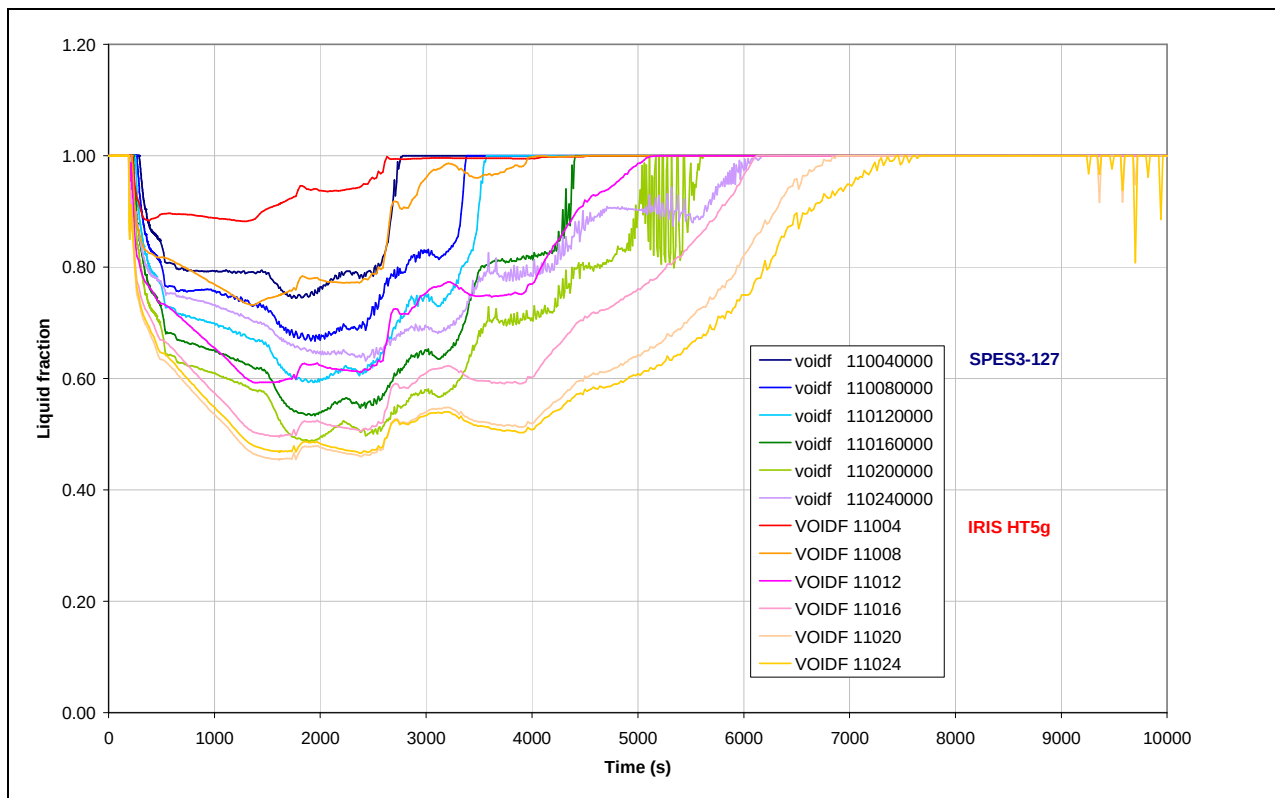


Fig.6. 53 – SPES3-127 and IRIS HT5g core liquid void fraction

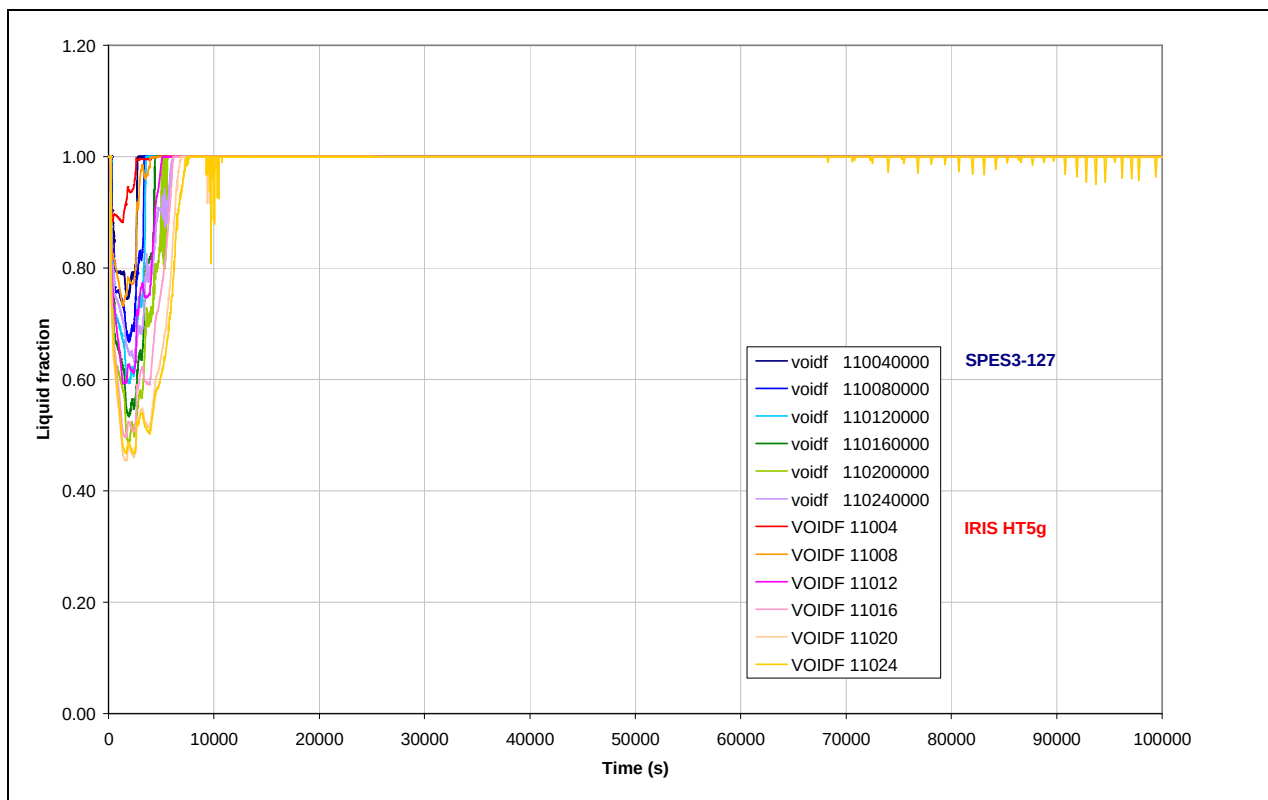
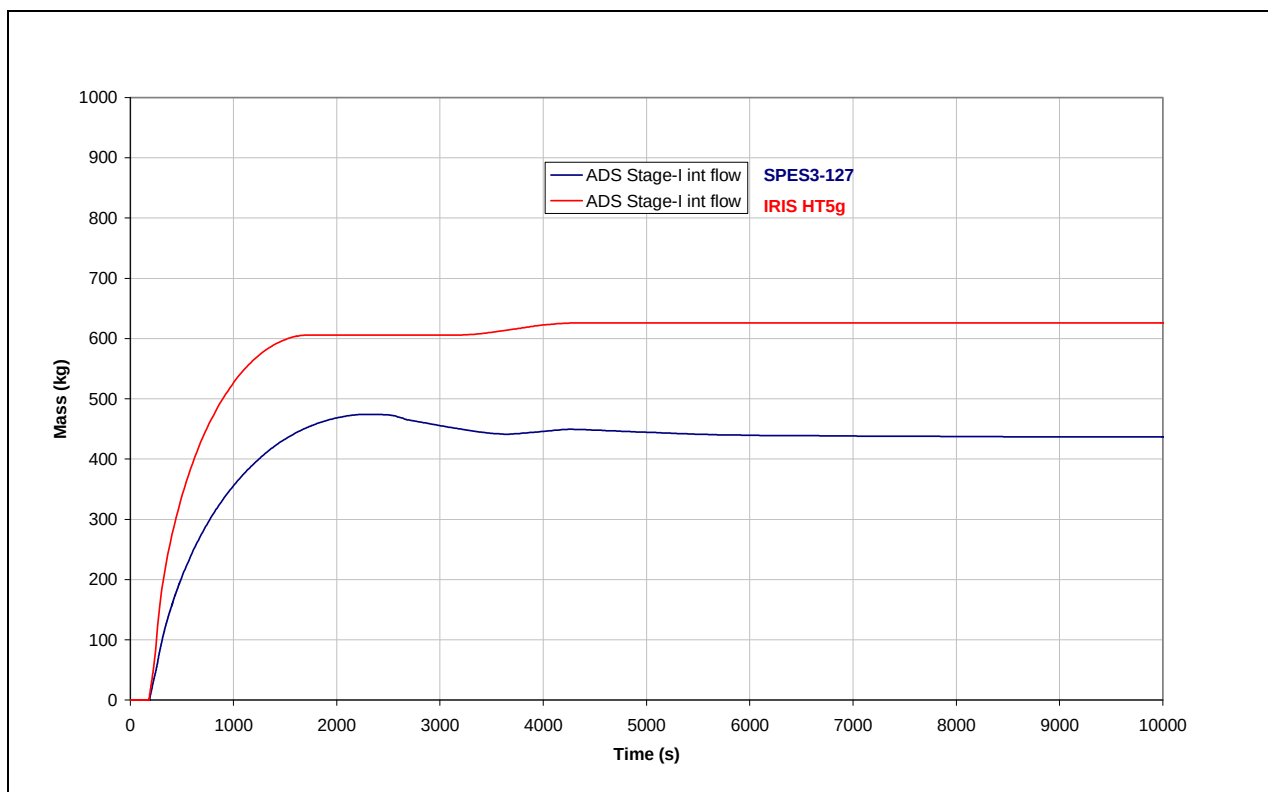
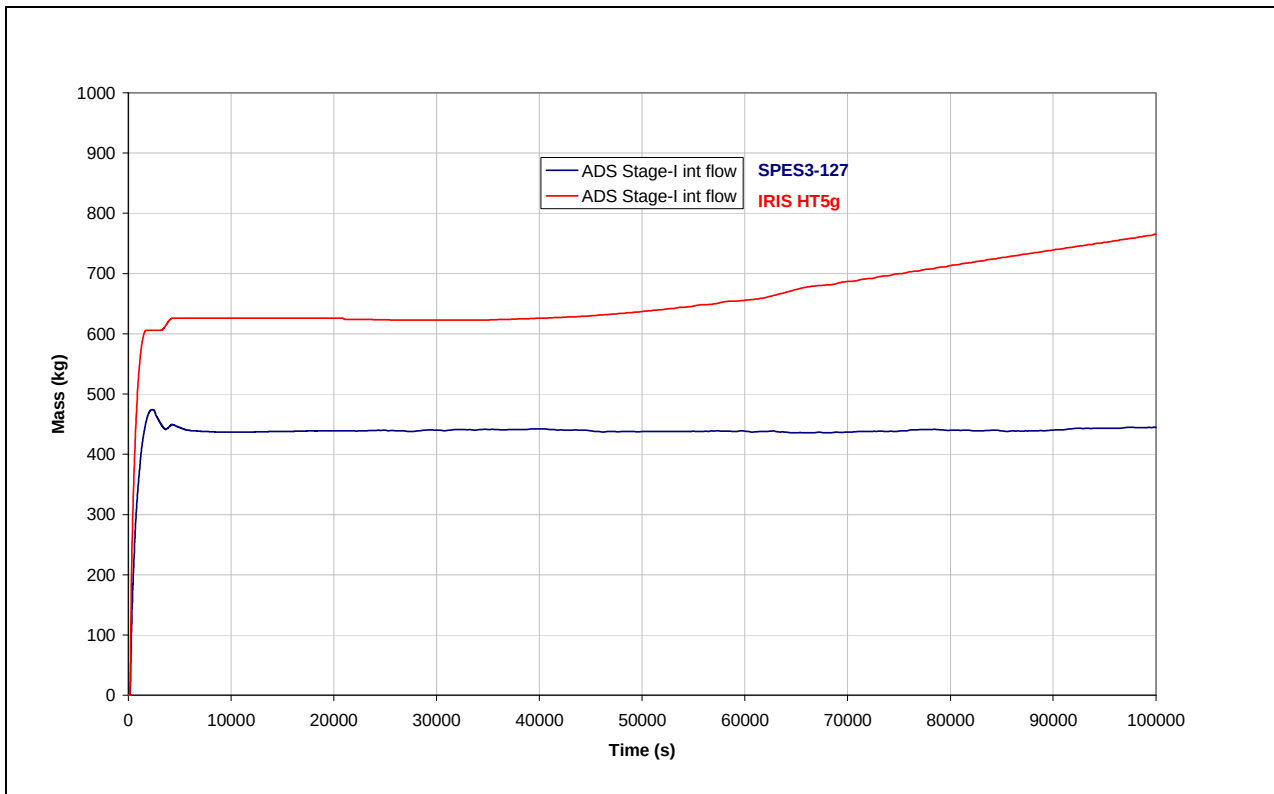


Fig.6. 54 – SPES3-127 and IRIS HT5g ADS Stage-I integral flow (window)



**Fig.6. 55 – SPES3-127 and IRIS HT5g ADS Stage-I integral flow**



**Fig.6. 56 – SPES3-127 and IRIS HT5g RV mass**

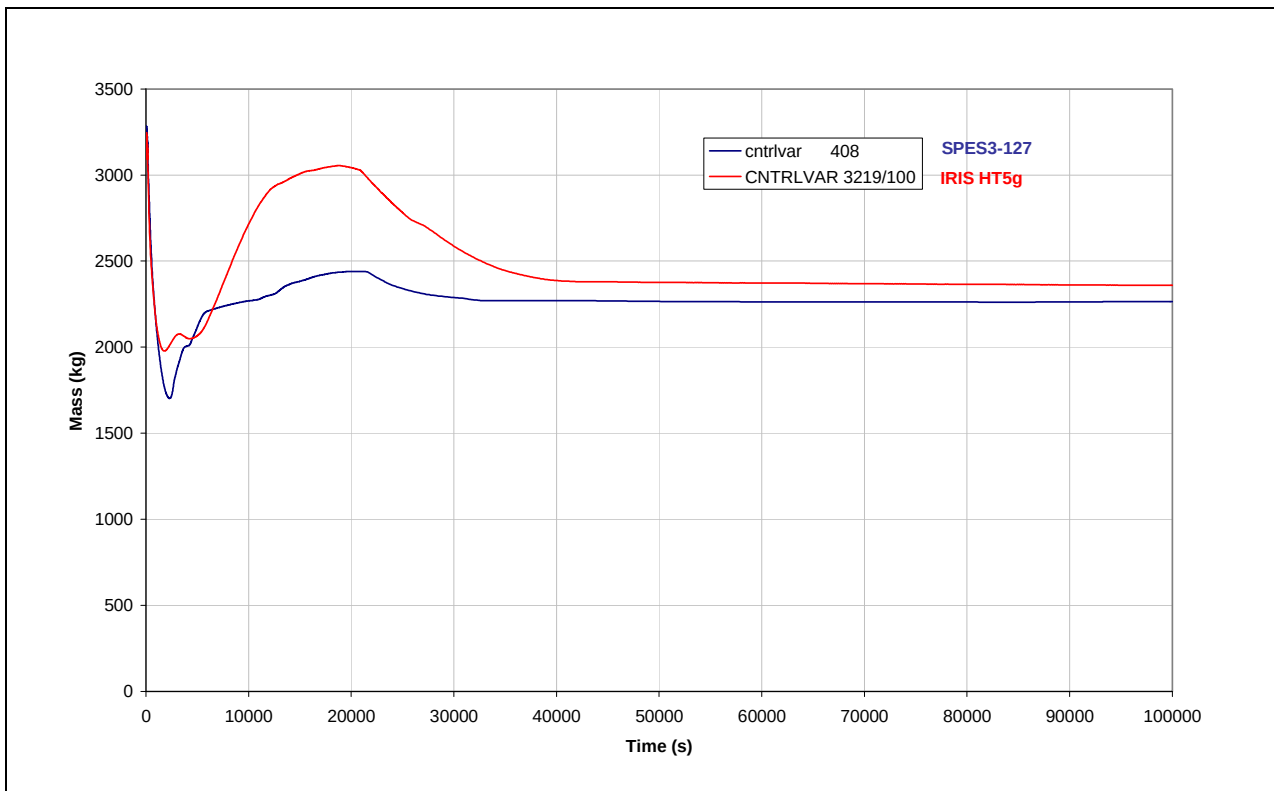


Fig.6. 57 – SPES3-127 and IRIS HT5g EBT injection mass flow (window)

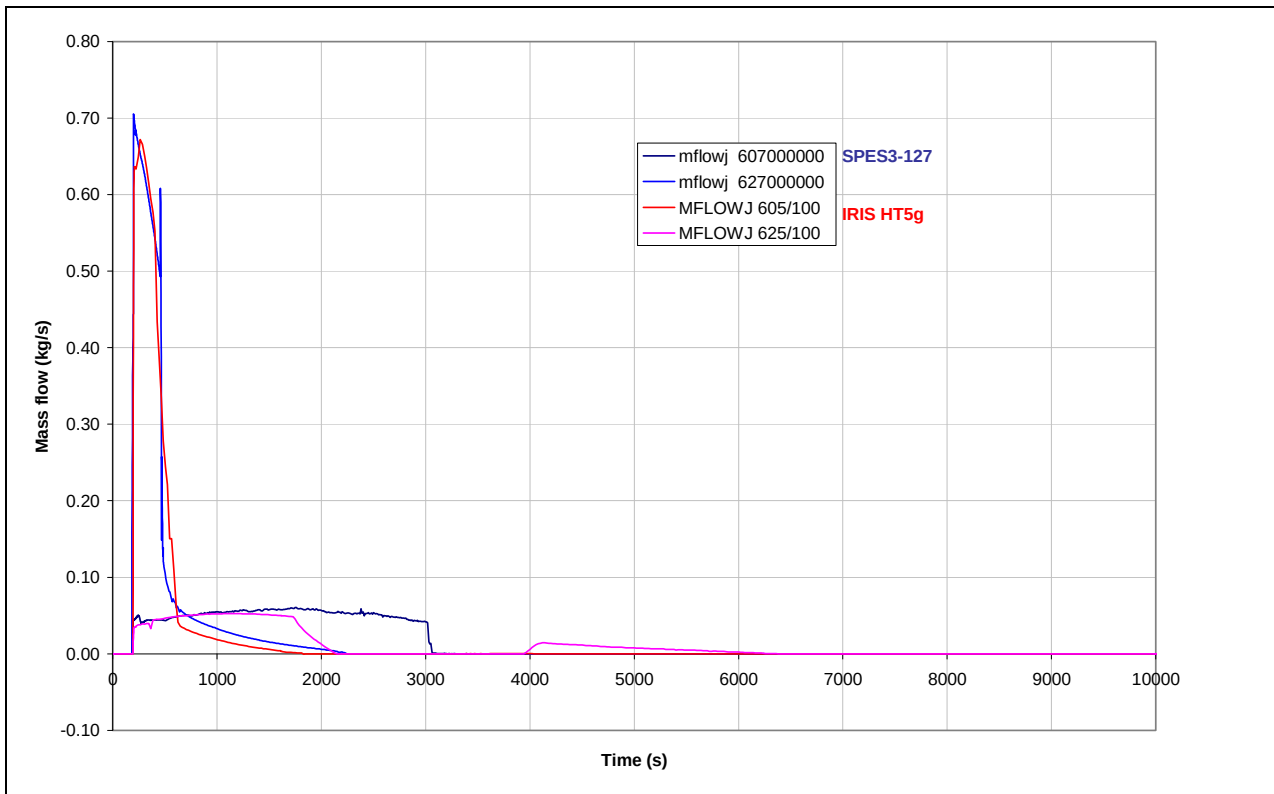
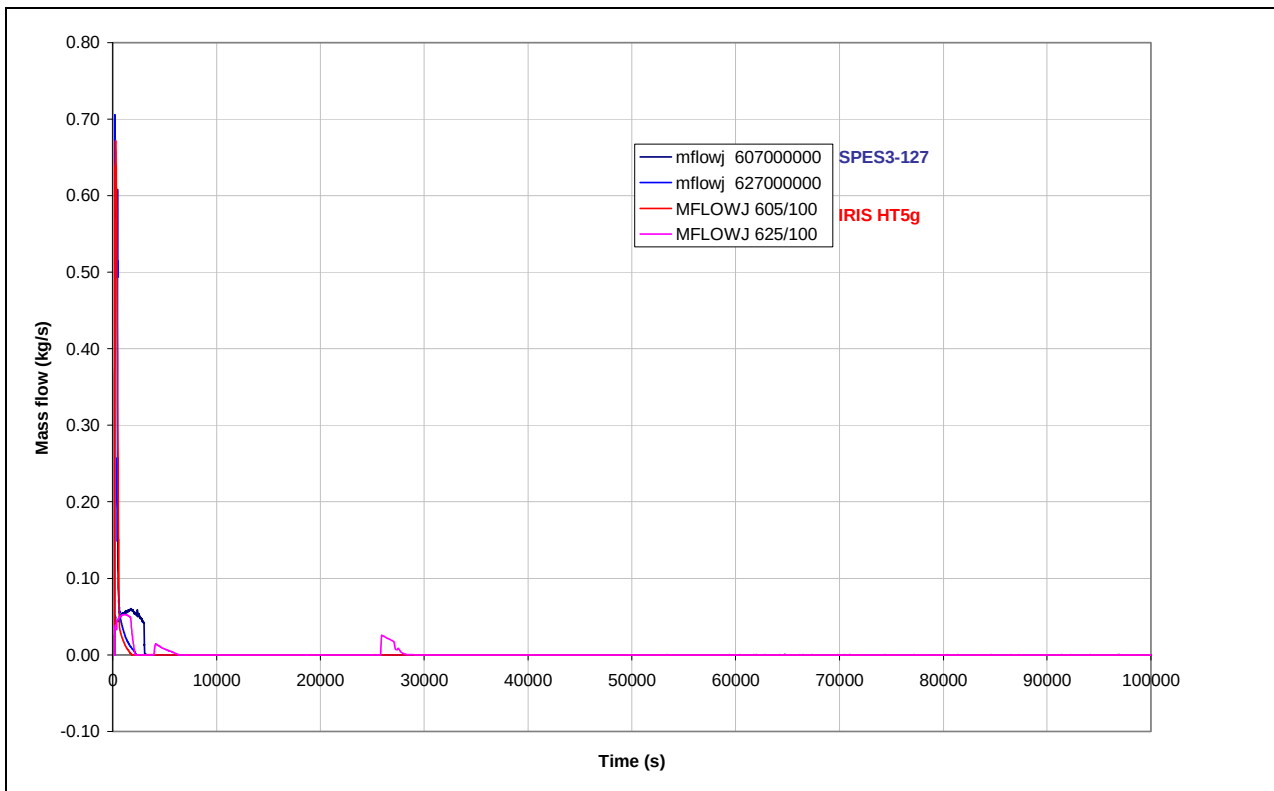
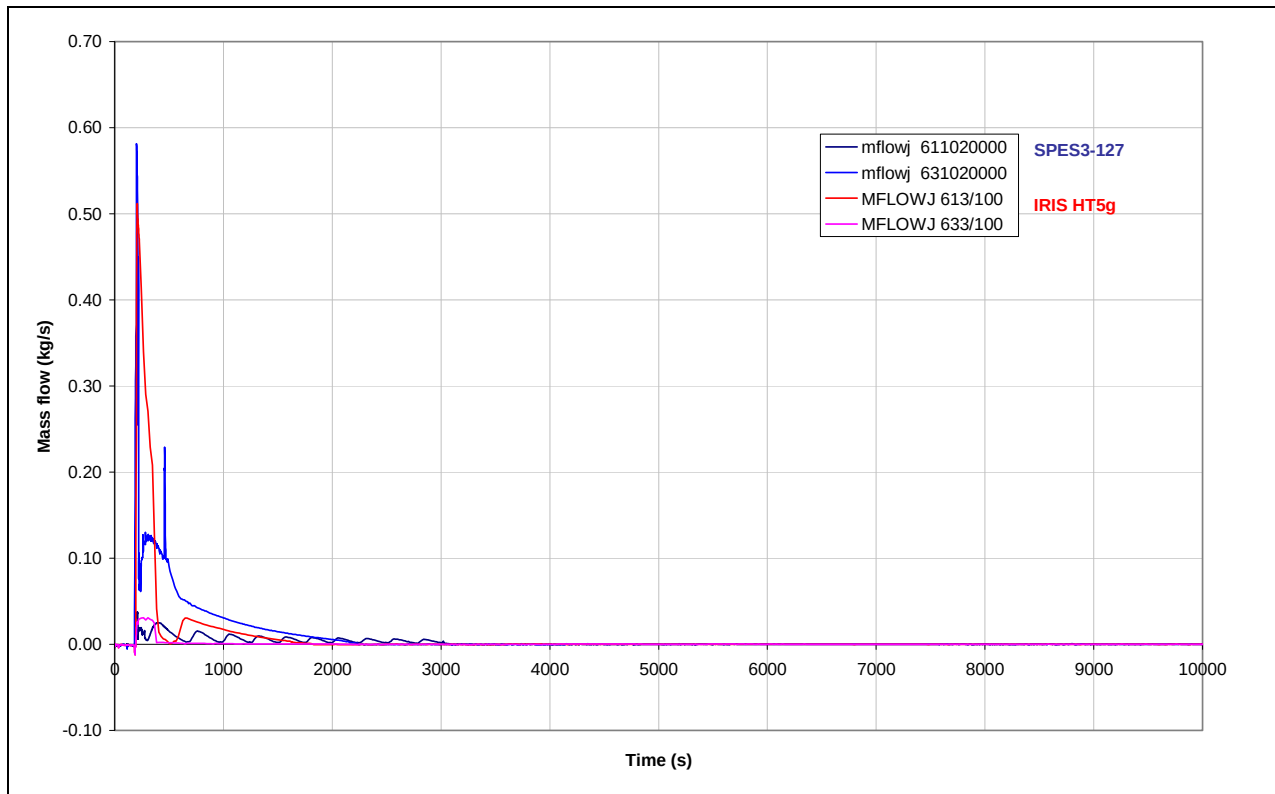


Fig.6. 58 – SPES3-127 and IRIS HT5g EBT injection mass flow





**Fig.6. 59 – SPES3-127 and IRIS HT5g EBT balance line to RV mass flow (window)**



**Fig.6. 60 – SPES3-127 and IRIS HT5g EBT level (window)**

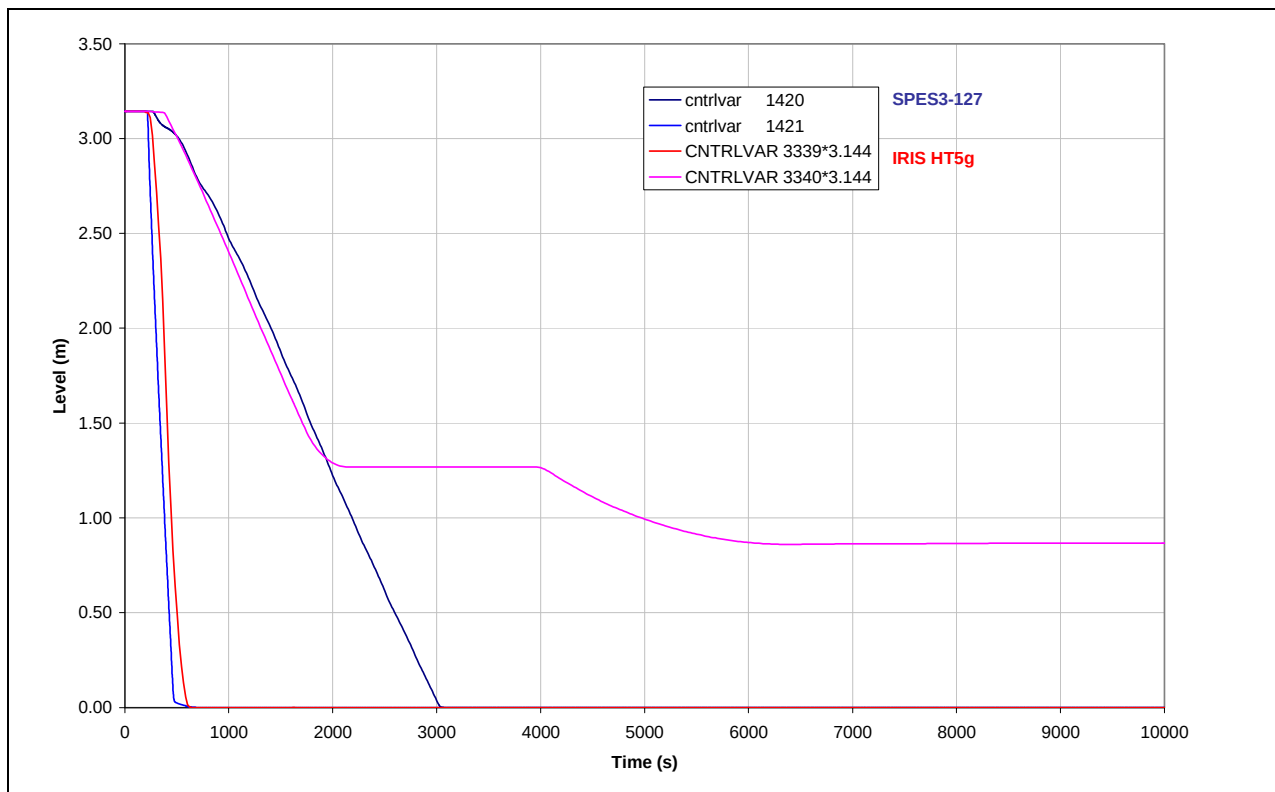


Fig.6. 61 – SPES3-127 and IRIS HT5g EBT level

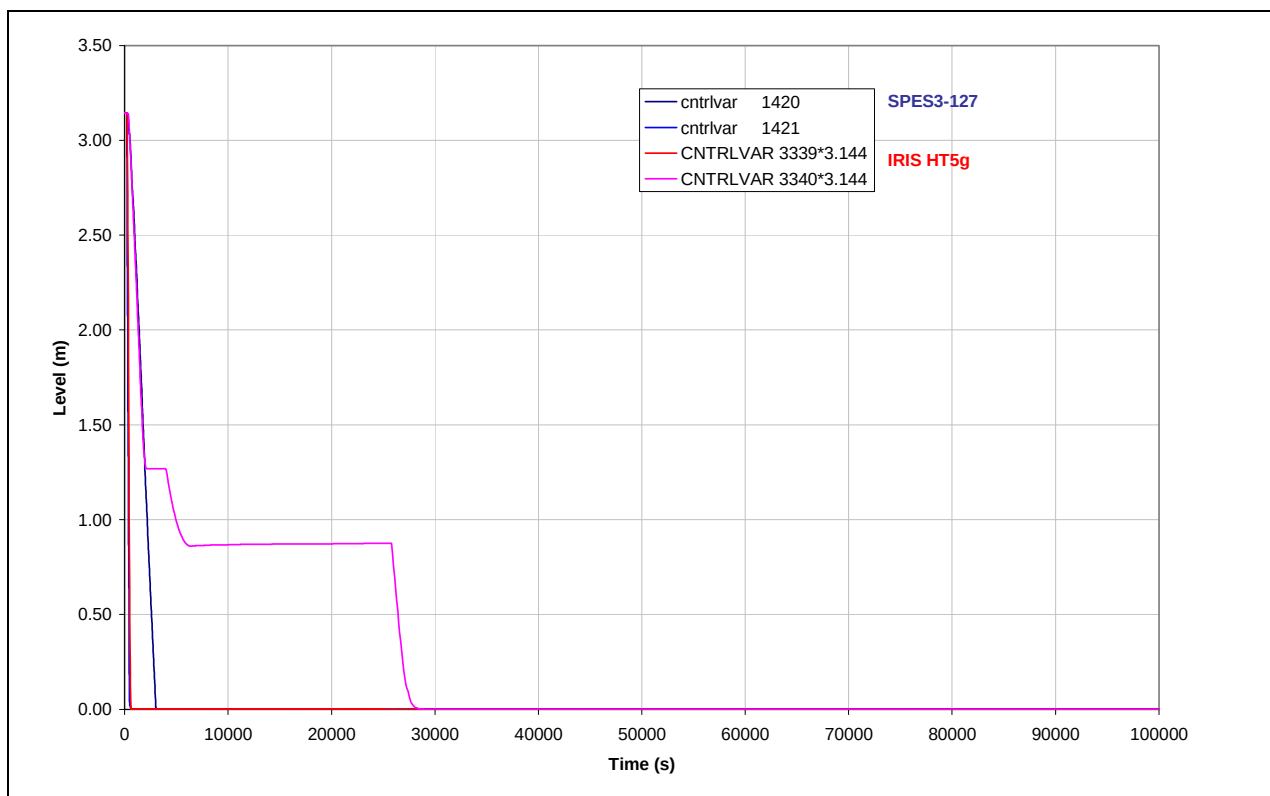


Fig.6. 62 – SPES3-127 and IRIS HT5g DVI mass flow (window)

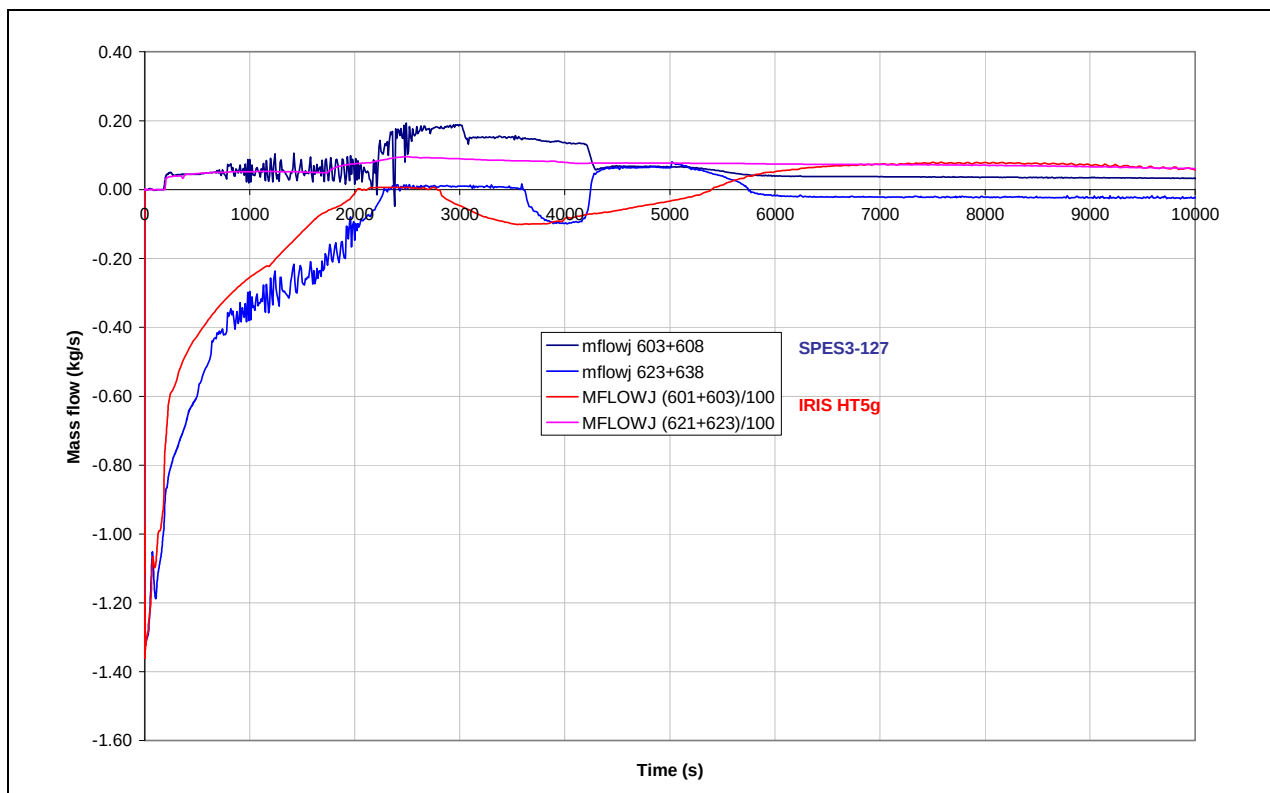


Fig.6. 63 – SPES3-127 and IRIS HT5g DVI mass flow

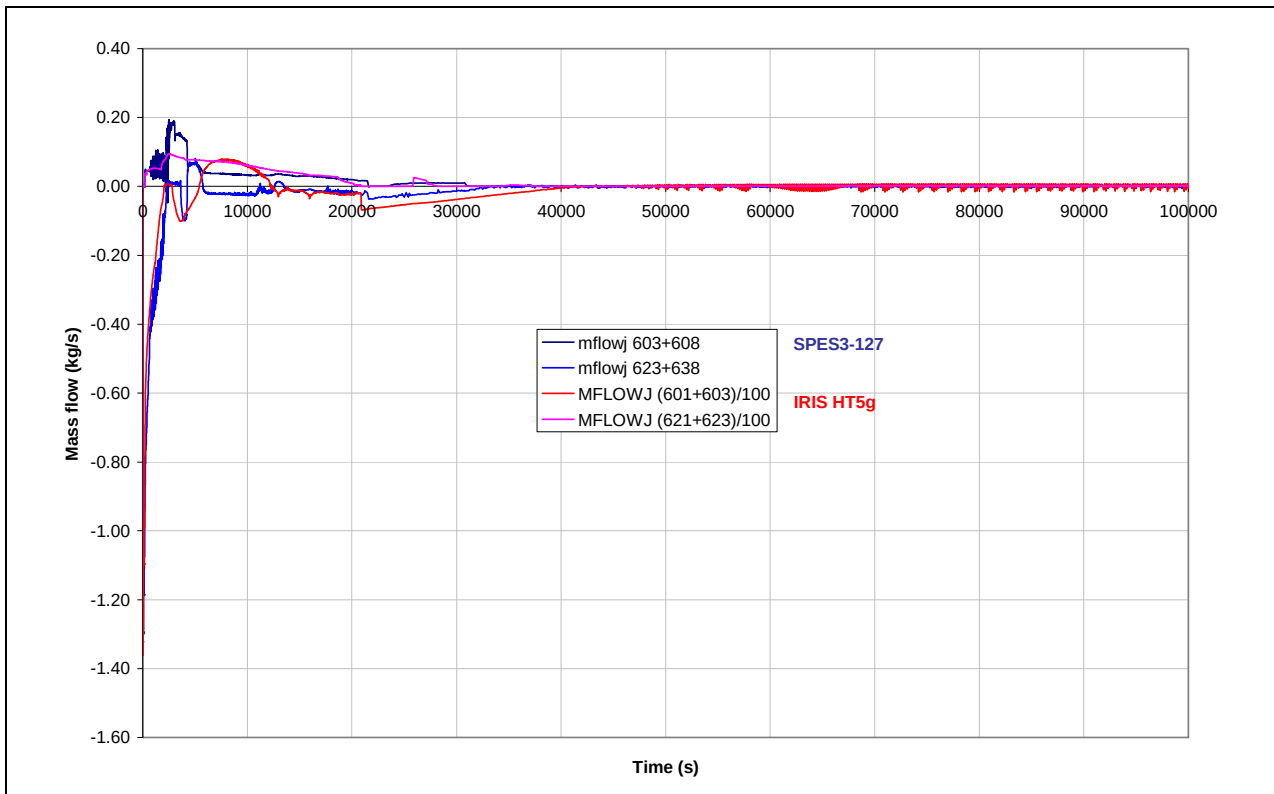


Fig.6. 64 – SPES3-127 and IRIS HT5g Core inlet and outlet temperatures (window)

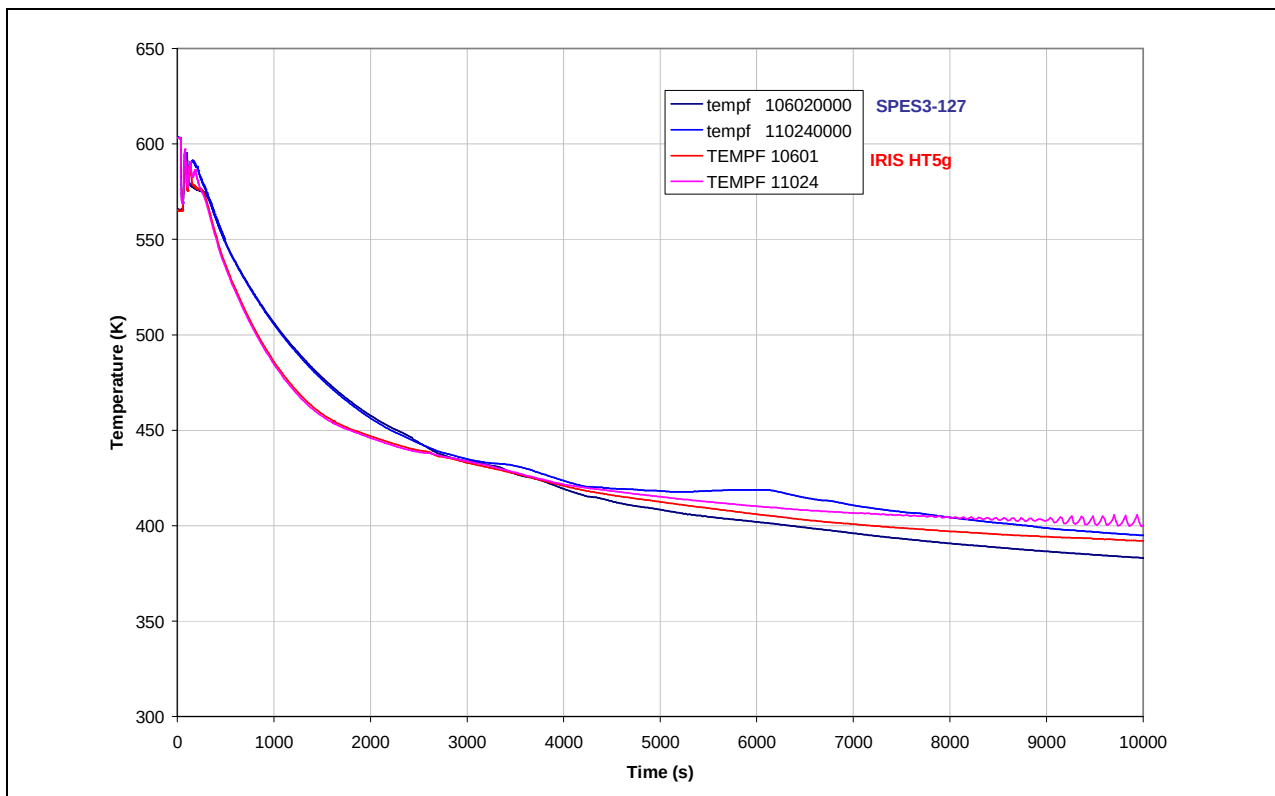


Fig.6. 65 – SPES3-127 and IRIS HT5g Core inlet and outlet temperatures

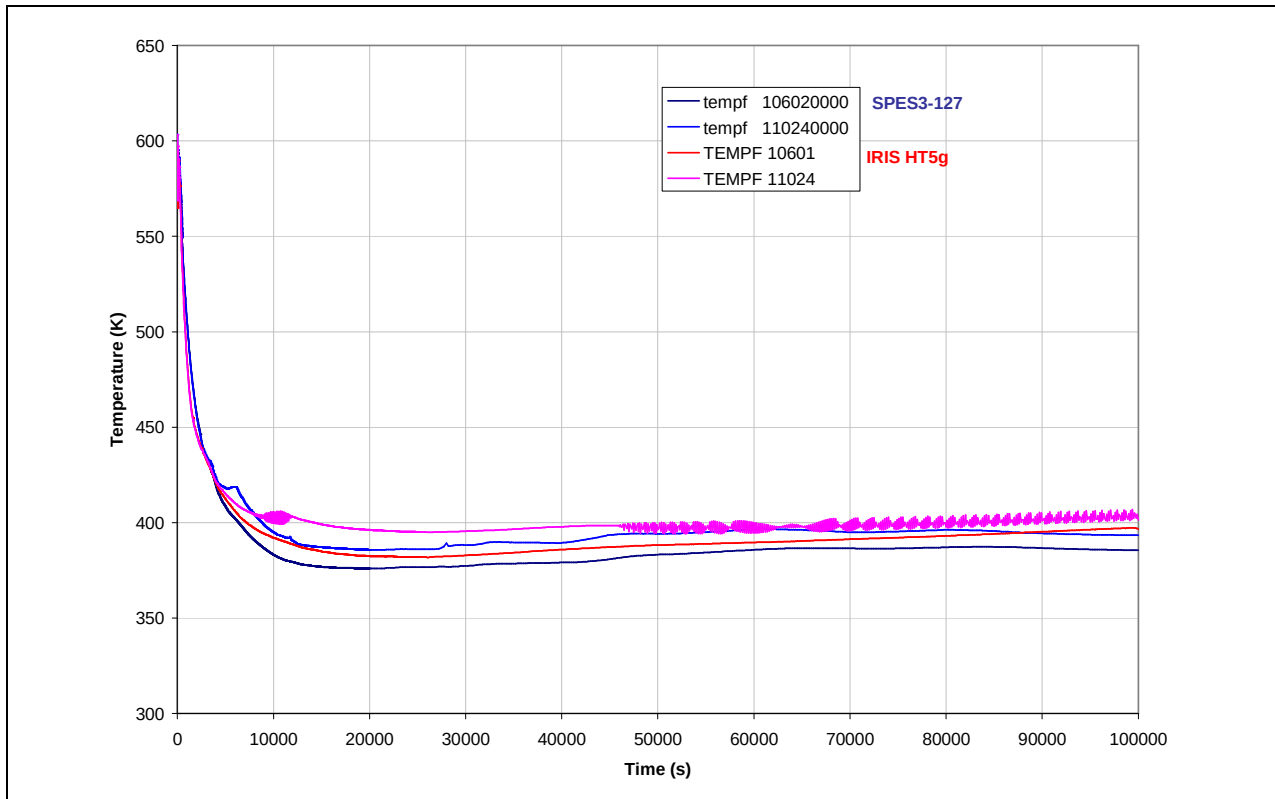


Fig.6. 66 – SPES3-127 and IRIS HT5g core heater rod outer surface temperature (window)

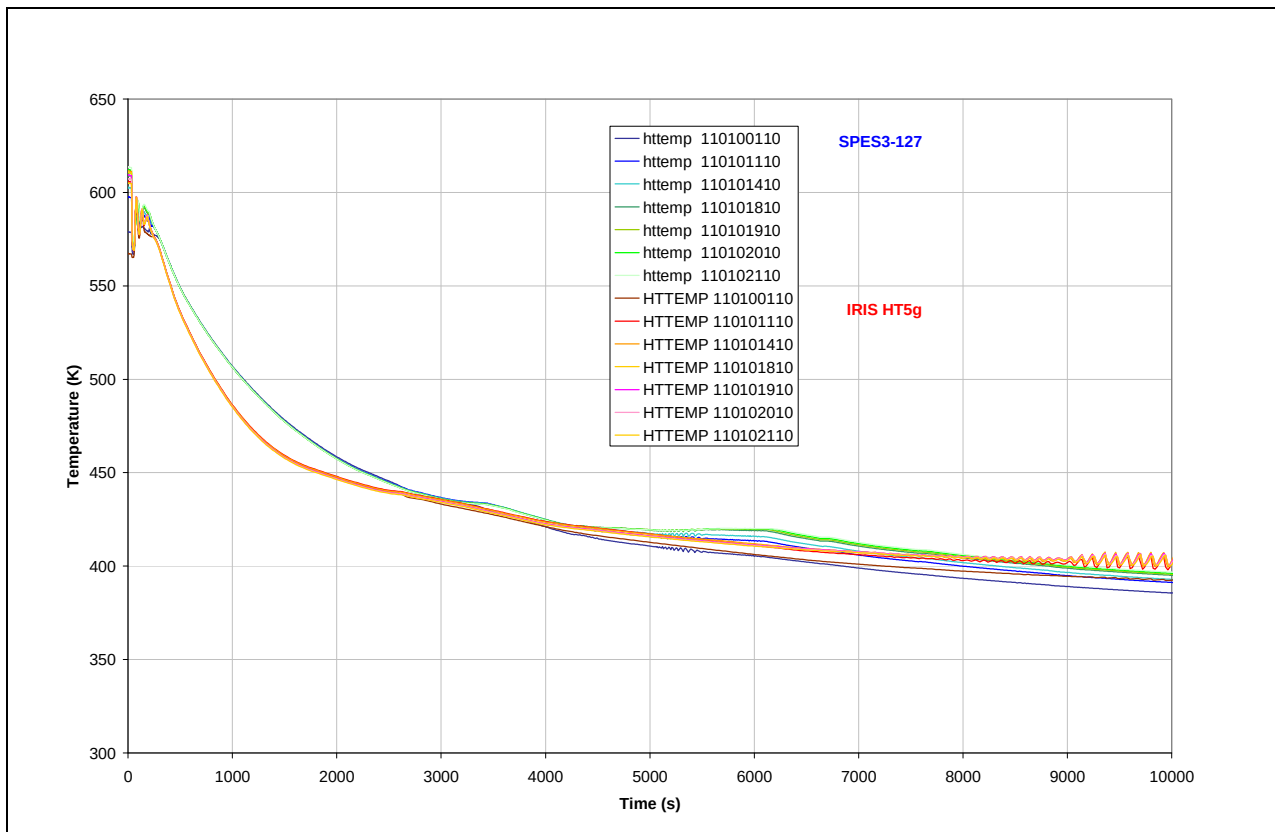


Fig.6. 67 – SPES3-127 and IRIS HT5g core heater rod outer surface temperature

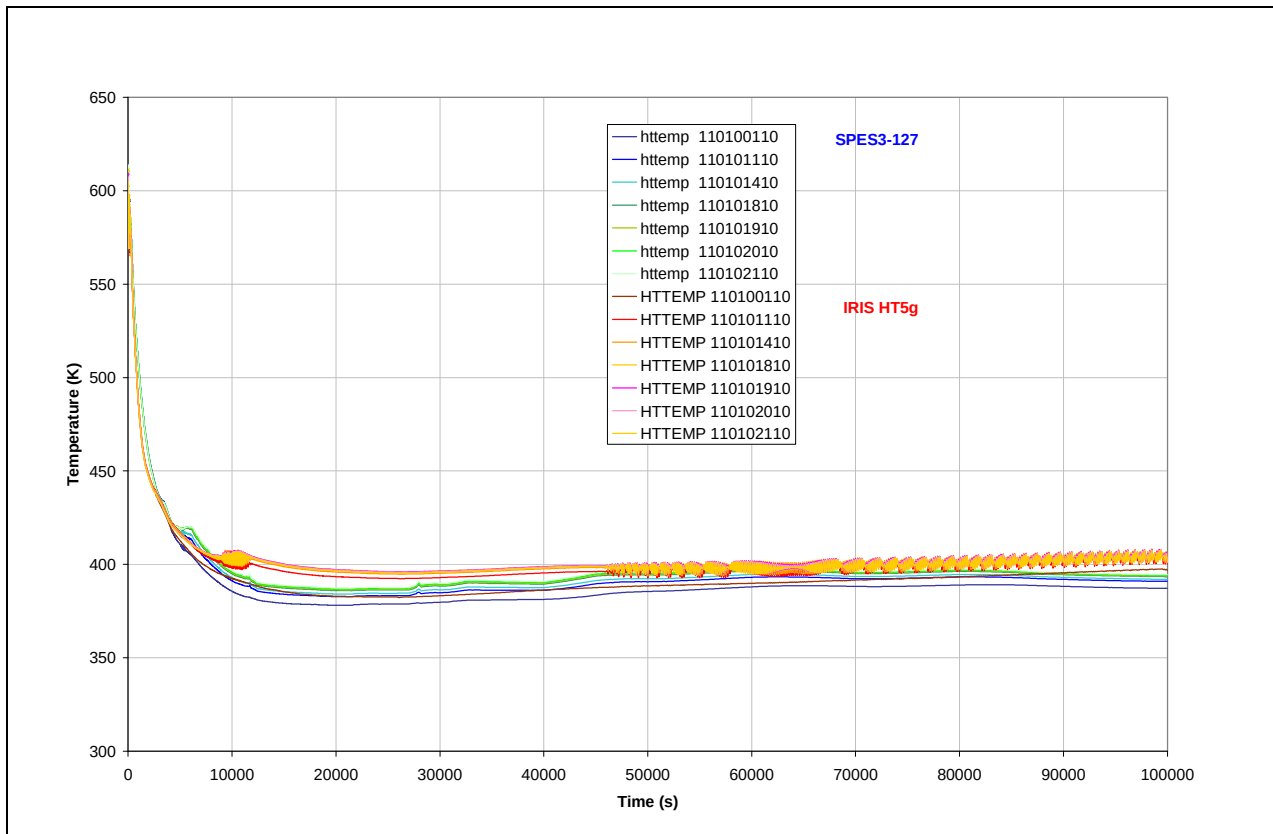


Fig.6. 68 – SPES3-127 and IRIS HT5g LGMS injection mass flow (window)

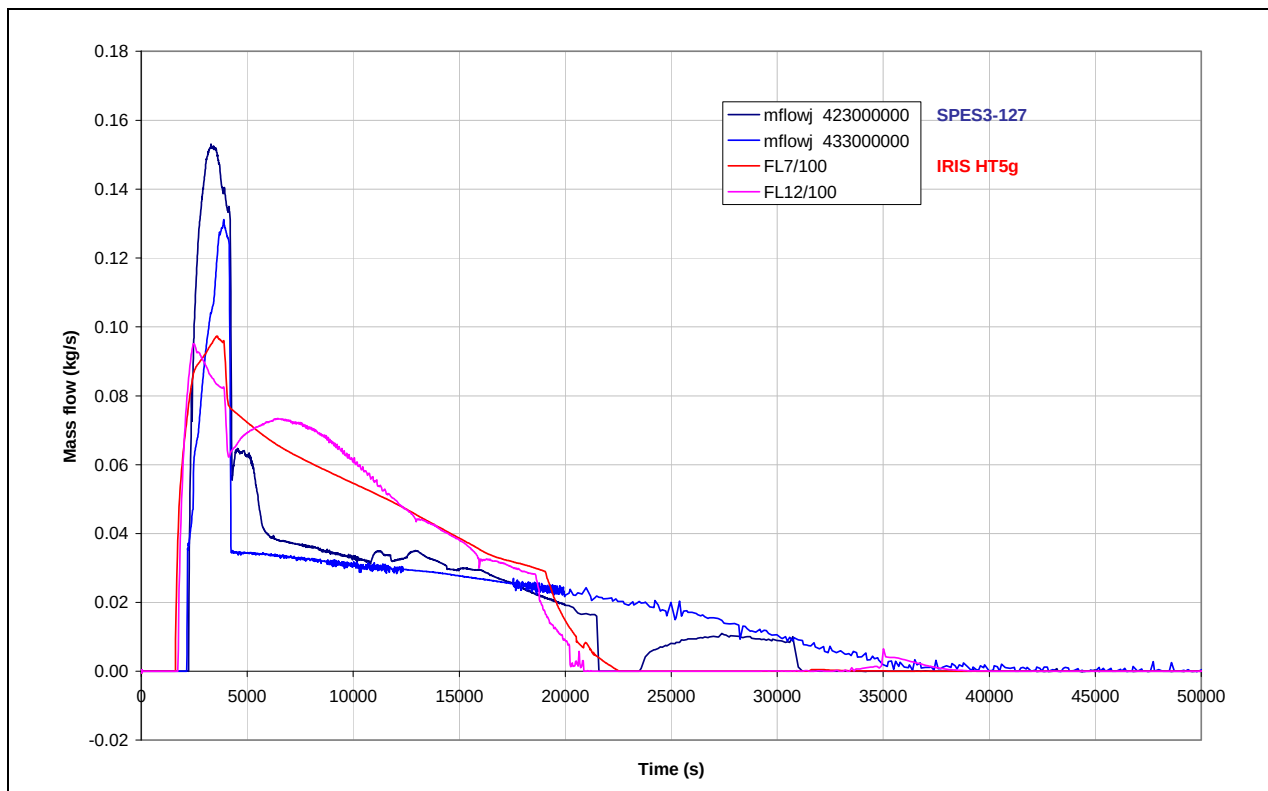


Fig.6. 69 – SPES3-127 and IRIS HT5g LGMS mass (window)

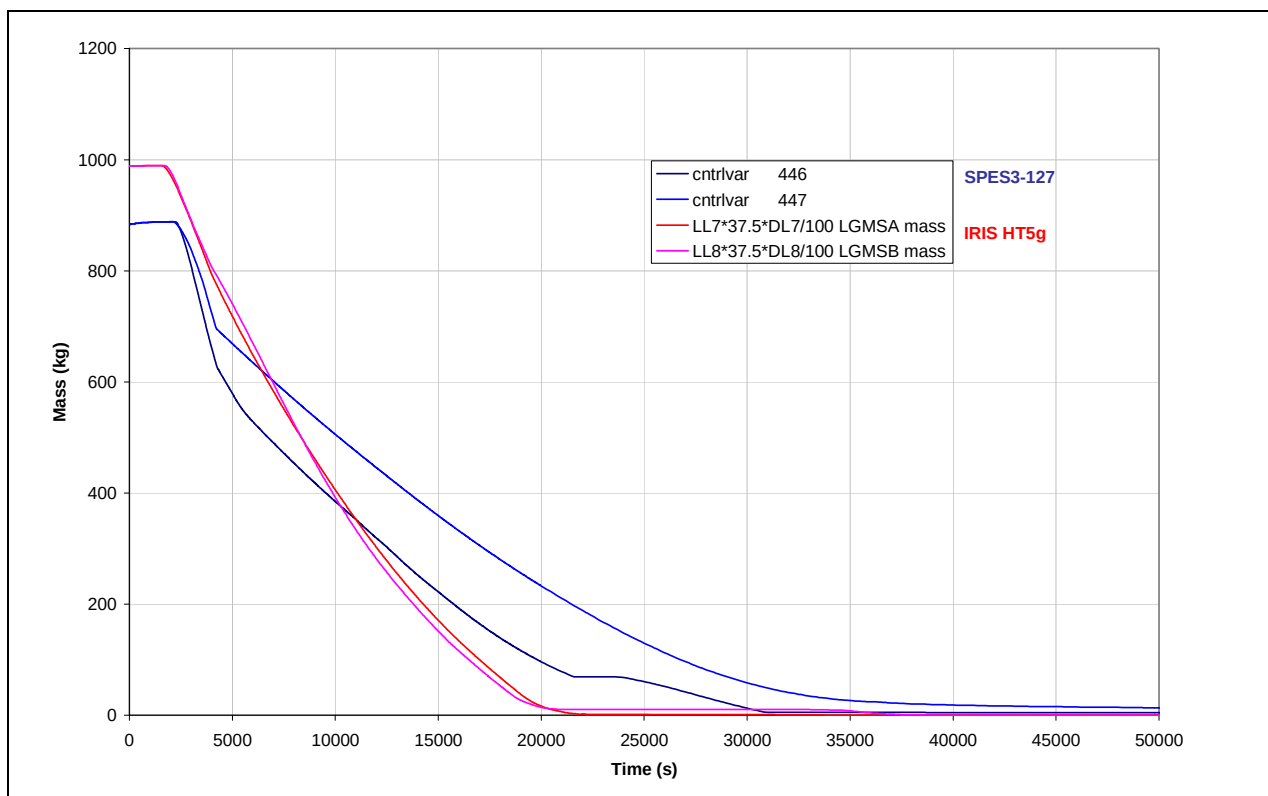


Fig.6. 70 – SPES3-127 and IRIS HT5g LGMS and DVI pressure (window)

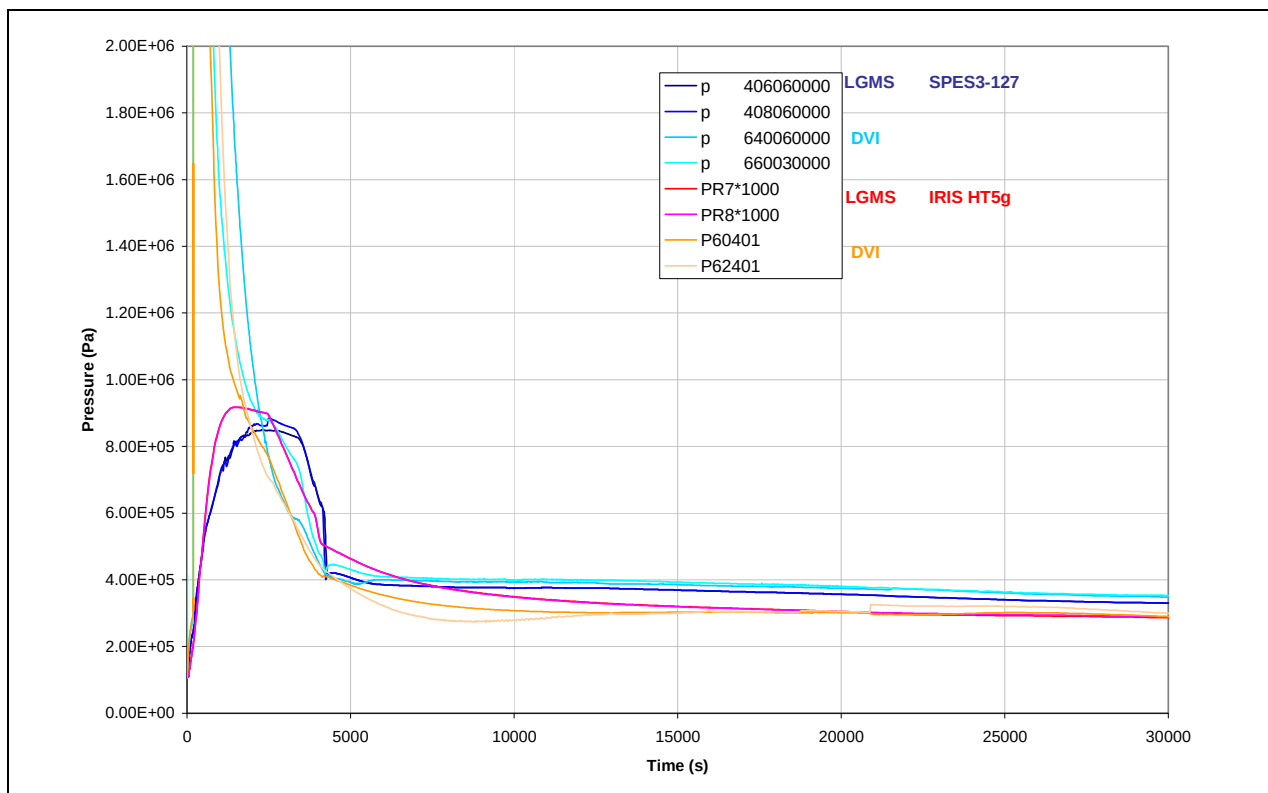


Fig.6. 71 – SPES3-127 and IRIS HT5g LGMS and DVI pressure

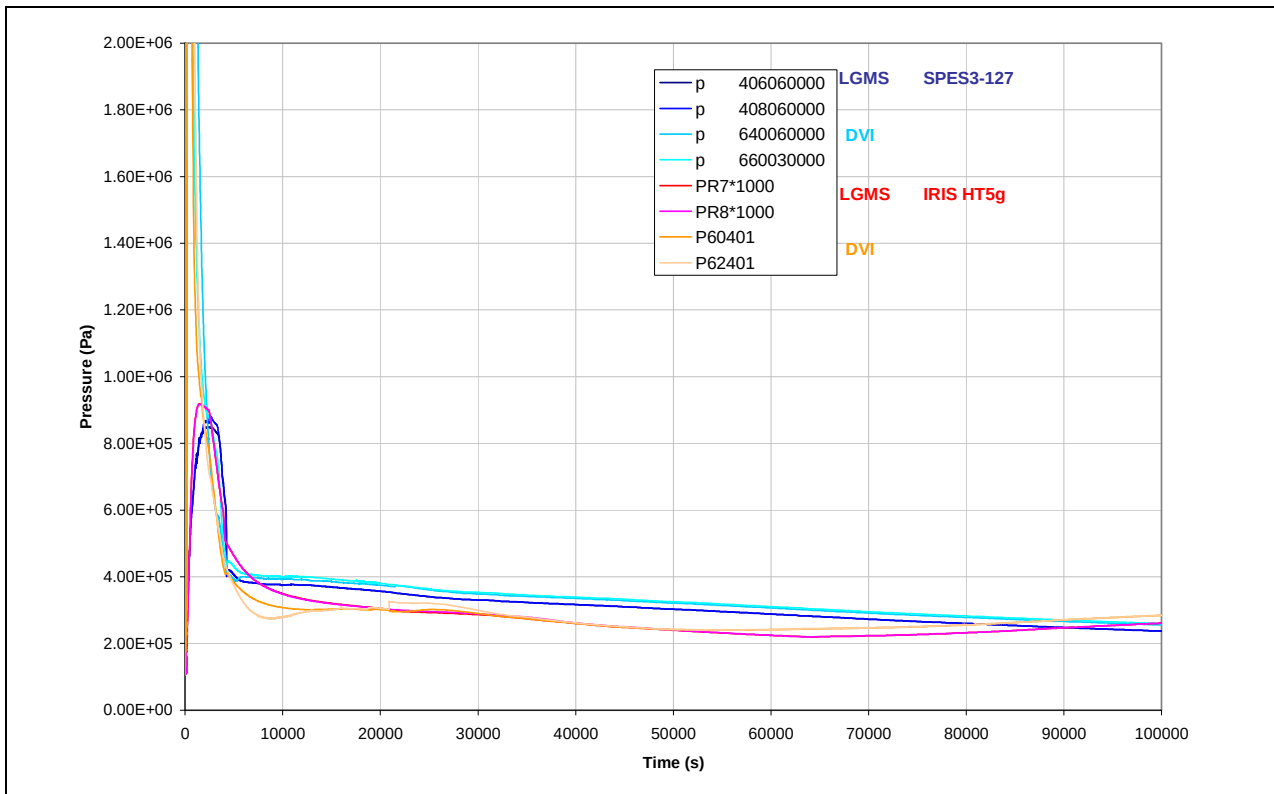


Fig.6. 72 – SPES3-127 and IRIS HT5g RC to DVI mass flow (window)

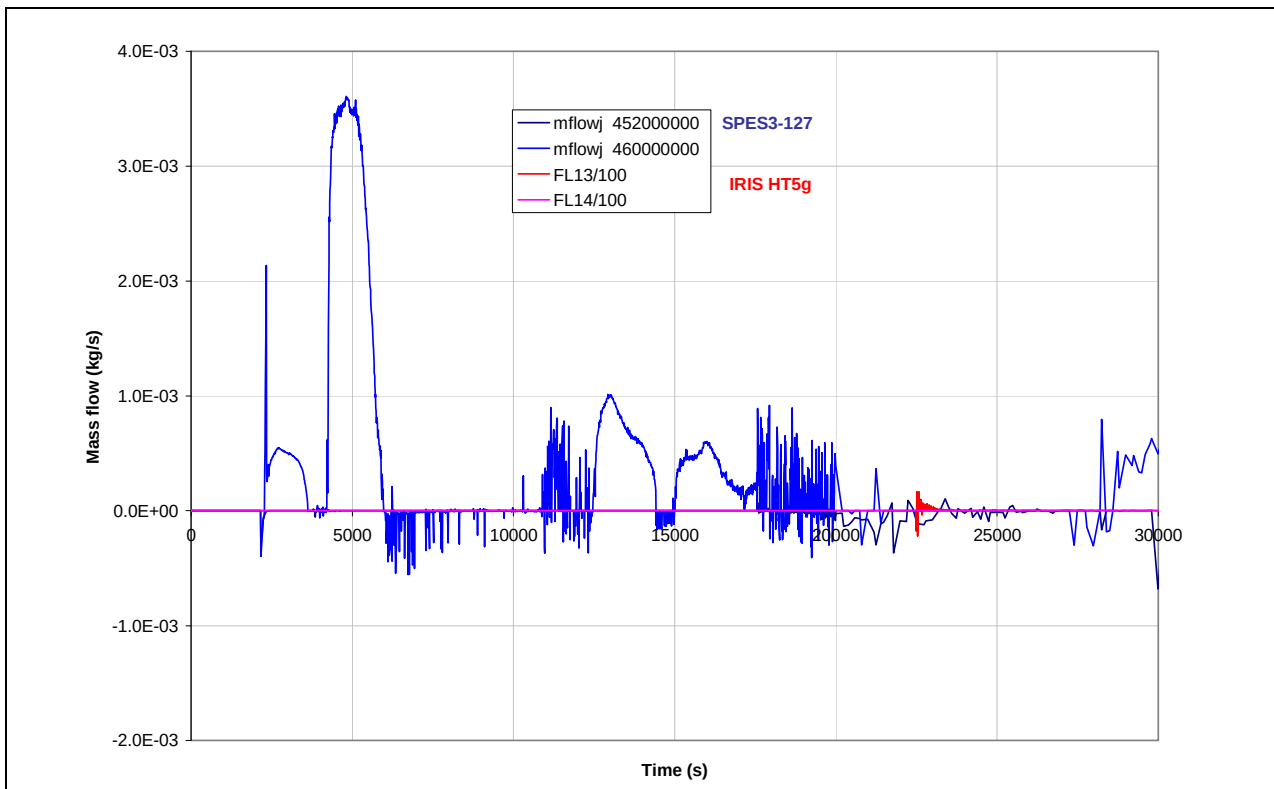


Fig.6. 73 – SPES3-127 and IRIS HT5g RC to DVI mass flow

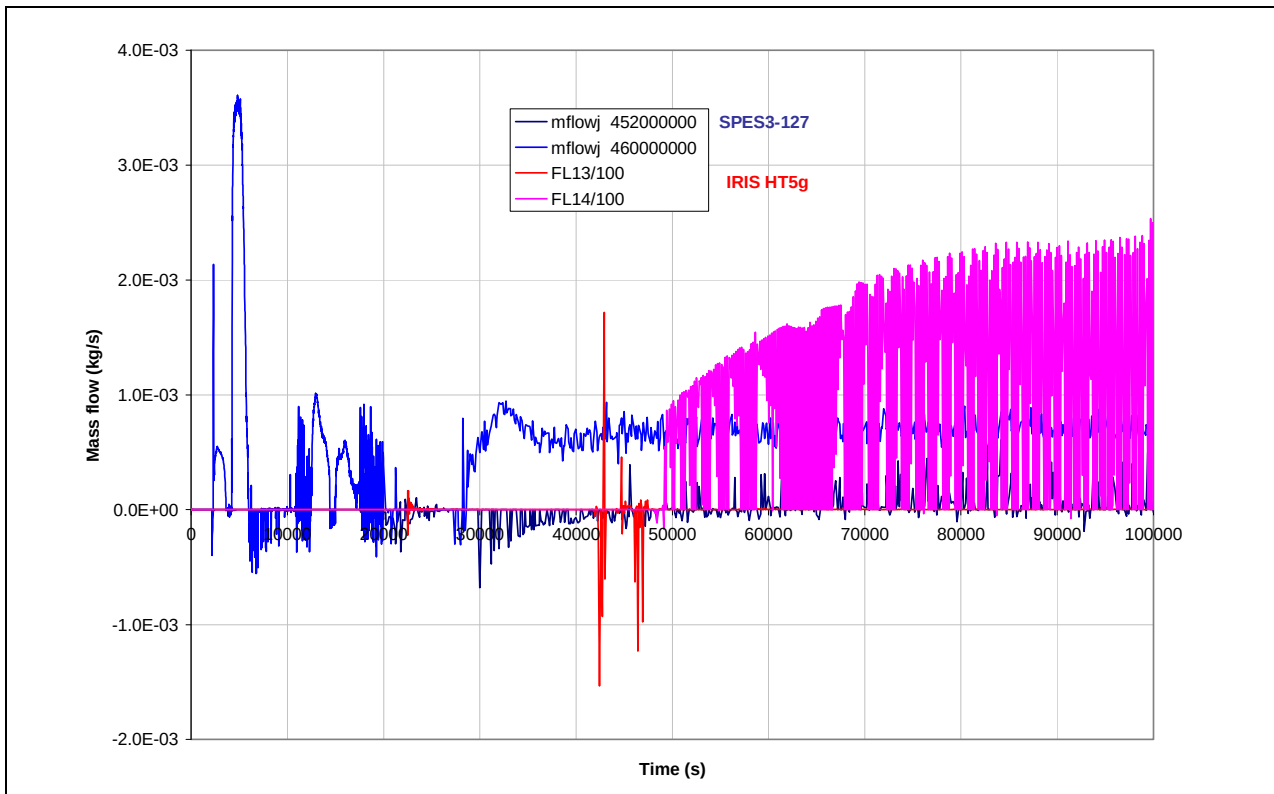


Fig.6. 74 – SPES3-127 and IRIS HT5g RC to DVI integral mass flow

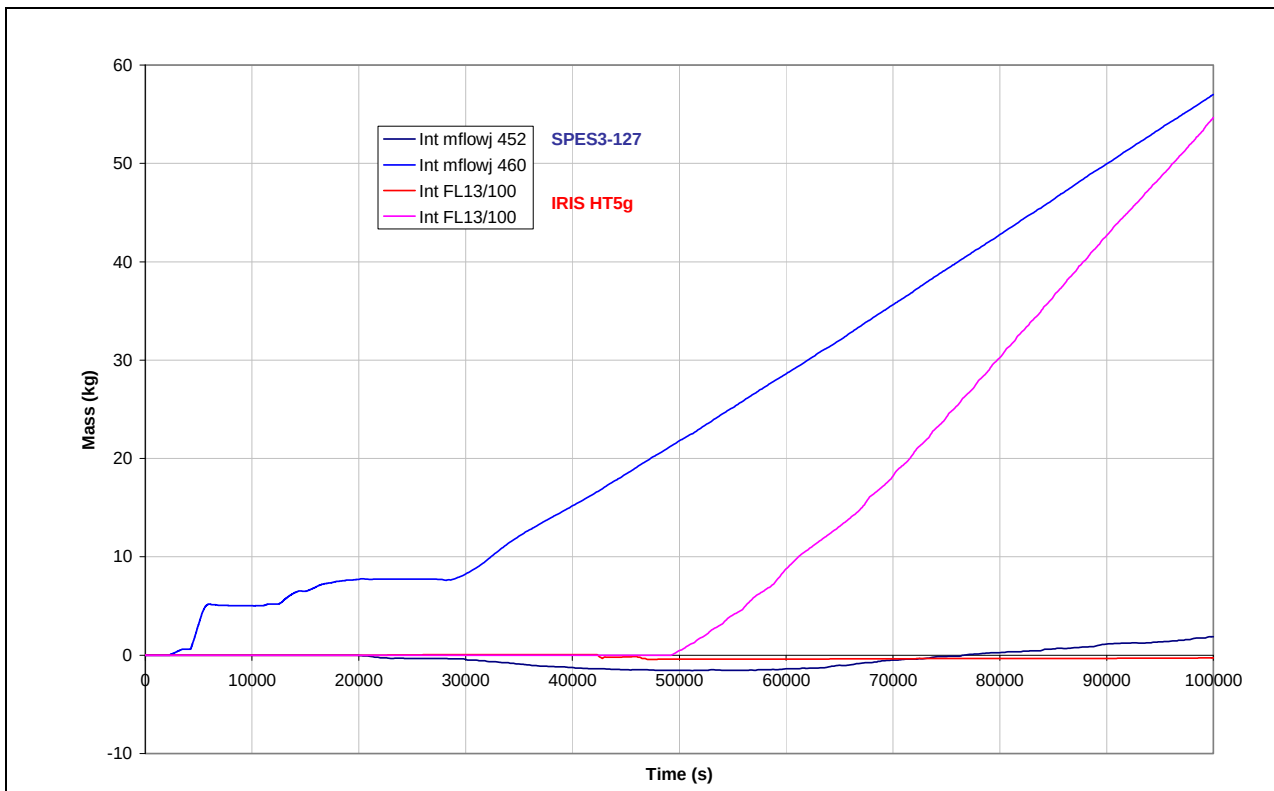




Fig.6. 75 – SPES3-127 and IRIS HT5g QT level

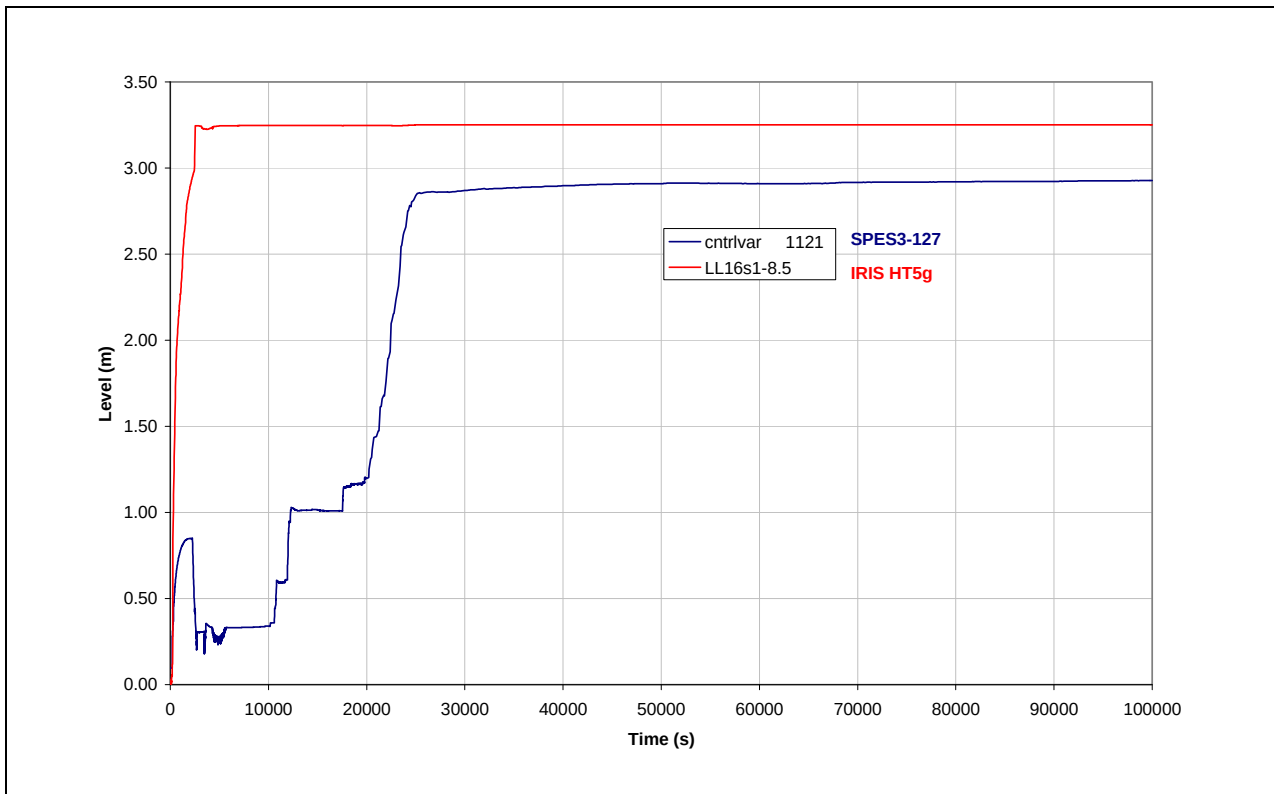


Fig.6. 76 – SPES3-127 and IRIS HT5g ADS Stage-II mass flow (window)

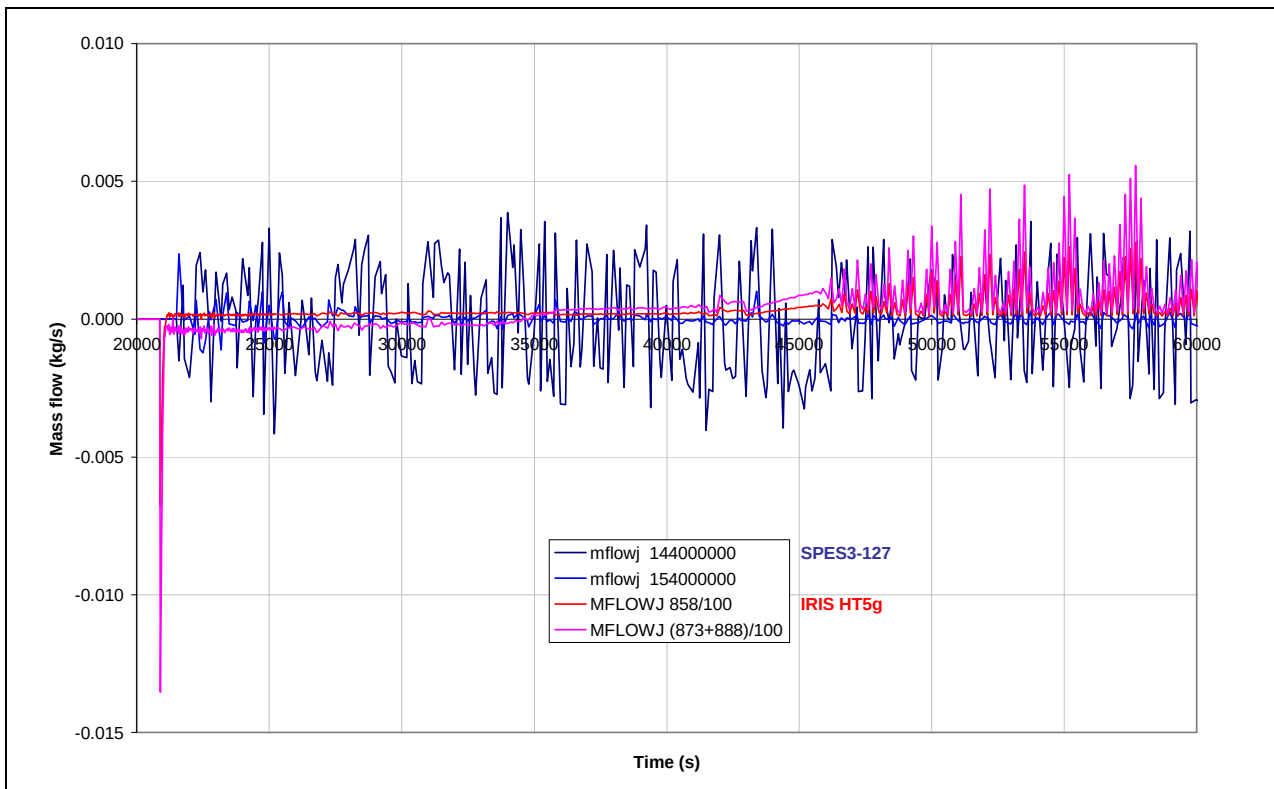


Fig.6. 77 – SPES3-127 and IRIS HT5g ADS Stage-II mass flow

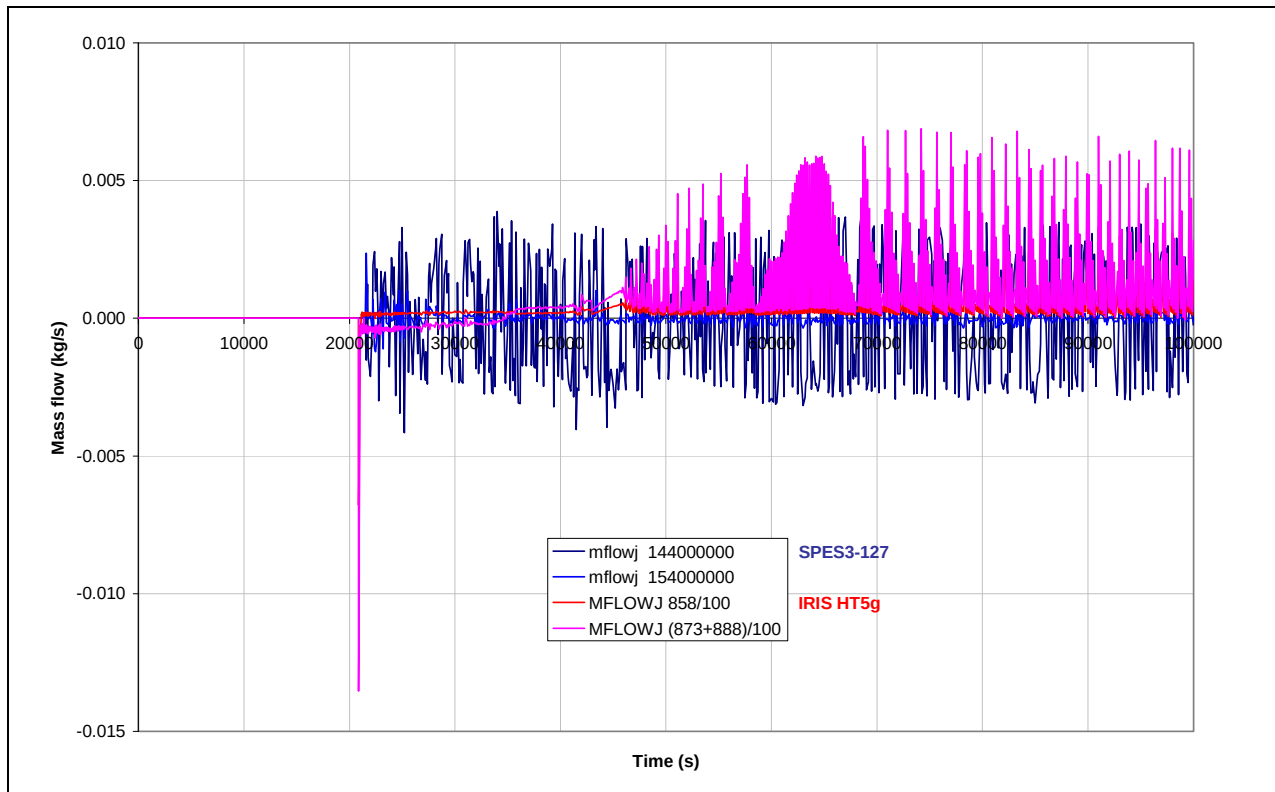
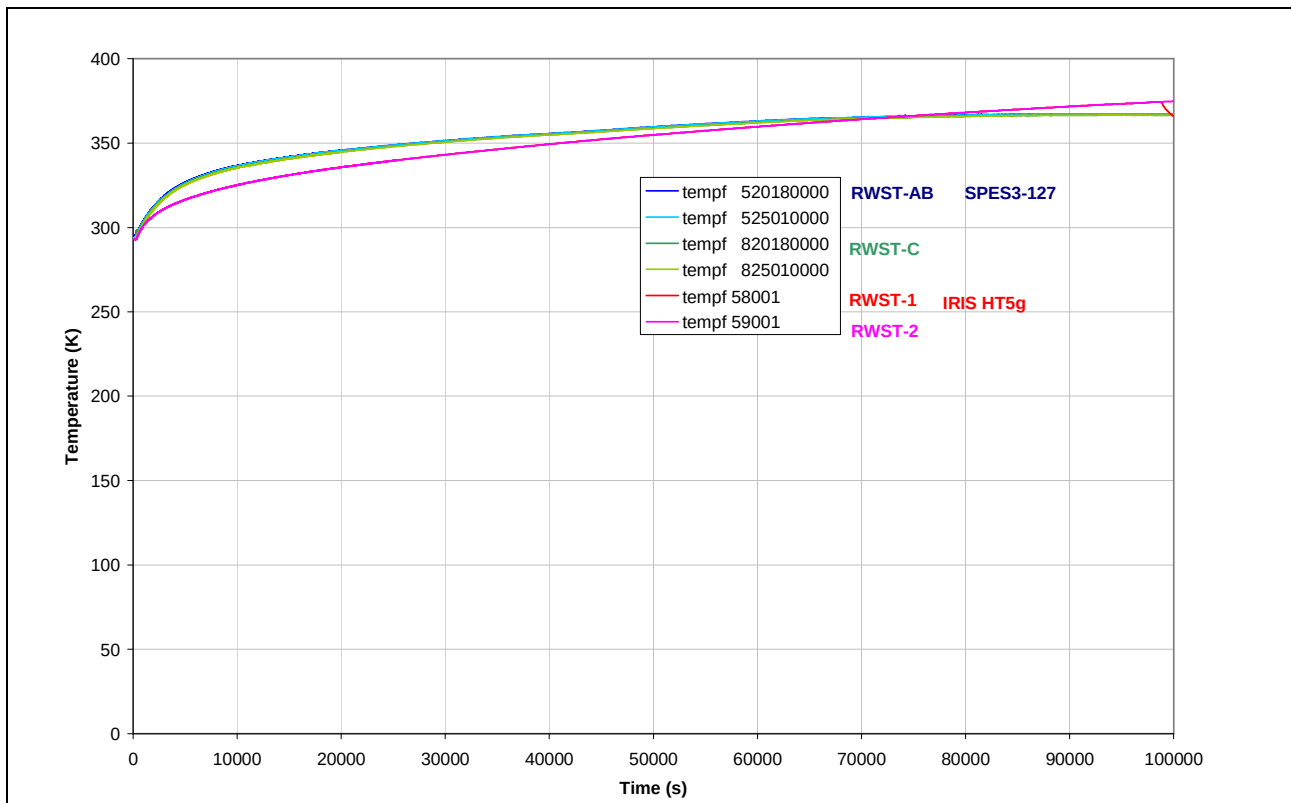
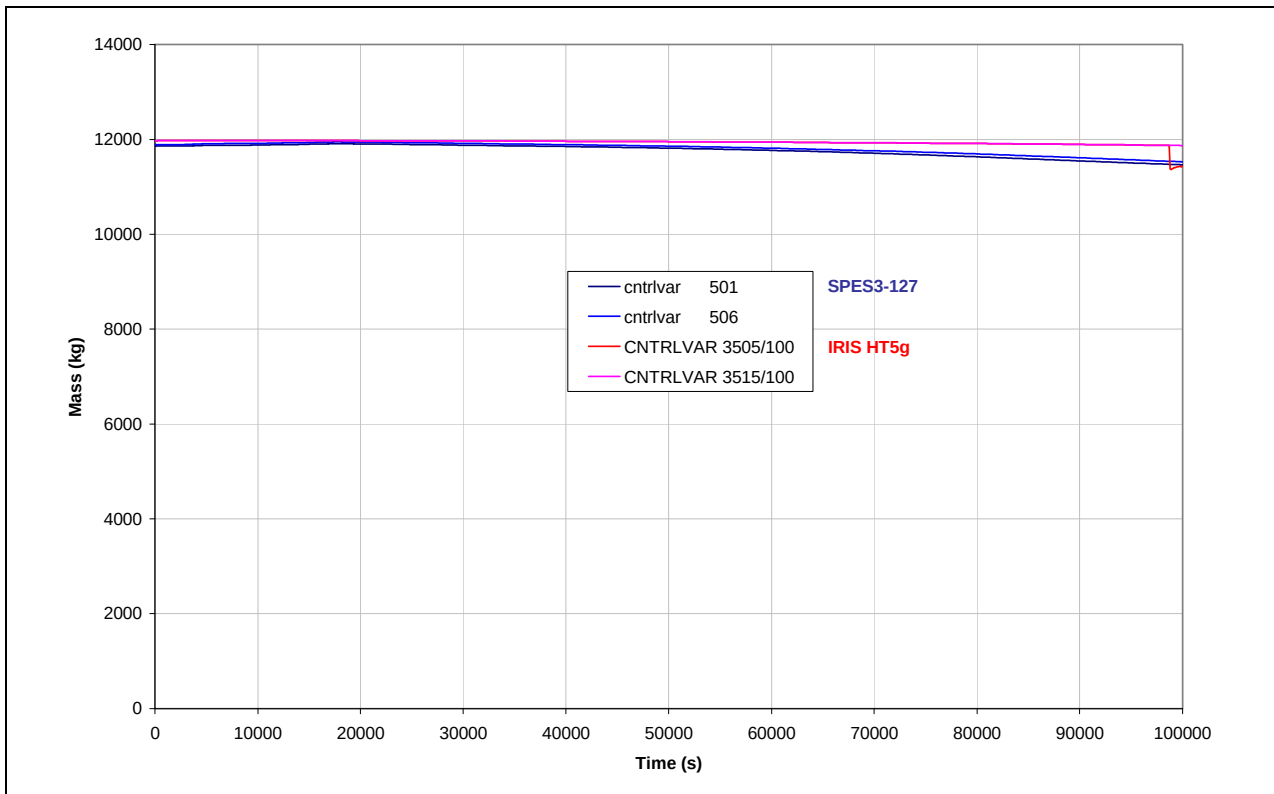


Fig.6. 78 – SPES3-127 and IRIS HT5g RWST temperature



**Fig.6. 79 – SPES3-127 and IRIS HT5g RWST mass**



**Fig.6. 80 – SPES3-127 and IRIS HT5g RWST pressure**

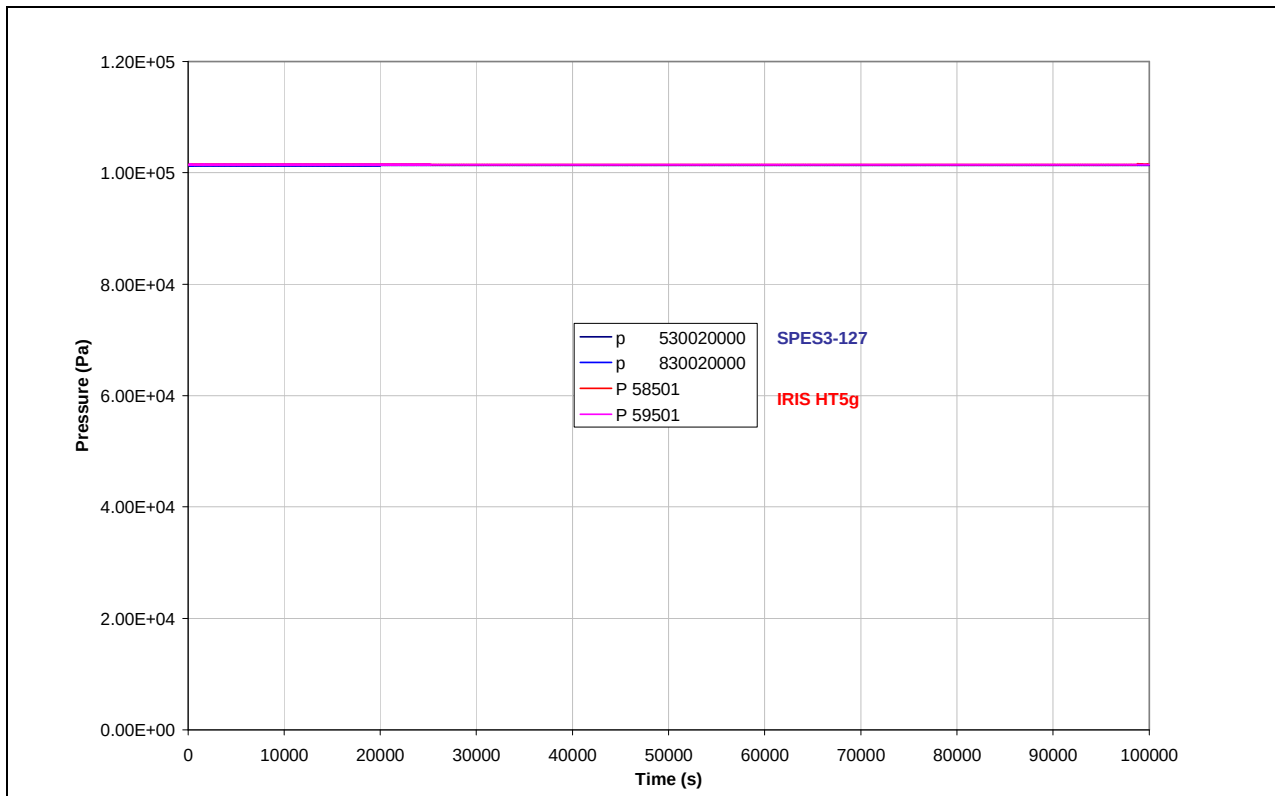


Fig.6. 81 – SPES3-127 and IRIS HT5g RWST top mass flow

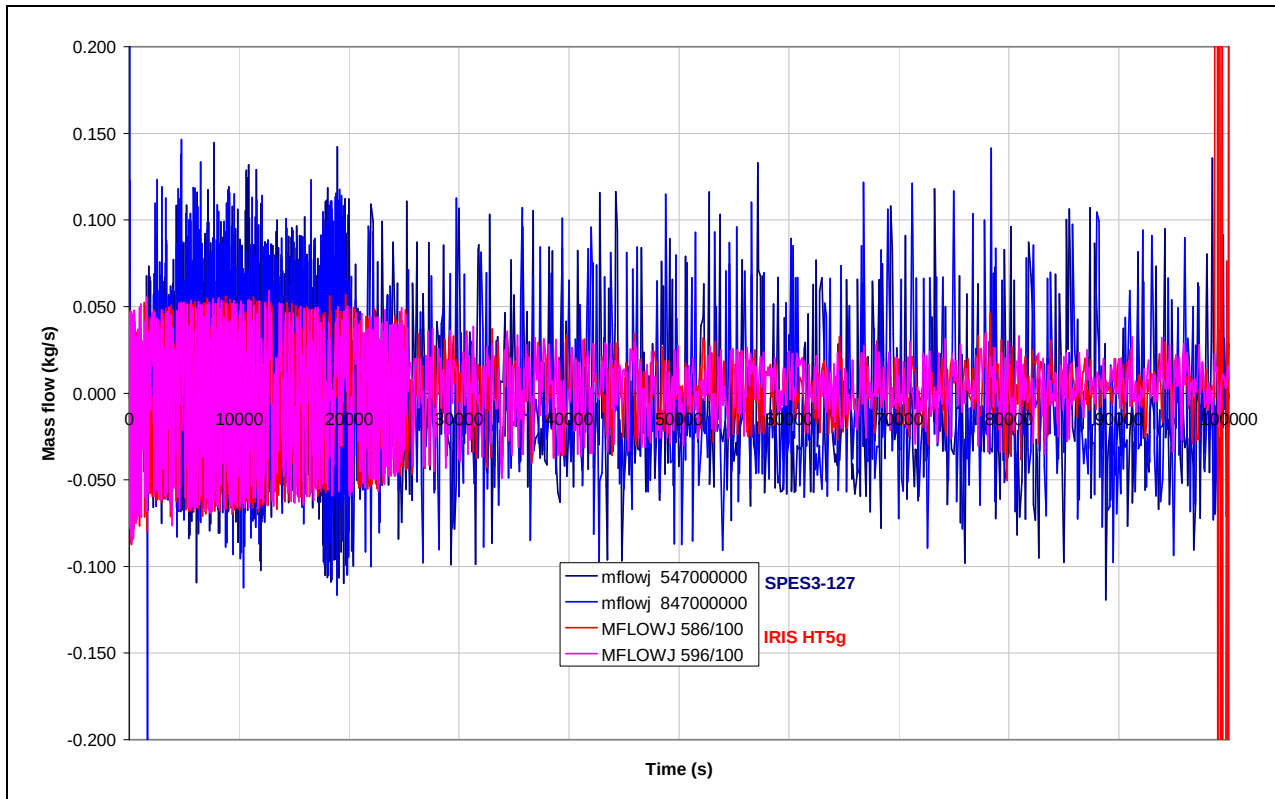


Fig.6. 82 – SPES3-127 and IRIS HT5g RWST top integral mass flow

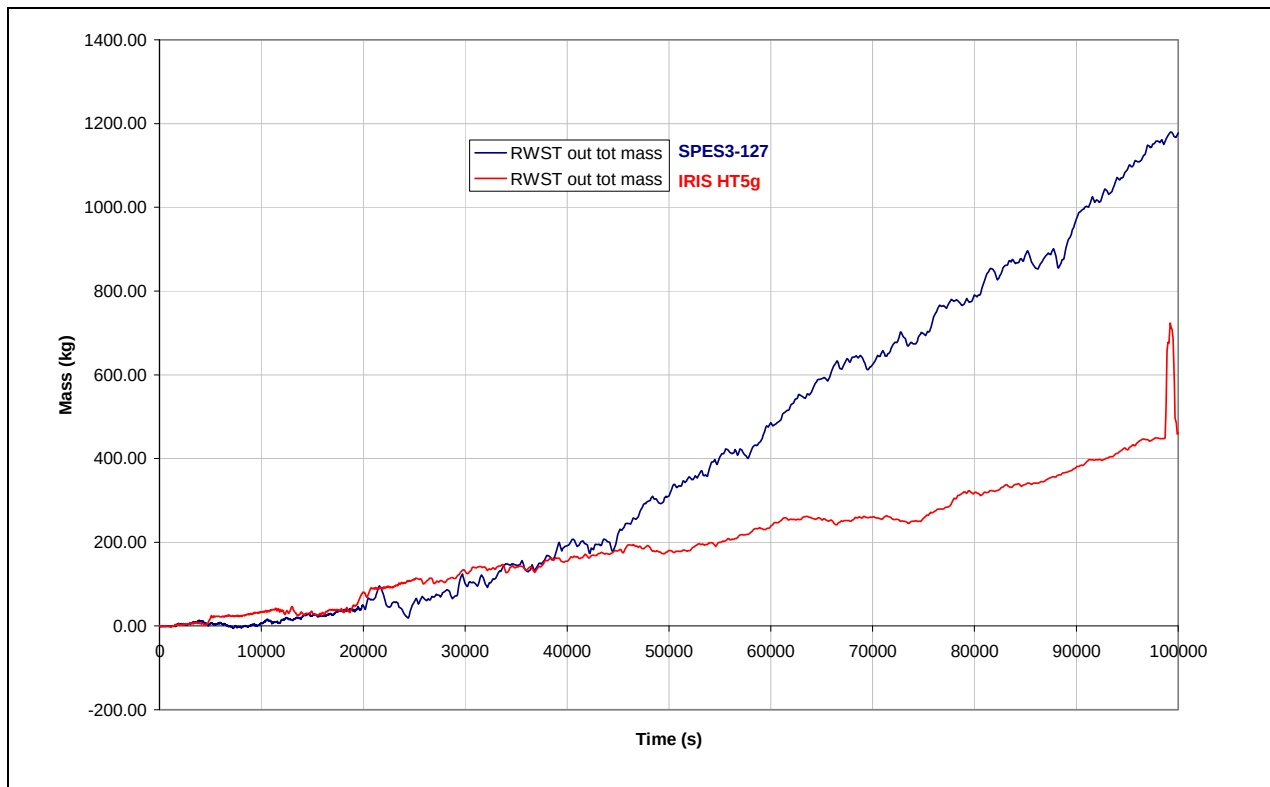


Fig.6. 83 – SPES3-127 and IRIS HT5g RWST power (window)

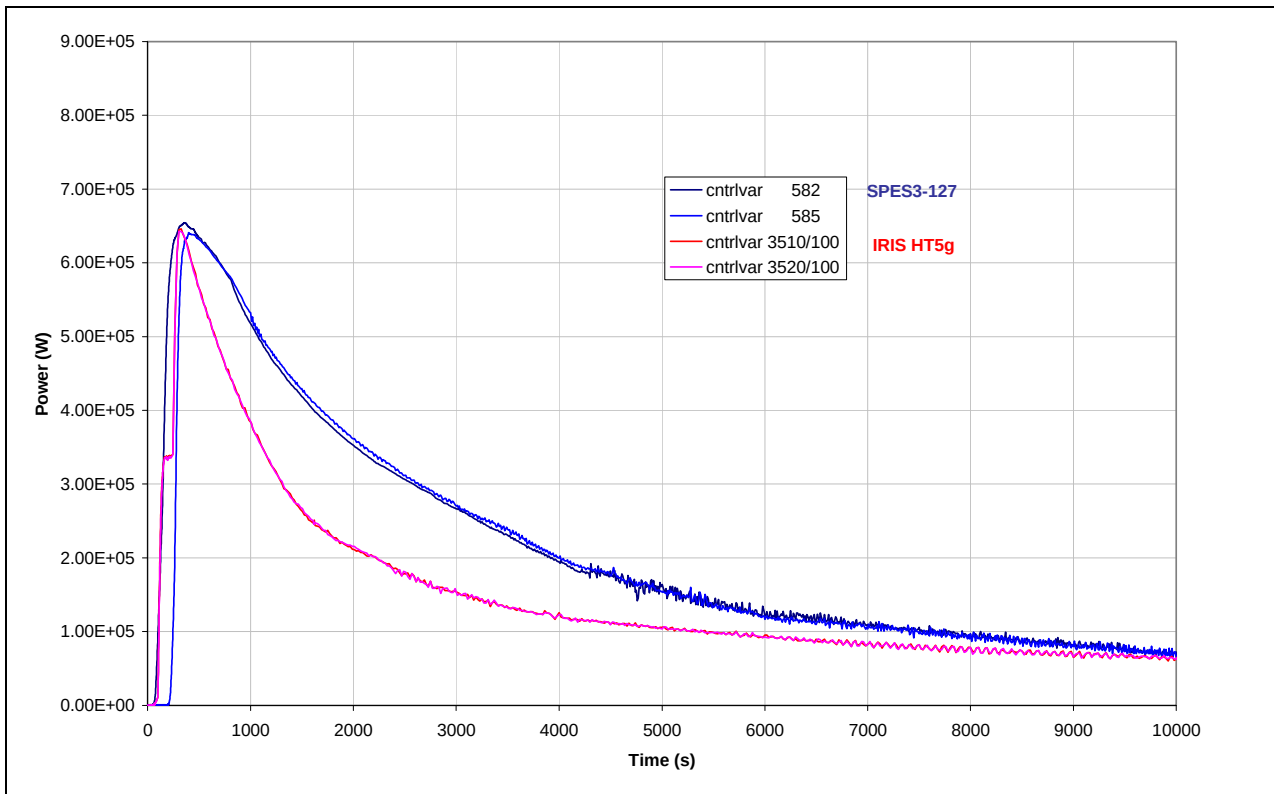
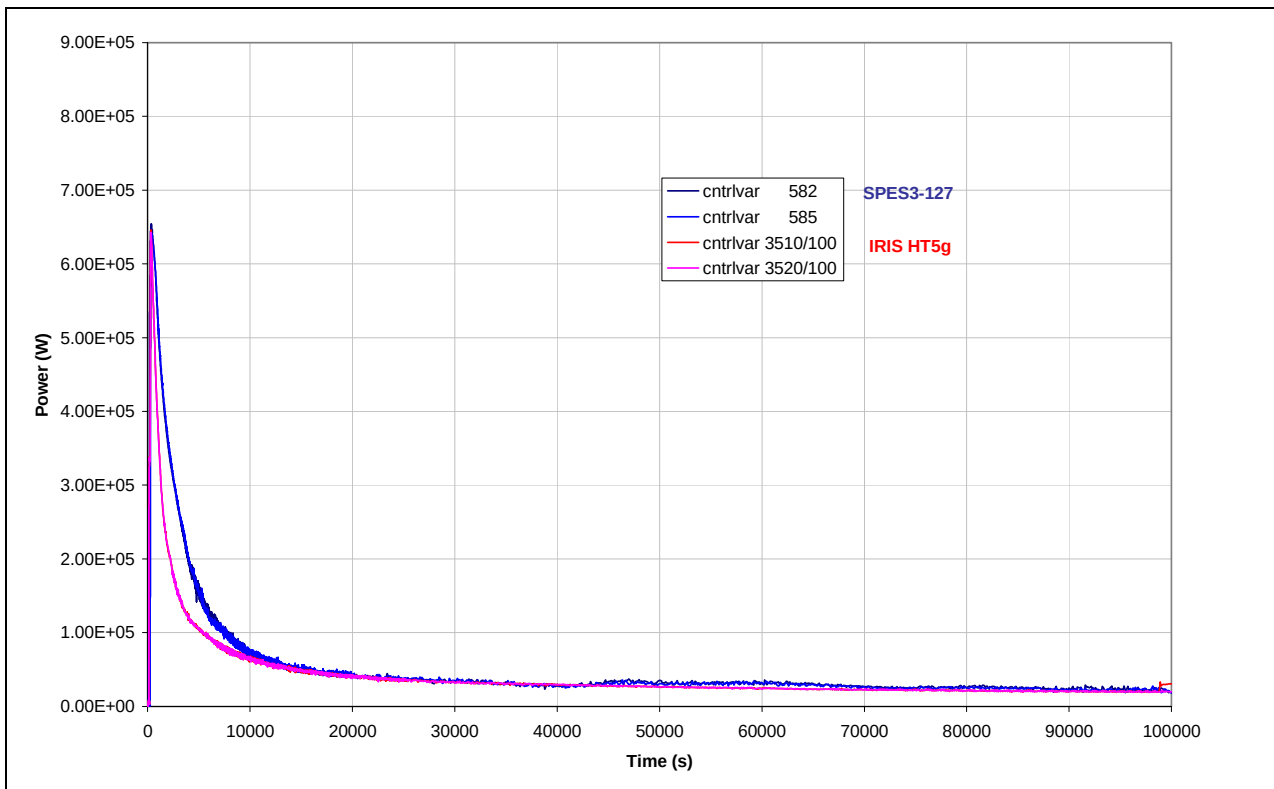
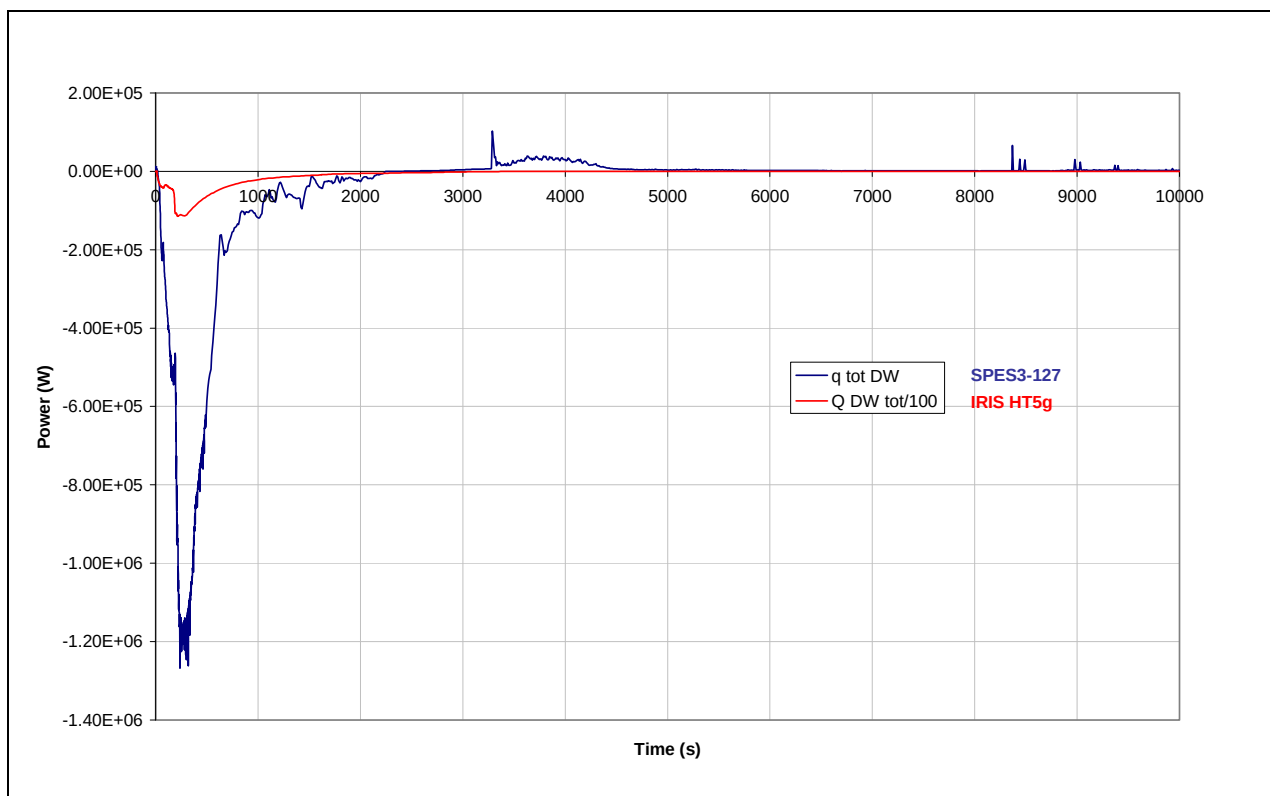


Fig.6. 84 – SPES3-127 and IRIS HT5g RWST power



**Fig.6. 85 – SPES3-127 and IRIS HT5g DW power (window)**



**Fig.6. 86 – SPES3-127 and IRIS HT5g DW power**

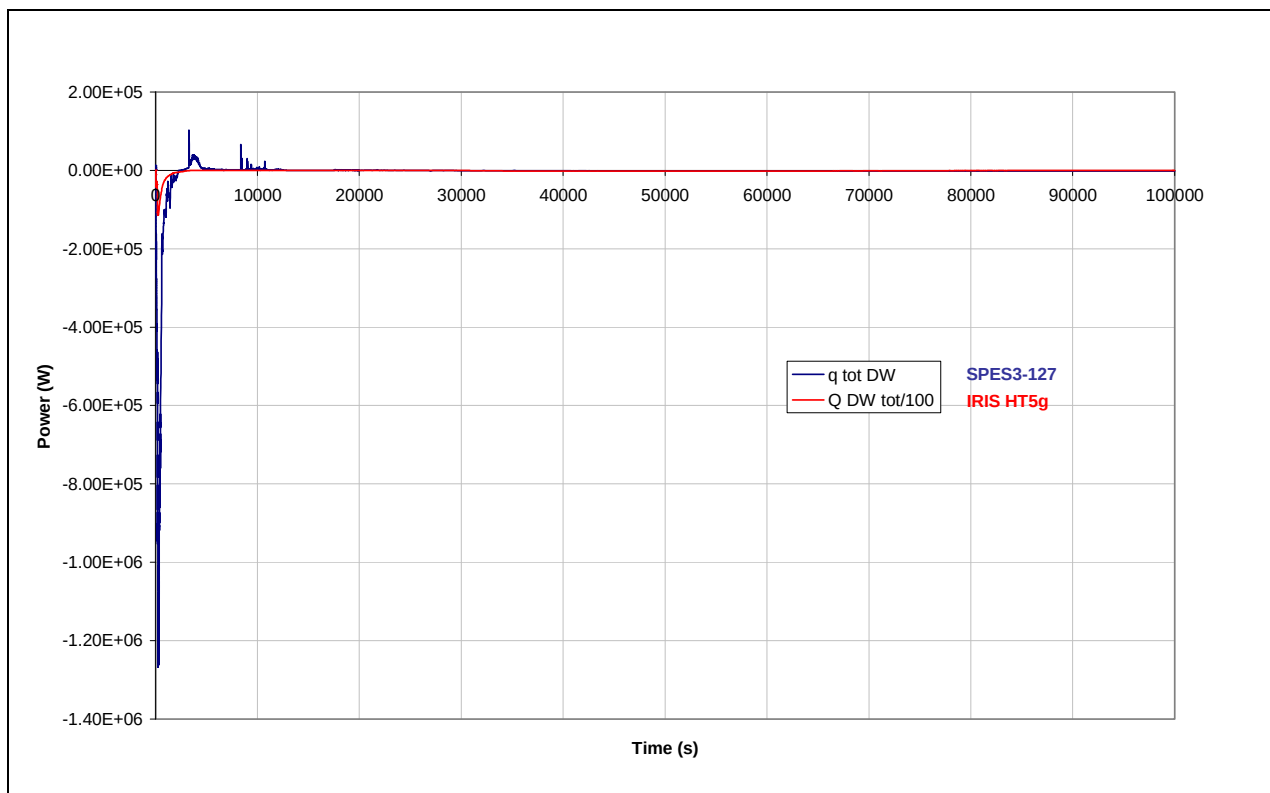


Fig.6. 87 – SPES3-127 and IRIS HT5g DW inner and outer wall temperature (window)

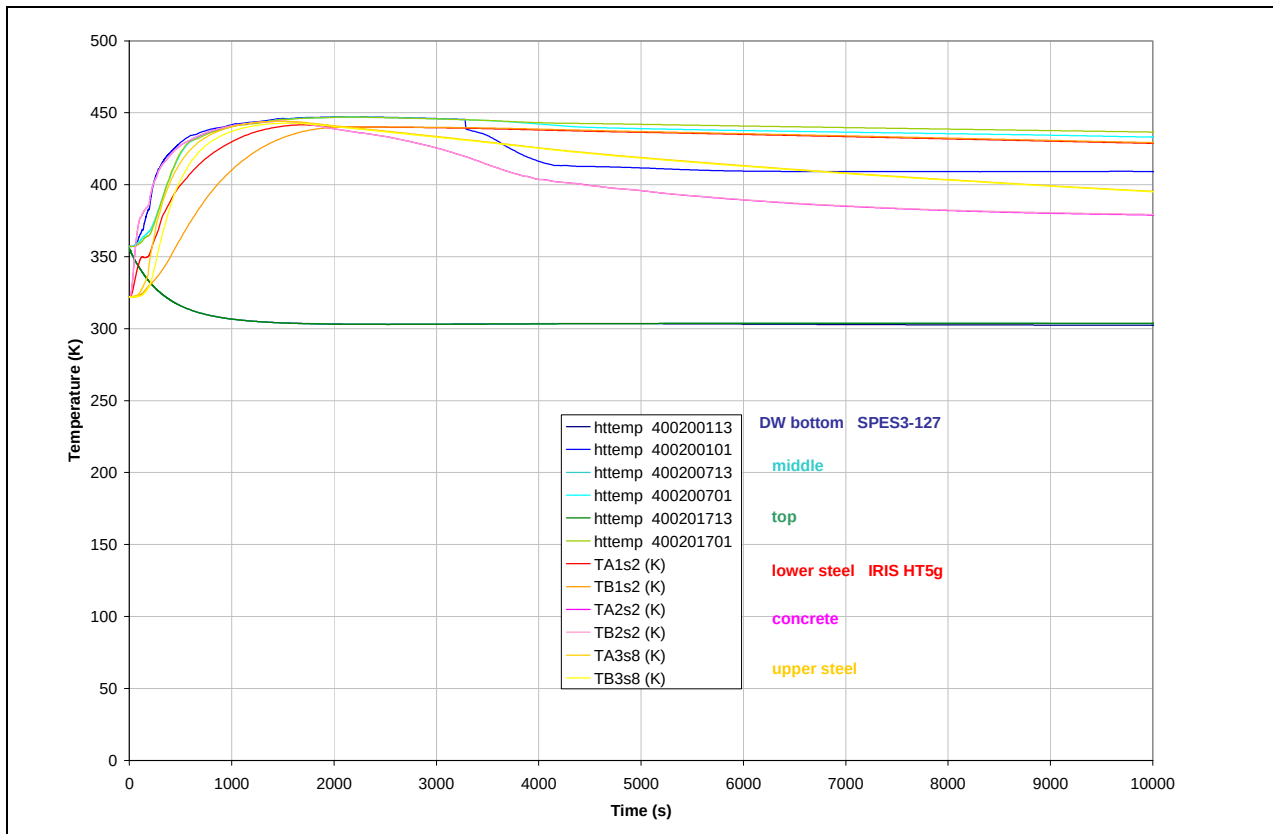


Fig.6. 88 – SPES3-127 and IRIS HT5g DW inner and outer wall temperature

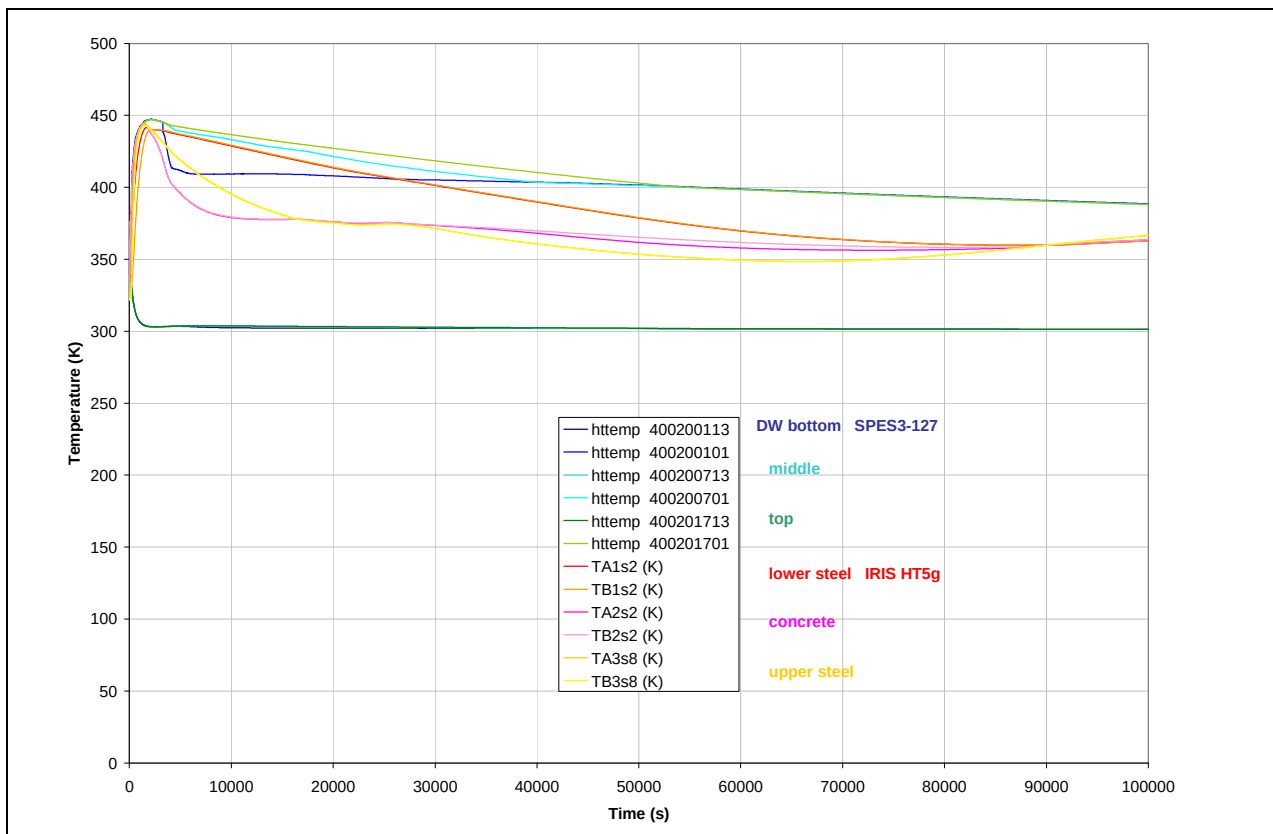


Fig.6. 89 – SPES3-127 and IRIS HT5g T (PRZ) – T (SG)

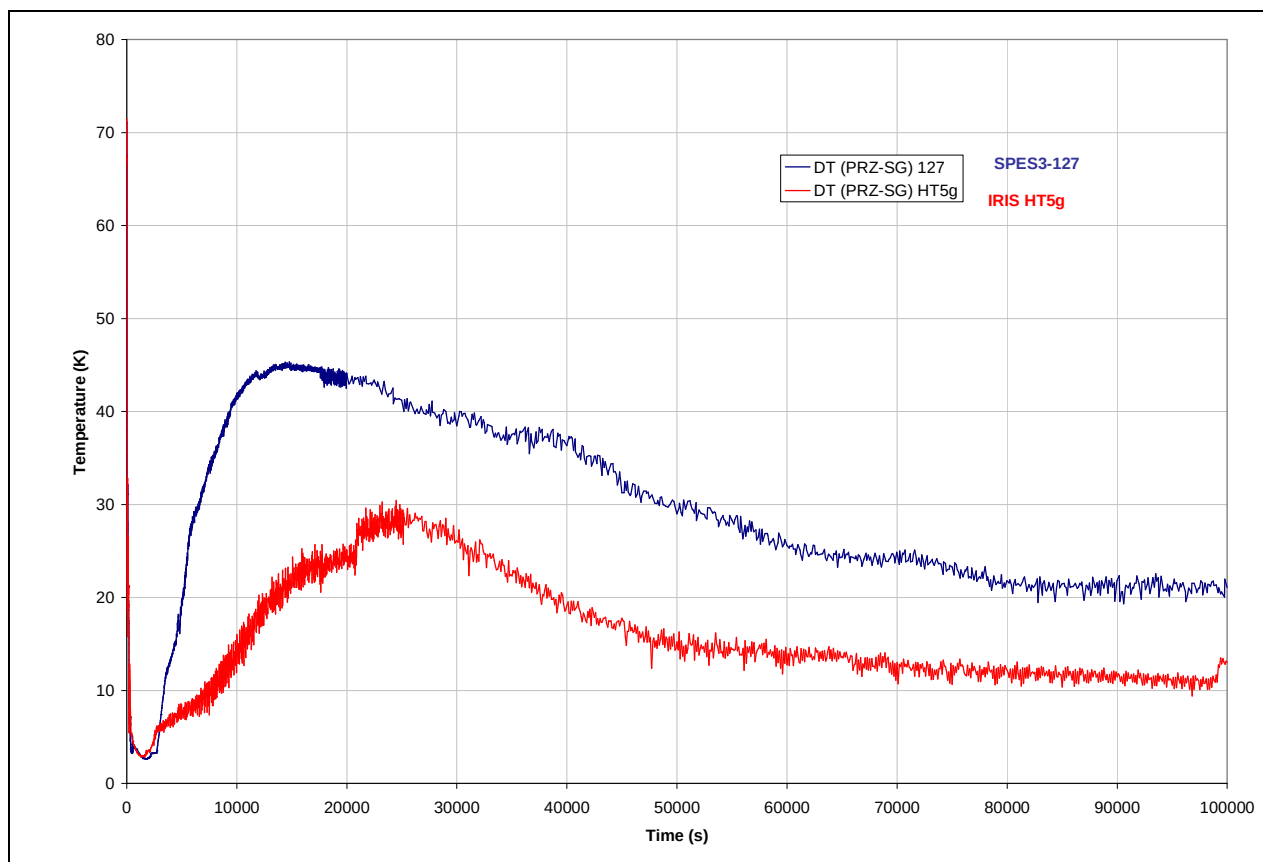
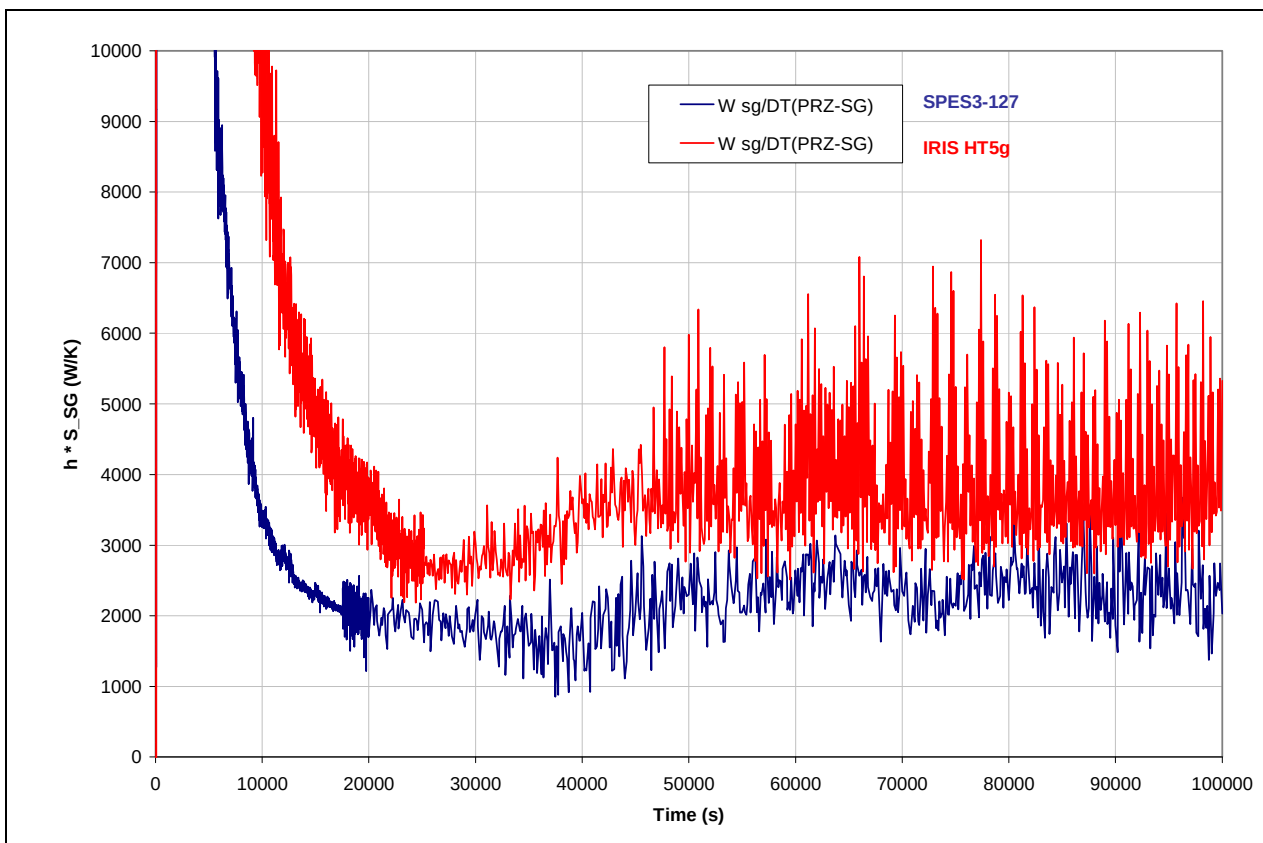
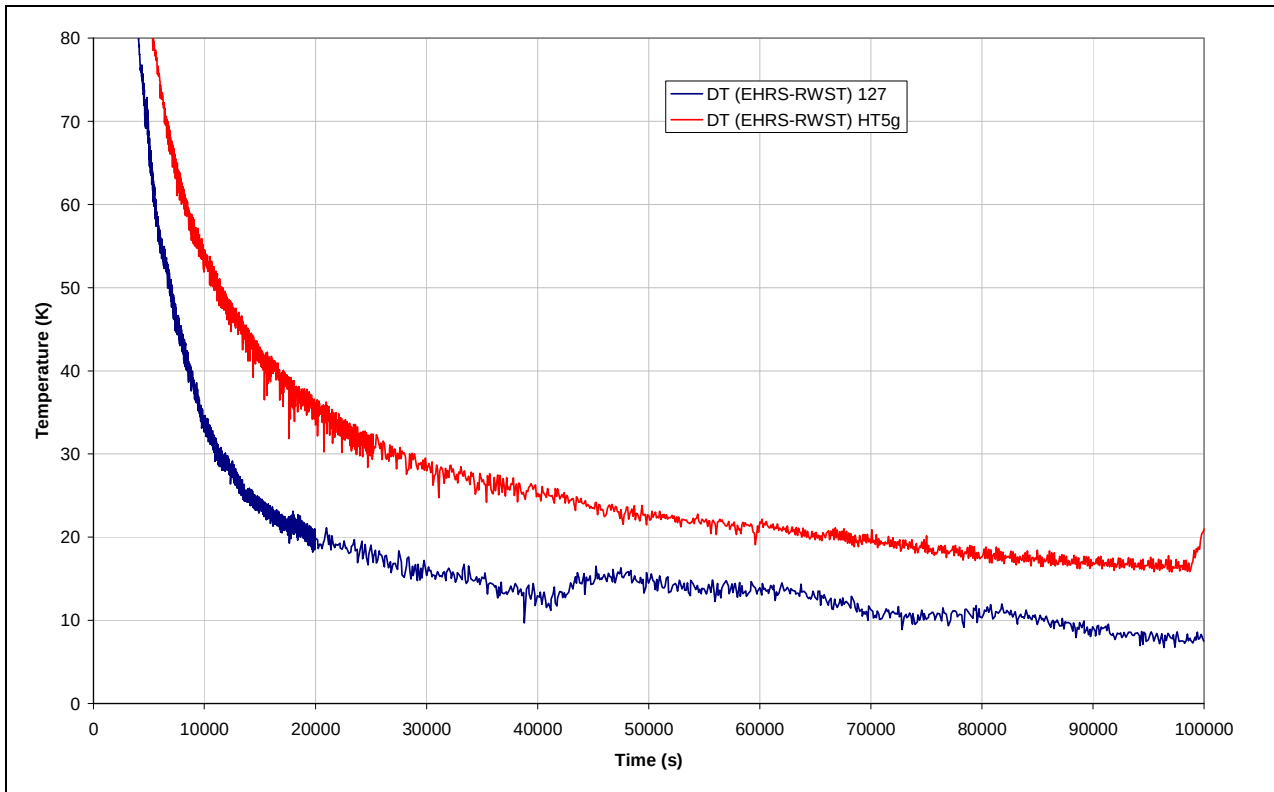


Fig.6. 90 – SPES3-127 and IRIS HT5g SG global heat transfer coefficient





**Fig.6. 91 – SPES3-127 and IRIS HT5g T (EHRS) – T (RWST)**



**Fig.6. 92 – SPES3-127 and IRIS HT5g EHRS global heat transfer coefficient**

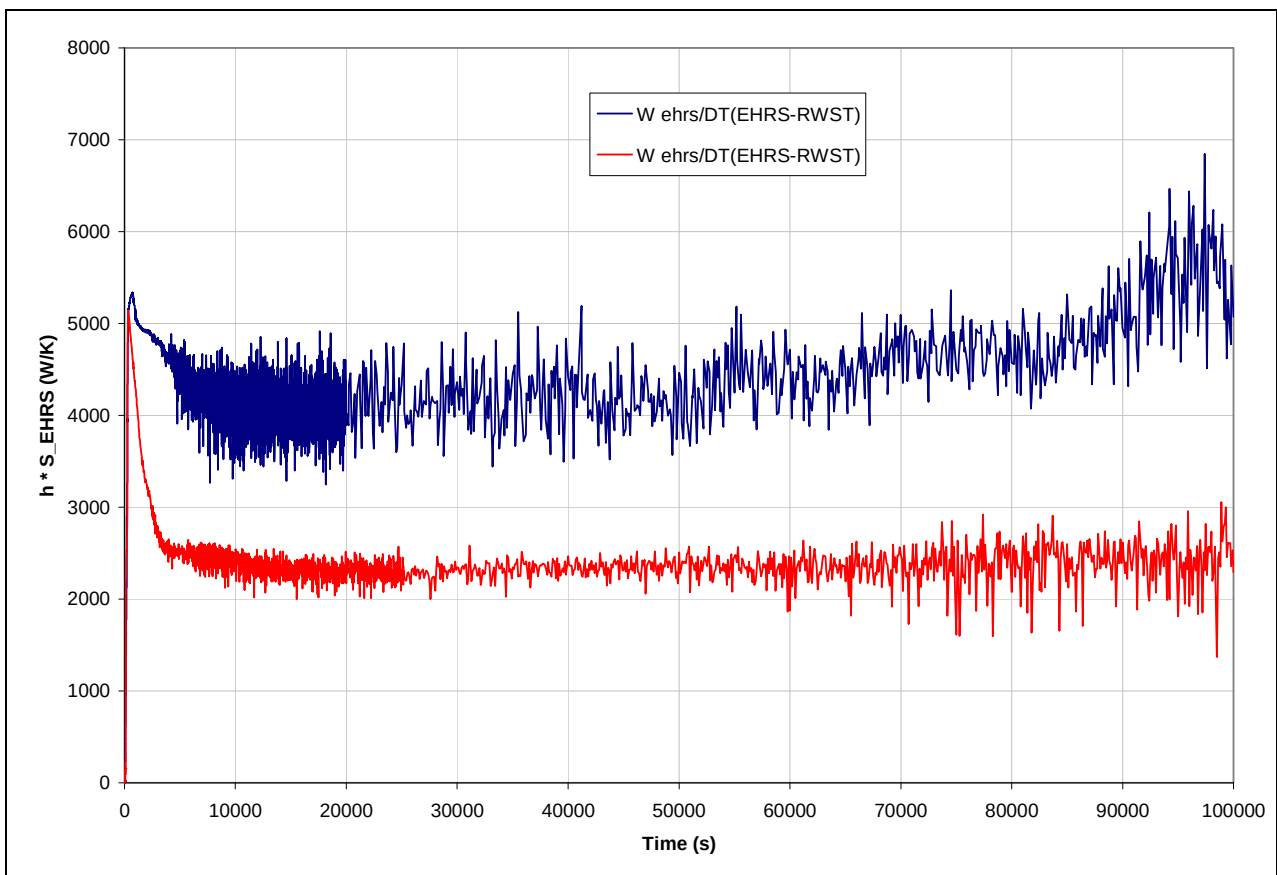


Fig.6. 93 – SPES3-127 and IRIS HT5g T (PRZ) – T (RWST)

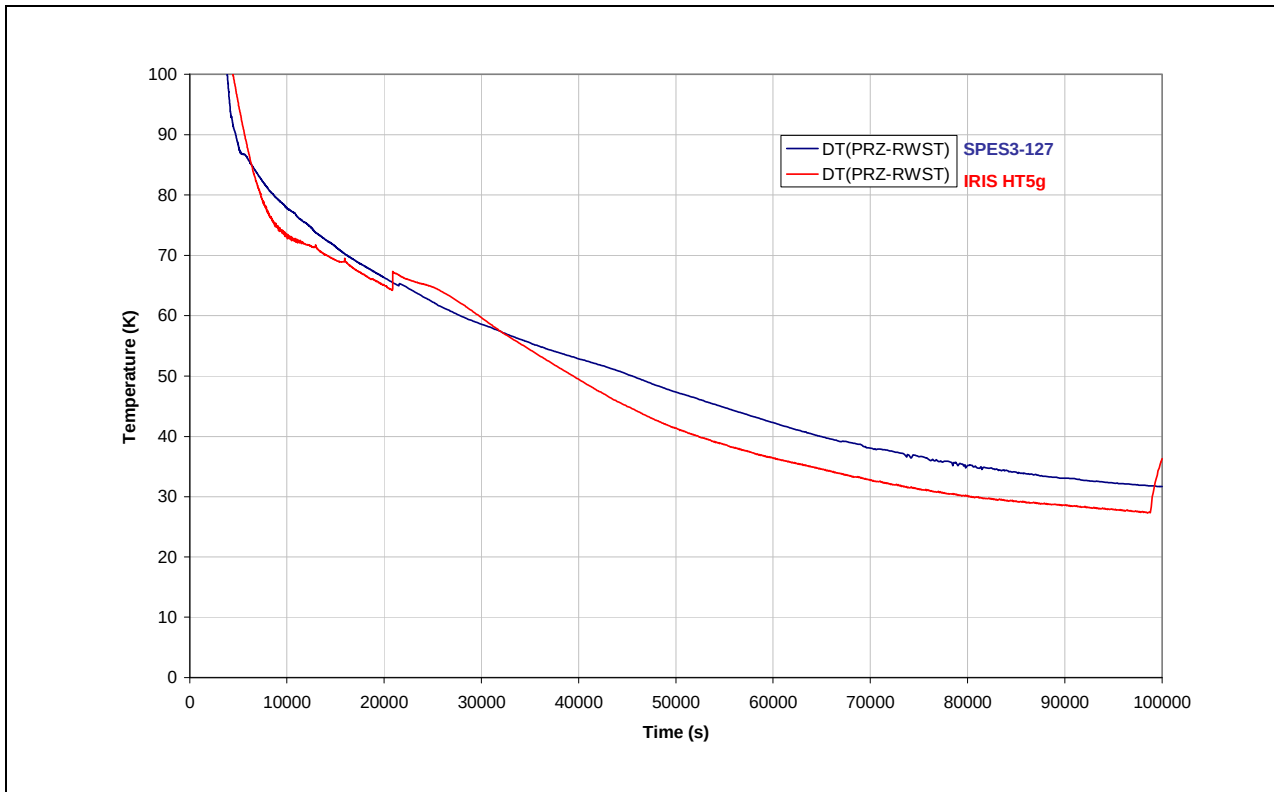
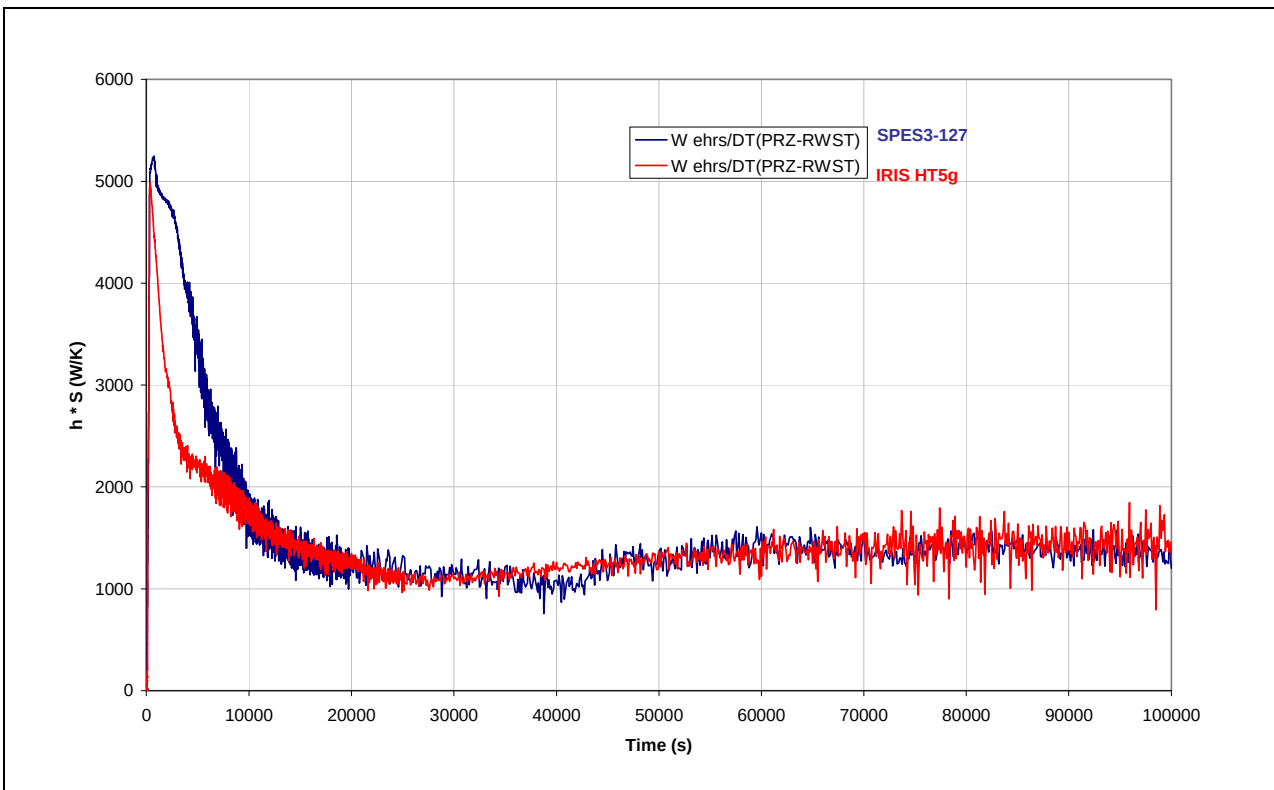


Fig.6. 94 – SPES3-127 and IRIS HT5g PRZ-RWST global heat transfer coefficient



## 7. DVI DEG BREAK: SENSITIVITY ON RWST AND EHRS

This Chapter describes the updates to the SPES3 RWST and EHRS models, up to the final DVI break case simulation (Chapters 8 and 9).

The following paragraphs describe the results of sensitivity cases aimed at solving specific problems evidenced in the SPES3-127 and IRIS HT5g comparison, Tab.7. 1, Tab.7. 3, Tab.7. 4, Tab.7. 5, Tab.7. 6.

### 7.1 Sensitivity case: SPES3-130

SPES3-130 is a sensitivity case on the RWST.

On the basis of the RWST behavior, evidenced in SPES3-127 case, where extra-mass was lost toward the atmosphere control volume, a 6 m (3 horizontal and 3 vertical) 5 inch Sch. 40 discharge pipe was added to connect the RWST top to the control volume in order to limit the water-air contact surface and avoid the loss of mass phenomenon. Actually, a discharge pipe will be installed in the plant to drive the pool boil-off out of the facility hall. The new RWST nodalization is shown in Fig.3. 10.

The characteristics of the case are summarized in the followings:

*SPES3-130: sensitivity on the RWST boil-off pipe*

- As in case SPES3-127:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle 10 mm;

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHRS-A and B cold leg calibrated orifice diameter 5 mm;

EHRS-C cold leg calibrated orifice diameter 7 mm;

RC to DVI line calibrated orifice diameter 1 mm;

Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);

Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);

LGMS to DVI line calibrated orifice diameter 3.6 mm;

Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);

Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);

PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom)

DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C.

PSS bottom modeled with two branches, Fig.3. 9.

- New for this case

RWST top pipe connection to atmosphere control volume, Fig.3. 10.

Fig.7. 1 reports the RWST water temperature in SPES3 127, 130 and IRIS HT5g. The SPES3 model modification has solved the loss of mass and cool-down problems that in SPES3-127 did not allow the pool to reach saturation, but the containment pressure trend is still similar to SPES3-127, Fig.7. 2.

It is clear that power transferred to RWST by EHRS is larger in SPES3 than IRIS, especially in the first part of the transient, and this requires further investigations on the EHRS heat exchangers.

### 7.1.1 SG-EHRS loop filling ratio

The mass distribution in the SG-EHRS loops has been investigated for SPES3-130 case in order to have information on its filling ratio and it is summarized in Tab.7. 2. The filling ratio, defined as the ratio between the total mass in the closed loop and the total mass of cold water that could be stored in the loop, for SPES3 is around 0.4.

Fig.7. 3 shows the three SG-EHRS loop total mass, while Fig.7. 4, Fig.7. 5 and Fig.7. 6 show the mass distribution in the various zones of each loop. Fig.7. 7 shows the EHRS heat exchanger collapsed level (from the lower header bottom). It can be observed that the mass oscillation around 4000-5000 s, due to condensate make-up in the heat exchanger for low discharge capabilities of the Cold Leg, with temporary emptying of the SG tubes, only fills the heat exchanger lower header, so leaving tube surface free for condensations. On the basis of these results, the filling ratio of 0.4 seems adequate to guarantee the heat transfer in SPES3 EHRS.

## 7.2 RWST-EHRS stand alone model sensitivity analyses

A series of sensitivity cases on a stand alone model including RWST and EHRS has been run in order to investigate in depth the phenomena related to the heat transfer between EHRS and RWST.

The stand alone model consists of a single RWST hosting the three EHRSs of SPES3, Fig.7. 8. It is based on the model developed by ENEA where the heat transfer coefficients were validated versus the experimental data of the PERSEO facility, consisting in an in-pool heat exchanger with geometrical and thermal-hydraulic conditions similar to IRIS ones [16] [17].

The heat transfer coefficients were calibrated by ENEA on a simplified model limited to the heat exchangers tubes that neglected the heat exchanger header contribution. The model shown in Fig.7. 8 includes also the heat exchanger headers and hot legs and cold legs at HX inlet and outlet.

### 7.2.1 Influence of EHRS tube material on exchanged power

The PERSEO heat exchanger material is Incone-600, the same material as IRIS EHRS. The SPES3 heat exchangers is AISI 304.

Sensitivity calculations have been run to test the influence of the material thermal conductivity on exchanged power. Inconel-600 and AISI 304 thermal conductivities versus temperature are shown in Fig.7. 9 in the SPES3 transient range of temperature. It is evident that AISI 304 thermal conductivity is larger than Inconel-600 one and this indicates the need to reduce the heat transfer surface of the EHRS heat exchangers to compensate for the AISI 304 higher conductivity. Four cases have been run, two at 7 MPa (rwtsi70\_J, rwtsi70\_K) and two at 0.5 MPa (rwtsi5\_L, rwtsi5\_M), by changing only the heat exchanger material. In order to simulate correctly the heat transfer surface of IRIS, the SPES3 heat exchanger headers are thermally insulated with a 0.03 m Teflon layer and also part of the tubes is insulated to correctly scale the tube number. In particular for EHRS A and B, 0.6 tubes out of 3 (final surface corresponding to 2.4 tubes) are insulated with 0.03 m of Teflon and for EHRS C, 0.2 tubes out of 5 (final surface corresponding to 4.8 tubes) are insulated with 0.03 m of Teflon.

At regime conditions, exchanged power are summarized in Tab.7. 3. On average, at high and low pressure, the exchanged power with AISI 304 is 2% higher than power with Inconel-600. This leads to the need of covering with Teflon 2% additional surface of the EHRS tubes.

### 7.2.2 Influence of RWST slice model and tube Fouling Factor on exchanged power

As explained in [17], the ENEA RWST was modeled with a two-slice approach according to the PERSEO post-test analyses [18] and the area of the “Hot column” (slice containing the heat exchanger) was set with the same slice area over tube number ratio as in PERSEO ( $1.3 \text{ m}^2/120 \text{ tubes} = 0.010833 \text{ m}^2/\text{tube}$ ).

The heat transfer coefficients were adjusted to match the experimental ones, corresponding to those obtained by a calibration with the Cathare code, by means of multiplying factors (Fouling Factors) at the inner (condensing [left]) and outer (boiling [right]) surface of the tubes. According to [16] such coefficients were FF left = 2.5 and FF right = 3.25.

When modeling the SPES3 RWST (up to SPES3-132 case included), the “Hot column” area was increased with respect to that of [17], on the basis of the actual location of the heat exchangers in the pools, and the FF coefficients multiplied by 1.09 factor in order to have the same exchanged power.

After coefficient calibration refinements by ENEA, the document [17] reports updated FF with respect to [16], in particular FF left = 2.9 and FF right = 2.77.

Some sensitivity cases on the stand alone model have been run in order to investigate the influence of the FF and of the “Hot column” area on the EHRS exchanged power. They are summarized in Tab.7. 4.

It appears that the “Hot column area” affects the exchanged power more than the variation of FF between [16] and [17].

This result leads to a review of the RWST model of the SPES3 nodalization with a reduction of the “Hot column area” according to the same slice area over tube number ratio as in PERSEO, as described in Paragraph 7.4.

### 7.3 Sensitivity case: SPES3-132

SPES3-132 is a sensitivity case on the EHRS tube surface insulation based on the results reported in Paragraph 7.2.1.

In particular, the SPES3 EHRS tube heat transfer surface has been reduced to keep into account of the larger thermal conductivity of AISI 304 (used in SPES3) than Inconel-600 (used in IRIS). Moreover, 0.2 equivalent tube has been thermally insulated in EHRS-C to correctly scale with 4.8 tubes the number of tubes of two IRIS heat exchanger modules ( $240 \times 2 \text{ tubes}$ ) because, up to case SPES3-130, the total surface of 5 tubes was used.

The main SPES3-132 characteristics are reported below:

#### *SPES3-132: sensitivity on EHRS tube surface*

- As in case SPES3-130:

DW volume  $32.27 \text{ m}^3$  ( $D_i = 1.62 \text{ m}$ );

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume  $4.5 \text{ m}^3$  ( $D_i \text{ top} = 0.961 \text{ m}$ ;  $D_i \text{ bot} = 0.553 \text{ m}$ );

RC thickness top 10 mm, bot 8 mm;

QT volume  $0.336 \text{ m}^3$  ( $D_i = 0.37 \text{ m}$ );

QT thickness 6 mm;

PSS volume  $4.59 \text{ m}^3$  ( $D_i \text{ top} = 1.182 \text{ m}$ ;  $D_i \text{ bot} = 0.679 \text{ m}$ );

PSS thickness top 12 mm, bot 8 mm;

LGMS volume  $1.5 \text{ m}^3$  ( $D_i \text{ top and bot} = 0.554 \text{ m}$ ;  $D_i \text{ mid} = 0.831 \text{ m}$ );

LGMS height 4 m;  
 LGMS thickness top and bot 8 mm, middle 10 mm;  
 ADS ST Stage-I calibrated orifice diameter 5.637 mm;  
 ADS DT Stage-I calibrated orifice diameter 7.973 mm;  
 EHRS-A and B cold leg calibrated orifice diameter 5 mm;  
 EHRS-C cold leg calibrated orifice diameter 7 mm;  
 RC to DVI line calibrated orifice diameter 1 mm;  
 Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);  
 Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);  
 LGMS to DVI line calibrated orifice diameter 3.6 mm;  
 Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);  
 Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);  
 PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom)  
 DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C.  
 PSS bottom modeled with two branches, Fig.3. 9.  
 RWST top pipe connection to atmosphere control volume, Fig.3. 10.

- New for this case

EHRS-A and B: covered with Teflon additional 2% surface of tubes (originally insulated with Teflon 0.6 tubes out of 3 to scale 240 tubes of IRIS EHRS).

EHRS-C: covered with Teflon 0.2 tube out of 5 (originally 5 tubes not insulated to simulate 480 tubes of two IRIS EHRS); covered additional 2% surface.

Corrected initial condition for LGMS level to have 1 m<sup>3</sup> water.

Fig.7. 10 and Fig.7. 11 show the EHRS power for cases SPES3-132, 130 and IRIS HT5g. The average power removed in the long term, between 70000 a and 95000 s, in SPES3-132 results 19.19 kW for EHRS-A+B and 19.10 kW for EHRS-C, around 20% lower than corresponding power of case SPES3-130 (EHRS-A+B 24.3 kW, EHRS-C 23.3 kW) and closer to IRIS HT5g (EHRS-A+B 21.2 kW; EHRS-C 21.3).

Fig.7. 12 shows the containment pressure. The SPES3-132 case shows a DW peak pressure closer to IRIS HT5g than SPES3-130. The pressure trend in the long term is very similar in SPES3-132 and 130, still opposite to IRIS, notwithstanding the EHRS removed power decrease.

Fig.7. 13 shows the RWST temperatures. Due to the lower power removed by the EHRSS, the SPES3-132 RWST reaches boiling conditions later than SPES3-130, getting closer to IRIS HT5g.

#### 7.4 SPES3 and PERSEO RWST-EHRS stand alone model sensitivity analyses

The results described in the previous chapters, with particular attention to the EHRS-RWST heat transfer led to investigate the item in depth to understand the reasons of the differences in transferred power between SPES3 and IRIS.

Stand alone models of the EHRS circuits were used for SPES3 and IRIS and ran at the same boundary conditions. The models included the Hot Leg, the heat exchanger, the Cold Leg and the RWST. Due to the difference between the loops, two model were developed for SPES3, one including the EHRS-A and B and RWST-AB (SPES3-AB) and the other one including the EHRS-C and RWST-C (SPES3-C), Fig.7. 14. Due to symmetry of IRIS loops, a single model was developed including two EHRS HXs and an RWST, Fig.7. 15, [19], Fig.7. 16.

The cases, summarized in Tab.7. 5 were run according to the following steps:

- direct comparison of exchanged power between IRIS and SPES3 in the geometrical and model configuration of IRIS-HT5h and an updated model with respect to SPES3-132, reviewed according to the same slice area over tube number ratio as in PERSEO and Fouling Factors FF as reported in [17].
- investigation of the possible causes for the different transferred power: Hot column area (slice containing the heat exchanger); piping pressure drops (HL and CL) and Heat exchanger tube flooding; HX tube material and thermal insulation with Teflon.
- SPES3 Hot Leg and Cold Leg resizing to have the same pressure drops as in IRIS; introduction of a calibrated orifice on the Hot Leg and resizing of the calibrated orifice on the Cold Leg.
- check of the loop pressure drops in the Feed Line (between MFIV and SG), SG tubes, and Steam Line (between SG and MSIV) and verification of the similarity between SPES3 and IRIS.
- identification of a final configuration for SPES3 EHRS loops: piping, HX and RWST.
- IRIS RWST model and HX heat transfer parameter modification according to [17] and to SPES3 nodalization.

The results of the above step process led to obtain for SPES3 the cases *rwtsi70\_TT.i* (SPES3-AB) and *rwtsi70\_UU.i* (SPES3-C) and for IRIS the case *ehrs-iris5* (IRIS Pereo), Tab.7. 5. Such cases, ran at 70 bar pressure, evidenced an acceptable difference in the exchanged power lower than 5% with SPES3 higher than IRIS.

## 7.5 SPES3 and IRIS EHRS-RWST stand alone model parametric cases

A further step, consequent to the outcomes of the process described in Paragraph 7.4, led to a series of parametric runs to check the variation of power versus pressure with the comparison of four cases: SPES3-AB, SPES3-C, IRIS Perseo and IRIS original, Tab.7. 5.

The results, summarized in Tab.7. 6 and shown in Fig.7. 17, indicate that the three cases based on PERSEO calibration give similar results, while the original IRIS case is quite different, especially at lower pressure, when the long term heat removal occurs following accidental transients.

These results suggest a review of IRIS nodalization by FER, based on the EHRS-RWST Perseo model.

## 7.6 Sensitivity case: SPES3-135

The SPES3-135 model includes all the design and model updates described in the previous paragraphs, in particular the review of the whole EHRS circuits with Hot and Cold Leg resizing, RWST slice area adjustment, Heat Exchanger heat transfer surface reduction and Fouling Factor updates (Paragraph 7.4);

The main SPES3-135 characteristics are reported below:

### *SPES3-135: DVI break base case*

- As in case SPES3-132:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;



LGMS volume  $1.5 \text{ m}^3$  (Di top and bot = 0.554 m; Di mid = 0.831 m);  
 LGMS height 4 m;  
 LGMS thickness top and bot 8 mm, middle 10 mm;  
 ADS ST Stage-I calibrated orifice diameter 5.637 mm;  
 ADS DT Stage-I calibrated orifice diameter 7.973 mm;  
 RC to DVI line calibrated orifice diameter 1 mm;  
 Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);  
 Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);  
 LGMS to DVI line calibrated orifice diameter 3.6 mm;  
 Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);  
 Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);  
 PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom);  
 DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C;  
 PSS bottom modeled with two branches, Fig.3. 9;  
 RWST top pipe connection to atmosphere control volume, Fig.3. 10;  
 LGMS initial level set to have  $1 \text{ m}^3$  water;  
 EHRS-A and B: 0.6 tubes out of 3 thermally insulated with Teflon to simulate 240 IRIS EHRS tubes; additional 2% surface of tubes insulated to compensate for AISI-304 instead of Inconel-600;  
 EHRS-C: 0.2 tubes out of 5 thermally insulated with Teflon to simulate 480 IRIS EHRS tubes; additional 2% surface of tubes insulated to compensate for AISI-304 instead of Inconel-600;

- New for this case

EHRS-A and B: additional 2% surface of tubes covered with Teflon (4% total extra surface covered to compensate for AISI-304 instead of Inconel-600).  
 EHRS-C: additional 2% surface of tubes covered with Teflon (4% total extra surface covered to compensate for AISI-304 instead of Inconel-600).  
 EHRS Hot Leg-A and B resized to 1 ¼" Sch. 80 (original size 2" Sch. 80);  
 EHRS Cold Leg-A and B resized to ½" Sch. 80 (original size 1 ¼" Sch. 80);  
 EHRS Hot Leg-C resized to 2" Sch. 80 (original size 2 ½" Sch. 80);  
 EHRS Cold Leg-C resized to ¾" Sch. 80 (original size 1 ½" Sch. 80);  
 Added an orifice (D = 17 mm ) on HL-A and B for pressure drop adjustment;  
 Added an orifice (D = 24 mm ) on HL-C for pressure drop adjustment;  
 Resized orifice (D = 5.9 mm ) on CL-A and B for pressure drop adjustment (original size 5 mm);  
 Resized orifice (D = 8.3 mm ) on CL-C for pressure drop adjustment (original size 7 mm);  
 EHRS tube Fouling Factor: Left 2.9 (original value 2.725); Right 2.77 (original value 3.54284);  
 RWST-AB slice: Hot column area  $0.119167 \text{ m}^2$  (original area  $0.490494 \text{ m}^2$ ); Cold column area  $1.601169 \text{ m}^2$  (original area  $1.217681 \text{ m}^2$ );  
 RWST-C slice: Hot column area  $0.119167 \text{ m}^2$  (original area  $0.492521 \text{ m}^2$ ); Cold column area  $1.601169 \text{ m}^2$  (original area  $1.217681 \text{ m}^2$ );  
 RWST-AB and C side junction area  $0.134618 \text{ m}^2$  (original value  $0.105772 \text{ m}^2$ ).



Fig.7. 18 compares the SPES3-135, SPES3-132 and IRIS HT5g DW pressure. In SPES3-135, the DW pressure results slightly (0.02 to 0.04 MPa) lower than in SPES3-132 and closer to IRIS HT5g pressure, especially after 5000 s. Anyway, the SPES3 pressure trend is the same observed in the previous cases, opposite to IRIS in the long term. The SPES3-135 case has been run until 150000 s to see if and at which value it reaches an equilibrium. Since 115000 s on, pressure stabilizes around 0.021 MPa.

Fig.7. 19 reports the secondary side mass flow in the natural circulation phase. It immediately appears that in SPES3-135 the SG-A and B behave differently from SPES3-132. i.e. there is a higher mass flow even in the late phase of the transient. An error in the input deck is found on a volume of their related EHRS-CLs that is overestimated affecting the filling ratio of loops A and B.

Another aspects that appears from Fig.7. 19 is that oscillations in Loop-C start earlier (~10000 s) and with grater amplitude in SPES3-135 than SPES3-132. Oscillations related to SG parallel tube rows seem related to the general modification of the EHRS loop pressure drops after HL and CL resizing. The modification of the SG tube inlet orifice is suggested to increase the local pressure drop and reduce oscillations.

**Tab.7. 1 – Summary of SPES3 sensitivity cases on the RWST and EHRS systems**

| SPES3 run | Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | New for this case                                                |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| SPES3-130 | <ul style="list-style-type: none"> <li>As in case SPES3-127:</li> </ul> <p>DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);<br/> DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);<br/> RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);<br/> RC thickness top 10 mm, bot 8 mm;<br/> QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);<br/> QT thickness 6 mm;<br/> PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);<br/> PSS thickness top 12 mm, bot 8 mm;<br/> LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);<br/> LGMS height 4 m;<br/> LGMS thickness top and bot 8 mm, middle 10 mm;<br/> ADS ST Stage-I calibrated orifice diameter 5.637 mm;<br/> ADS DT Stage-I calibrated orifice diameter 7.973 mm;<br/> EHRS-A and B cold leg calibrated orifice diameter 5 mm;<br/> EHRS-C cold leg calibrated orifice diameter 7 mm;<br/> RC to DVI line calibrated orifice diameter 1 mm;<br/> Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);<br/> Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);<br/> LGMS to DVI line calibrated orifice diameter 3.6 mm;<br/> Extension PSS vent pipe calibrated orifice diameter 19 mm (from 7.3 mm);<br/> Extension PSS vent pipe length decreased to match IRIS length.<br/> Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);<br/> PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom)<br/> DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C.<br/> PSS bottom modeled with two branches, Fig.3. 9.</p> | RWST top pipe connection to atmosphere control volume, Fig.3. 10 |

to be continued....

...continued

|           |                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----------|----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SPES3-132 | <ul style="list-style-type: none"> <li>As SPES3-130</li> </ul> | <p>EHRS-A and B: covered with Teflon additional 2% surface of tubes (originally insulated with Teflon 0.6 tubes out of 3 to scale 240 tubes of IRIS EHRS).</p> <p>EHRS-C: covered with Teflon 0.2 tube out of 5 (originally 5 tubes not insulated to simulate 480 tubes of two IRIS EHRS); covered additional 2% surface.</p> <p>Corrected initial condition for LGMS level to have 1 m<sup>3</sup> water.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| SPES3-135 | <ul style="list-style-type: none"> <li>As SPES3-132</li> </ul> | <p>EHRS-A and B: additional 2% surface of tubes covered with Teflon (4% total extra surface covered to compensate for AISI-304 instead of Inconel-600).</p> <p>EHRS-C: additional 2% surface of tubes covered with Teflon (4% total extra surface covered to compensate for AISI-304 instead of Inconel-600).</p> <p>EHRS Hot Leg-A and B resized to 1 ¼" Sch. 80 (original size 2" Sch. 80);</p> <p>EHRS Cold Leg-A and B resized to ½" Sch. 80 (original size 1 ¼" Sch. 80);</p> <p>EHRS Hot Leg-C resized to 2" Sch. 80 (original size 2 ½" Sch. 80);</p> <p>EHRS Cold Leg-C resized to ¾" Sch. 80 (original size 1 ½" Sch. 80);</p> <p>Added an orifice (D = 17 mm ) on HL-A and B for pressure drop adjustment;</p> <p>Added an orifice (D = 24 mm ) on HL-C for pressure drop adjustment;</p> <p>Resized orifice (D = 5.9 mm ) on CL-A and B for pressure drop adjustment (original size 5 mm);</p> <p>Resized orifice (D = 8.3 mm ) on CL-C for pressure drop adjustment (original size 7 mm);</p> <p>EHRS tube Fouling Factor: Left 2.9 (original value 2.725); Right 2.77 (original value 3.54284);</p> <p>RWST-AB slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.490494 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);</p> <p>RWST-C slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.492521 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);</p> <p>RWST-AB and C side junction area 0.134618 m<sup>2</sup> (original value 0.105772 m<sup>2</sup>).</p> |

**Tab.7. 2 – SPES3-130 SG-EHRS loop mass distribution**

|                                         |           |                                     |
|-----------------------------------------|-----------|-------------------------------------|
| <b>EHRS-SG A loop</b>                   | Volume m3 |                                     |
|                                         |           |                                     |
| SG-A tubes                              | 0.070     |                                     |
| FL-A from MFIV to SG inlet              | 0.017     |                                     |
| SL-A from SG outlet to MSIV             | 0.036     |                                     |
| HL-A                                    | 0.022     |                                     |
| EHRS-A HX                               | 0.034     |                                     |
| CL-A                                    | 0.015     |                                     |
|                                         |           |                                     |
| Total loop A volume                     | 0.193     |                                     |
| Total loop A cold mass kg               | 193.282   |                                     |
| Initial mass (spes3-130) kg             | 79.800    |                                     |
| Initial mass SG isolated (spes3-130) kg | 76.200    | mass after Secondary loop isolation |
| Filling ratio                           | 0.394     |                                     |
|                                         |           |                                     |
| <b>EHRS-SG B loop</b>                   | Volume m3 |                                     |
|                                         |           |                                     |
| SG-B tubes                              | 0.070     |                                     |
| FL-B from MFIV to SG inlet              | 0.012     |                                     |
| SL-B from SG outlet to MSIV             | 0.029     |                                     |
| HL-B                                    | 0.022     |                                     |
| EHRS-B HX                               | 0.034     |                                     |
| CL-B                                    | 0.014     |                                     |
|                                         |           |                                     |
| Total loop B volume                     | 0.182     |                                     |
| Total loop B cold mass                  | 181.610   |                                     |
| Initial mass (spes3-130) kg             | 76.100    |                                     |
| Initial mass SG isolated (spes3-130) kg | 72.490    | mass after Secondary loop isolation |
| Filling ratio                           | 0.399     |                                     |
|                                         |           |                                     |
| <b>EHRS-SG C loop</b>                   | Volume m3 |                                     |
|                                         |           |                                     |
| SG-C1+C2 tubes                          | 0.140     |                                     |
| FL-C from MFIV to SG inlet              | 0.029     |                                     |
| SL-C from SG outlet to MSIV             | 0.066     |                                     |
| HL-C                                    | 0.029     |                                     |
| EHRS-C HX                               | 0.059     |                                     |
| CL-C                                    | 0.019     |                                     |
|                                         |           |                                     |
| Total loop C volume                     | 0.342     |                                     |
| Total loop C cold mass                  | 341.902   |                                     |
| Initial mass (spes3-130) kg             | 135.700   |                                     |
| Initial mass SG isolated (spes3-130) kg | 131.680   | mass after Secondary loop isolation |
| Filling ratio                           | 0.385     |                                     |

**Tab.7. 3 – EHRS power with Inconel-600 and AISI 304**

| Case      | Characteristics               | Power (MW) |
|-----------|-------------------------------|------------|
|           |                               |            |
| rwtsi70_J | 7 MPa pressure; AISI 304      | 1.46       |
| rwtsi70_K | 7 MPa pressure; Inconel-600   | 1.42       |
|           |                               |            |
| rwtsi5_L  | 0.5 MPa pressure; AISI 304    | 0.502      |
| rwtsi5_M  | 0.5 MPa pressure; Inconel-600 | 0.493      |

**Tab.7. 4 – RWST-EHRS sensitivity on FF and “Hot column” area**

| Case      | Characteristics                                                               | Power (MW) |
|-----------|-------------------------------------------------------------------------------|------------|
|           |                                                                               |            |
| rwtsi70_P | FF left = 2.9; FF right 2.77 [17];<br>Hot column area 0.502655 m <sup>2</sup> | 1.46       |
| rwtsi70_Q | FF left = 2.9; FF right 2.77 [17];<br>Hot column area 0.11917 m <sup>2</sup>  | 1.55       |
| rwtsi5_R  | FF left = 2.5; FF right 3.25 [16];<br>Hot column area 0.11917 m <sup>2</sup>  | 1.47       |

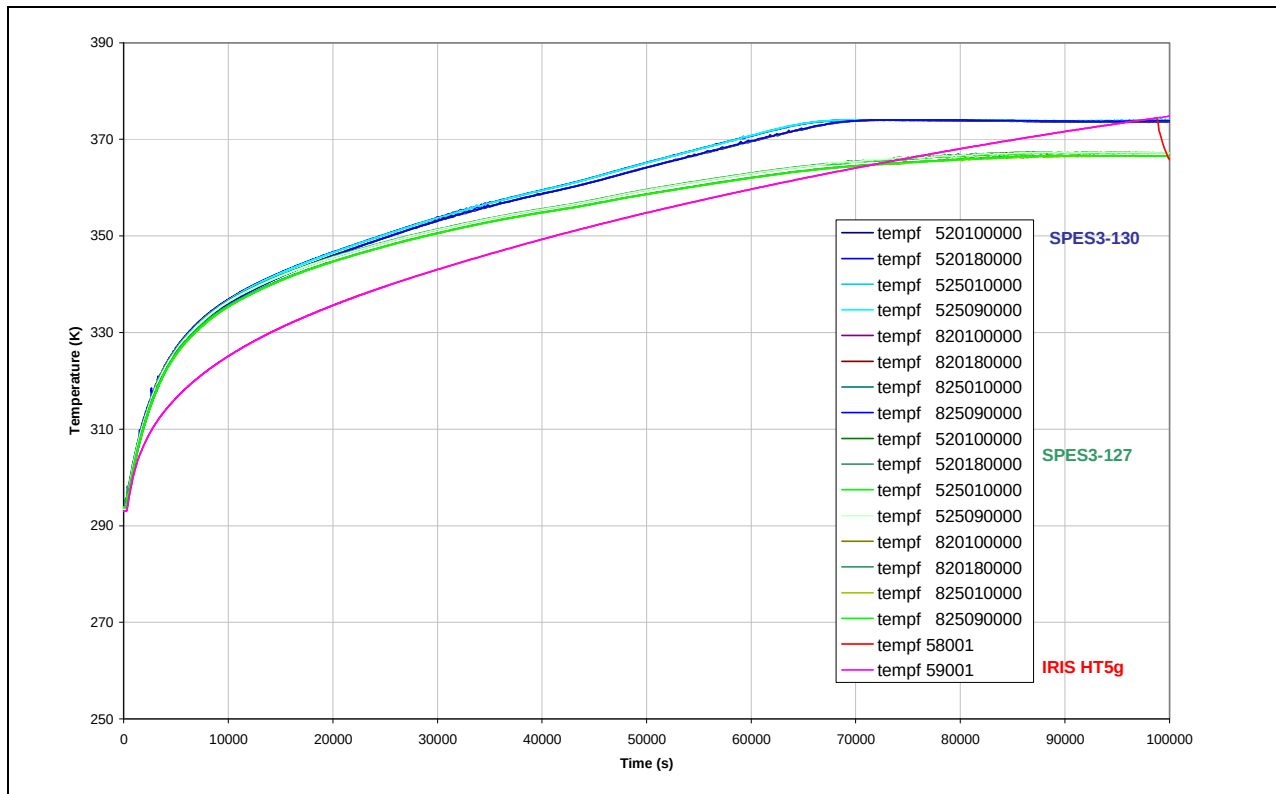
**Tab.7. 5 – SPES3 and IRIS RWST-EHRS stand alone model sensitivities**

|                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ehrs-iris1.i                 | IRIS base case. Geometry as provided by FER [19]. Modified inlet/outlet boundary conditions for comparison with SPES3. Inlet P 70 bar saturated steam; Outlet P 70.5 bar liquid. Not imposed inlet mass flow.<br>RES: 2 EHRS tot power 66.1 MW/100 = 0.661 MW (12.3% power less than rwstsi70_AA). HX tubes 0.42 m flooded.                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| rwstsi70_AA.i                | Reference case for SPES3, loops A and B, stand alone for comparison with IRIS. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. EHRS: FF Left 2.9; FF Right 2.77; Area hot column 0.11917 m <sup>2</sup> (area related to 11 tubes, instead of the actual 6 tubes, to keep into account of the tube bundle side effects); Area Cold column 1.589004 m <sup>2</sup> . side junctions (tube zone) 0.13454 m <sup>2</sup> ; RWST top zone 5.377 m <sup>3</sup> . Hydraulic diameters in the hot and cold columns according to HX tube number HC Dh 0.2186 m; CC Dh 2.1445 m. Covered 2% tube surface (AISI 304-Inconel 600) in EHRS A and B. Adjusted non-cond quality at RWST top (vol 530-01) to have 12m <sup>3</sup> water Xg = 6.32435e-3.<br>RES: Total 2 EHRS power at 3000 s 0.742 MW |
| ehrs-iris2.i                 | As ehrs-iris1. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified HC and CC areas according to Perseo ratio: HC 1.3/120*240 =5.2 m <sup>2</sup> ; CC 121.1 m <sup>2</sup> . Modified Dh HC 0.4484 m (it was 0.0508 m).<br>RES: 2 EHRS tot power 66.2 MW/100 = 0.662 MW (0.15% power higher than ehrs-iris1 - little influence of HC area)                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| ehrs-iris3.i                 | As ehrs-iris2. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Added side junctions as in spes3 model. Side junction area 2.299 m <sup>2</sup> ; Kf/r 0.2 (side area of HC divided by junction number).<br>RES: 2 EHRS tot power 65.9 MW/100 = 0.659 MW (the addition of side junction decreases power of 0.4% compared to iris2 – little effect).                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| rwstsi70_BB.i                | As rwstsi70_AA. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified: W2, W3 (heated lengthh f/r), W10 (pitch/D) of EHRS HX Heat Structure (tubes and header).<br>RES: Total 2 EHRS power at 3000 s 0.740 MW (~same power as rwstsi70_AA; 0.3% lower power – little effect)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| ehrs-iris4.i                 | As ehrs-iris3. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified the thermal parameters at EHRS HX heat structures according to rwstsi70_BB for a direct comparison.<br>RES: 2 EHRS tot power 61.5 MW/100 = 0.615 MW (20% lower power in IRIS than SPES3). The reason is IRIS EHRS is partially flooded (up to 507-09), while SPES3 is empty. Larger pressure drops in IRIS loop.                                                                                                                                                                                                                                                                                                                                                                                                  |
| rwstsi70_CC.i                | As rwstsi70_BB. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified: updated HL and CL geometry as in SPES3-133.<br>RES: Total 2 EHRS power at 3000 s 0.546 MW. 35% power decrease compared to rwstsi70_BB. EHRS flooded up to 558-12. Different DP in HL and CL between S3 and IRIS.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| rwstsi70_DD.i                | As rwstsi70_CC. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified: updated HL and CL geometry as after diameter re-sizing for DP conservation with IRIS.<br>RES: Total 2 EHRS power at 3000 s 0.604 MW. 2% power lower than ehrs-iris4. HX SPES3 flooded up to 0.4 m, HX IRIS up to 0.2 m                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| rwstsi70_EE.i                | As rwstsi70_CC. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified: enlarged CL orifice with D 10mm (beta~0.75).<br>RES: Total 2 EHRS power at 3000 s 0.725 MW. 18% power higher than ehrs-iris4. HX SPES3 completely empty down to CL vol 511-02. HX IRIS flooded up to 0.2 m above header.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| rwstsi70_FF.i                | As rwstsi70_EE. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. CL orifice with D 10mm (beta~0.75). Modified: HL orifice D 17 mm, Kf/r 1.794 (from ehrrdp3.i)<br>RES: Total 2 EHRS power at 3000 s 0.713 MW. 16% power higher than ehrs-iris4. HX SPES3 completely empty down to lower header. CL pipe full of water. HX IRIS flooded up to 0.2 m above header.                                                                                                                                                                                                                                                                                                                                                                                                                           |
| rwstsi70_GG.i                | As rwstsi70_FF. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified CL orifice with D 5 mm (beta~0.36).<br>RES: Total 2 EHRS power at 3000 s 0.711 MW. 15.5% power higher than ehrs-iris4. HX SPES3 completely empty down to lower header. CL pipe full of water. HX IRIS flooded up to 0.2 m above header.                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| rwstsi70_HH.i                | As rwstsi70_FF. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified CL orifice with D 3.5 mm (beta~0.07).<br>RES: Total 2 EHRS power at 3000 s 0.711 MW. 15.5% power higher than ehrs-iris4. HX SPES3 completely empty down to lower header. CL pipe full of water. HX IRIS flooded up to 0.2 m above header.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| rwstsi70_II.i                | As rwstsi70_FF. Inlet P 70 bar steam; Outlet P 70.5 bar liquid. Modified CL orifice with D 6.5 mm (beta~0.47). Abrupt area change=1<br>RES: Total 2 EHRS power at 3000 s 0.671 MW. 9% power higher than ehrs-iris4. HX SPES3 XH tubes flooded 0.2 m. HX IRIS flooded up to 0.2 m above header                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| ehrs-iris5.i (IRIS Perseo)   | As ehrs-iris4. Inlet P 70 bar steam; Outlet P 70. bar liquid. Modified outlet pressure to avoid EHRS tube flooding.<br>RES: 2 EHRS tot power 65.6 MW/100 = 0.656 MW (7.7% lower power in IRIS than rwstsi70_JJ). XH tubes empty. Lower header full. CL full. Mass flow                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| rwstsi70_JJ.i                | As rwstsi70_II. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified: outlet pressure to EHRS to avoid tube flooding. Adjusted RWST area and volumes according to Perseo ratio (file merge Rev11).<br>RES: Total 2 EHRS power at 3000 s 0.707 MW. 7.7% power higher than ehrs-iris5. HX SPES3 XH tubes and lower header empty. CL flooded.                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ehrs-iris6.i (IRIS original) | As ehrs-iris1. IRIS base case. Geometry as provided by FER. Modified inlet/outlet boundary conditions for comparison with SPES3. Inlet P 70 bar steam; Outlet P 70.0 bar liquid.<br>RES: 2 EHRS tot power 74.6 MW/100 = 0.746 MW (same power as rwstsi70_JJ, but with HX flooded tubes. So, IRIS power is higher than SPES3 power). HX tubes flooded 0.17 m                                                                                                                                                                                                                                                                                                                                                                                                                               |
| rwstsi70_KK.i                | Analogous to JJ, but with EHRS-C and RWST-C. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. CL orifice D 8.6 mm<br>RES: EHRS-C power at 3000 s 0.701 MW. Very similar to rwstsi70_JJ. HX SPES3 XH tubes and lower header empty. CL flooded.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| rwstsi70_LL.i                | As rwstsi70_JJ. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified top RWST. Unified volumes to be similar to IRIS model.<br>RES: Total 2 EHRS power at 3000 s 0.705 MW. 7.4% power higher than ehrs-iris5. HX SPES3 XH tubes and lower header empty. CL flooded. No sensible change in exchanged power.                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| rwstsi70_MM.i                | As rwstsi70_JJ. Inlet P 60 bar steam; Outlet P 60.0 bar liquid. Modified in/out pressure to reduce CL level.<br>RES: Total 2 EHRS power at 3000 s 0.674 MW. 7.1% power higher than IRIS7. HX SPES3 XH tubes and lower header empty. CL flooded.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| ehrs-iris7.i                 | As ehrs-iris5. Inlet P 60 bar steam; Outlet P 60. bar liquid. Modified in/out pressure to reduce CL level.<br>RES: 2 EHRS tot power 62.9 MW/100 = 0.629 MW (7.1% lower power than SPES3 MM). XH tubes empty. Lower header flooded. Mass flow 0.196 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| rwstsi70_NN.i                | As rwstsi70_JJ. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified CL orifice D 6.2 mm (it was 6.5 mm) to increase CL pressure drops.<br>RES: Total 2 EHRS power at 3000 s 0.701 MW. 6.8% power higher than ehrs-iris5. HX SPES3 XH tubes empty. Lower header partially full. CL full.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| rwstsi70_OO.i                | As rwstsi70_NN. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified CL orifice D 6.0 mm (it was 6.2 mm) to increase CL pressure drops.<br>RES: Total 2 EHRS power at 3000 s 0.703 MW. 6.8% power higher than ehrs-iris5. HX SPES3 XH tubes empty. Lower header full. Mass flow 0.209 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| rwstsi70_PP.i                | As rwstsi70_OO. Inlet P 10 bar steam; Outlet P 10.0 bar liquid. Modified: reduced in/out P.<br>RES: Total 2 EHRS power at 3000 s 0.333 MW. % power higher than ehrs-iris5. HX SPES3 XH tubes empty. Lower header empty. Mass flow 0.087 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| ehrs-iris8.i                 | As ehrs-iris7. Inlet P 10 bar steam; Outlet P 10. bar liquid. Modified in/out pressure to compare to rwstsi70_PP.<br>RES: 2 EHRS tot power 32.5 MW/100 = 0.325 MW (2.5% lower power than rwstsi70_PP). XH tubes empty. Lower header 0.2 m flooded. Mass flow 0.084 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| rwstsi70_QQ.i                | As rwstsi70_OO. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified header FF set to 1.<br>RES: Total 2 EHRS power at 3000 s 0.697 MW. 6.5% power higher than IRIS9. HX SPES3 XH tubes empty. Lower header full. Mass flow 0.210 kg/s. 0.9% power lower than rwstsi70_OO. Little effect of FF on headers.                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ehrs-iris9.i                 | As ehrs-iris4. Inlet P 70 bar steam; Outlet P 70. bar liquid. Modified header FF set to 1.<br>RES: 2 EHRS tot power 65.4 MW/100 = 0.654 MW (6.5% lower power in IRIS than rwstsi70_QQ). XH tubes empty. Lower header full. CL full. Mass flow 0.202 kg/s. 0.3% power lower than ehrs-iris5 (negligible effect of FF on header)                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| rwstsi70_RR.i                | As rwstsi70_OO. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified: EHRS tube material set to Inconel-600<br>RES: Total 2 EHRS power at 3000 s 0.687 MW. 4.7% power higher than ehrs-iris5. AISI 304 causes 2% larger power in rwstsi70_RR than rwstsi70_OO.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| rwstsi70_SS.i                | As rwstsi70_OO. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified Covered 4% tube surface with Teflon to compensate for AISI 304.<br>RES: Total 2 EHRS power at 3000 s 0.686 MW. 4.5% power higher than ehrs-iris5. HX SPES3 XH tubes empty. Lower header 0.53 m flooded. Mass flow 0.208 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| rwstsi70_TT.i (SPES3-AB)     | As rwstsi70_SS. EHRS A/B. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified Reduced CL orifice to D 5.9 mm (it was 6 mm)<br>RES: Total 2 EHRS power at 3000 s 0.685 MW. 4.4% power higher than ehrs-iris5. HX SPES3 XH tubes empty. Lower header flooded. Mass flow 0.206 kg/s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| rwstsi70_UU.i (SPES3-C)      | Analogous to rwstsi70_KK, EHRS-C and RWST-C. Inlet P 70 bar steam; Outlet P 70.0 bar liquid. Modified: covered 4% tube surface with Teflon to compensate for AISI 304. CL orifice D 8.3 mm.<br>RES: EHRS-C power at 3000 s 0.677 MW. 3.2 % power higher than ehrs-iris5. HX tubes empty, lower header flooded. CL flooded. Mass flow 0.397 kg/s (0.1985 *2 kg/s)                                                                                                                                                                                                                                                                                                                                                                                                                          |

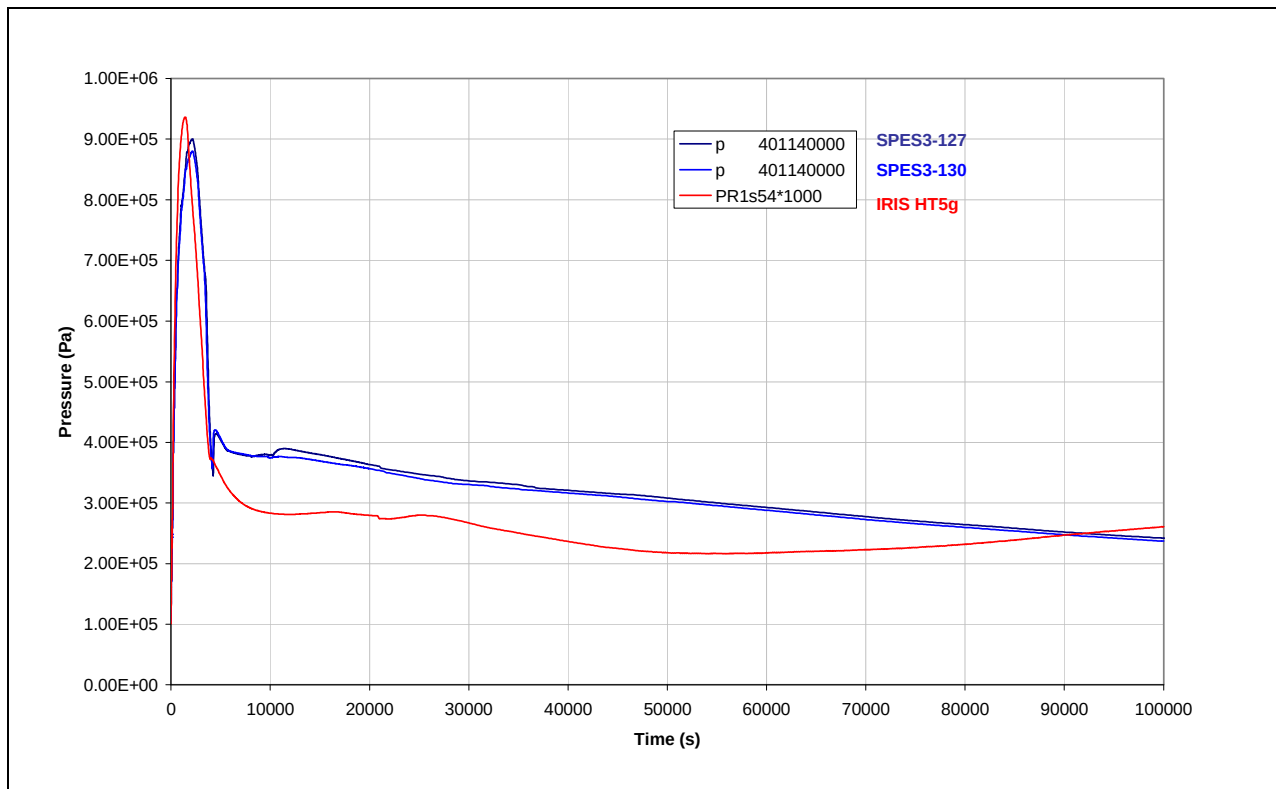
**Tab.7. 6 – SPES3 and IRIS EHRS-RWST parametric cases: power versus pressure**

| <b>P<br/>(MPa)</b> | <b>SPES3-AB<br/>(MW)</b> | <b>SPES3-C<br/>(MW)</b> | <b>IRIS-Perseo<br/>(MW)</b> | <b>IRIS-original<br/>(MW)</b> | <b>IRISoriginal/IRISperseo<br/>%</b> | <b>IRISperseo/SPES3ab<br/>%</b> | <b>IRISperseo/SPES3c<br/>%</b> |
|--------------------|--------------------------|-------------------------|-----------------------------|-------------------------------|--------------------------------------|---------------------------------|--------------------------------|
| 9                  | 0.707                    | 0.704                   | 0.688                       | 0.726                         | 5.234                                | -2.762                          | -2.326                         |
| 8                  | 0.704                    | 0.694                   | 0.68                        | 0.722                         | 5.817                                | -3.529                          | -2.059                         |
| 7                  | 0.686                    | 0.677                   | 0.656                       | 0.699                         | 6.152                                | -4.573                          | -3.201                         |
| 6                  | 0.655                    | 0.646                   | 0.629                       | 0.684                         | 8.041                                | -4.134                          | -2.703                         |
| 5                  | 0.624                    | 0.608                   | 0.592                       | 0.641                         | 7.644                                | -5.405                          | -2.703                         |
| 4                  | 0.578                    | 0.569                   | 0.55                        | 0.588                         | 6.463                                | -5.091                          | -3.455                         |
| 3                  | 0.518                    | 0.504                   | 0.492                       | 0.52                          | 5.385                                | -5.285                          | -2.439                         |
| 2                  | 0.425                    | 0.432                   | 0.427                       | 0.43                          | 0.698                                | 0.468                           | -1.171                         |
| 1                  | 0.325                    | 0.325                   | 0.325                       | 0.286                         | -13.636                              | 0.000                           | 0.000                          |
| 0.5                | 0.254                    | 0.253                   | 0.253                       | 0.168                         | -50.595                              | -0.395                          | 0.000                          |
| 0.3                | 0.203                    | 0.206                   | 0.205                       | 0.124                         | -65.323                              | 0.976                           | -0.488                         |
| 0.2                | 0.169                    | 0.173                   | 0.167                       | 0.105                         | -59.048                              | -1.198                          | -3.593                         |

**Fig.7. 1 - SPES3-130, 127 and IRIS HT5g: RWST temperature**

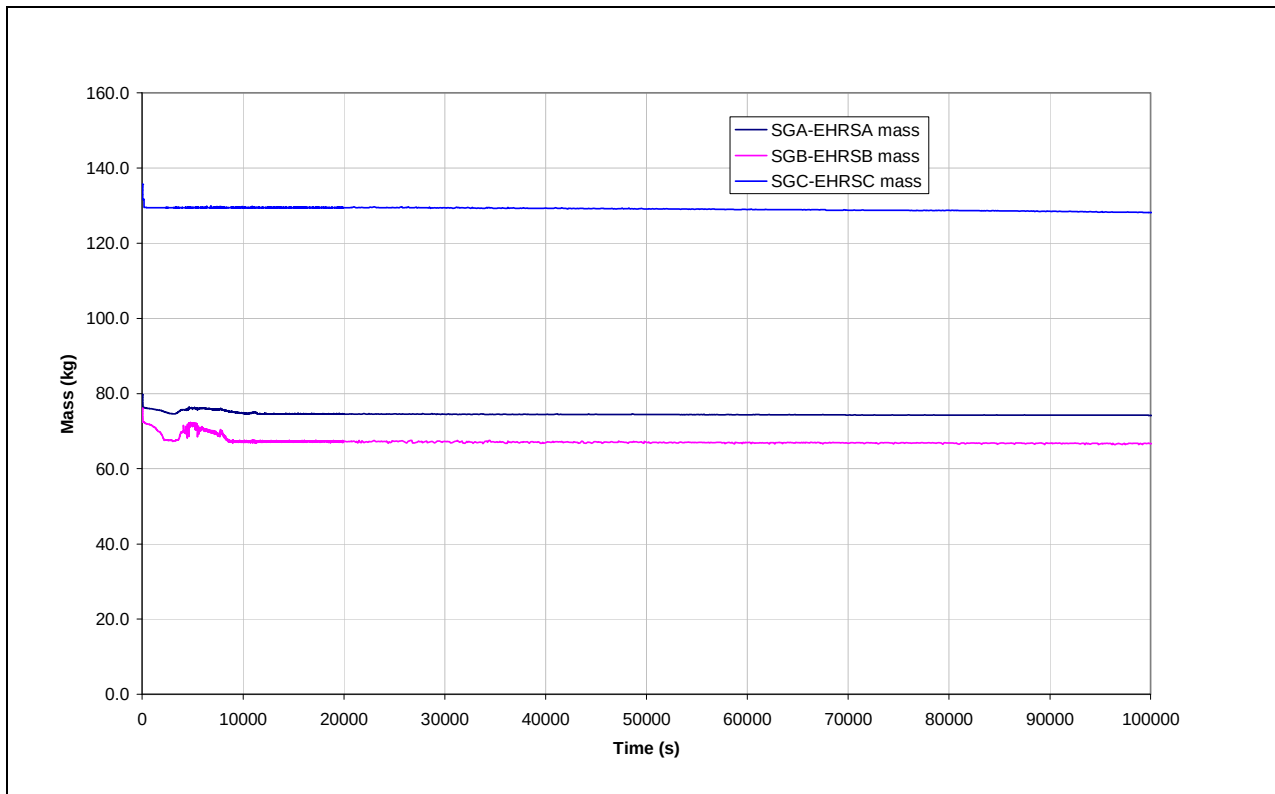


**Fig.7. 2 - SPES3-130, 127 and IRIS HT5g: DW pressure**





**Fig.7. 3 - SPES3-130: SG-EHRS loop mass**



**Fig.7. 4 - SPES3-130: SG-EHRS loop A partial masses**

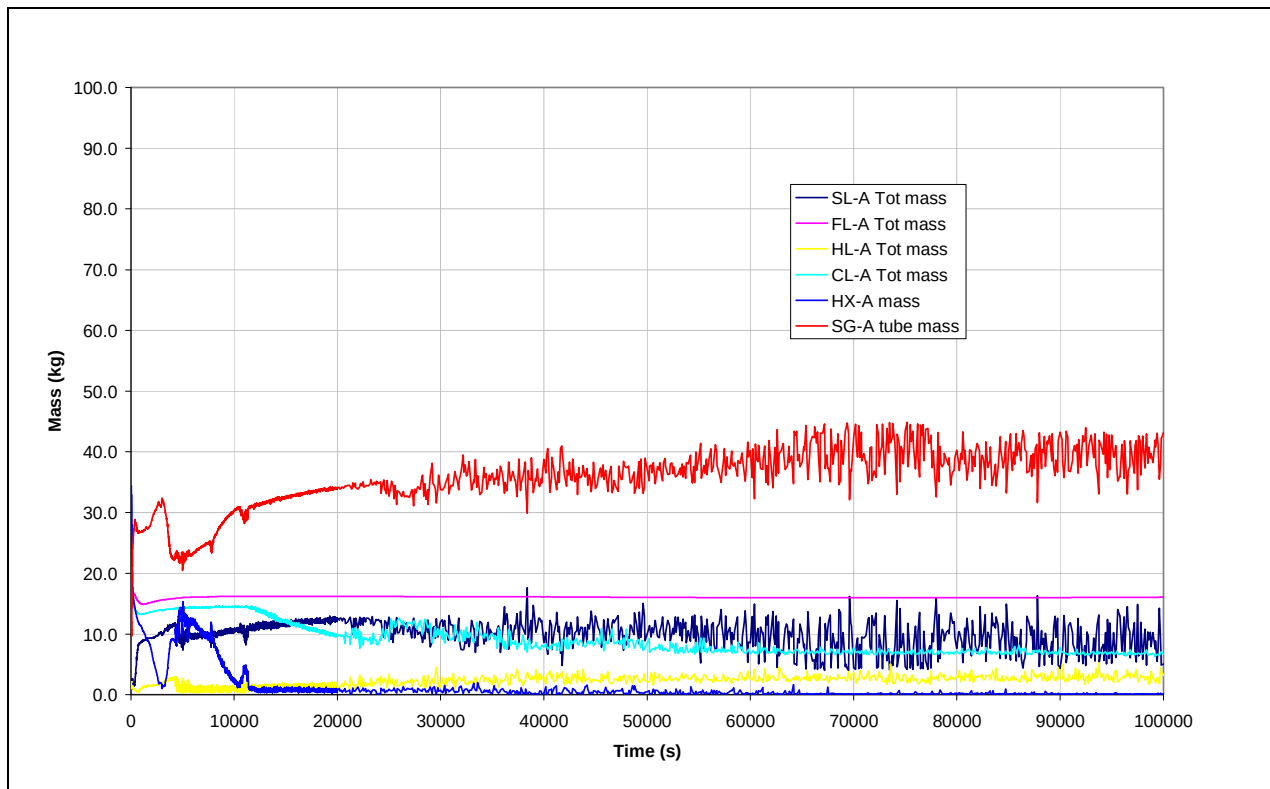


Fig.7. 5 - SPES3-130: SG-EHRS loop B partial masses

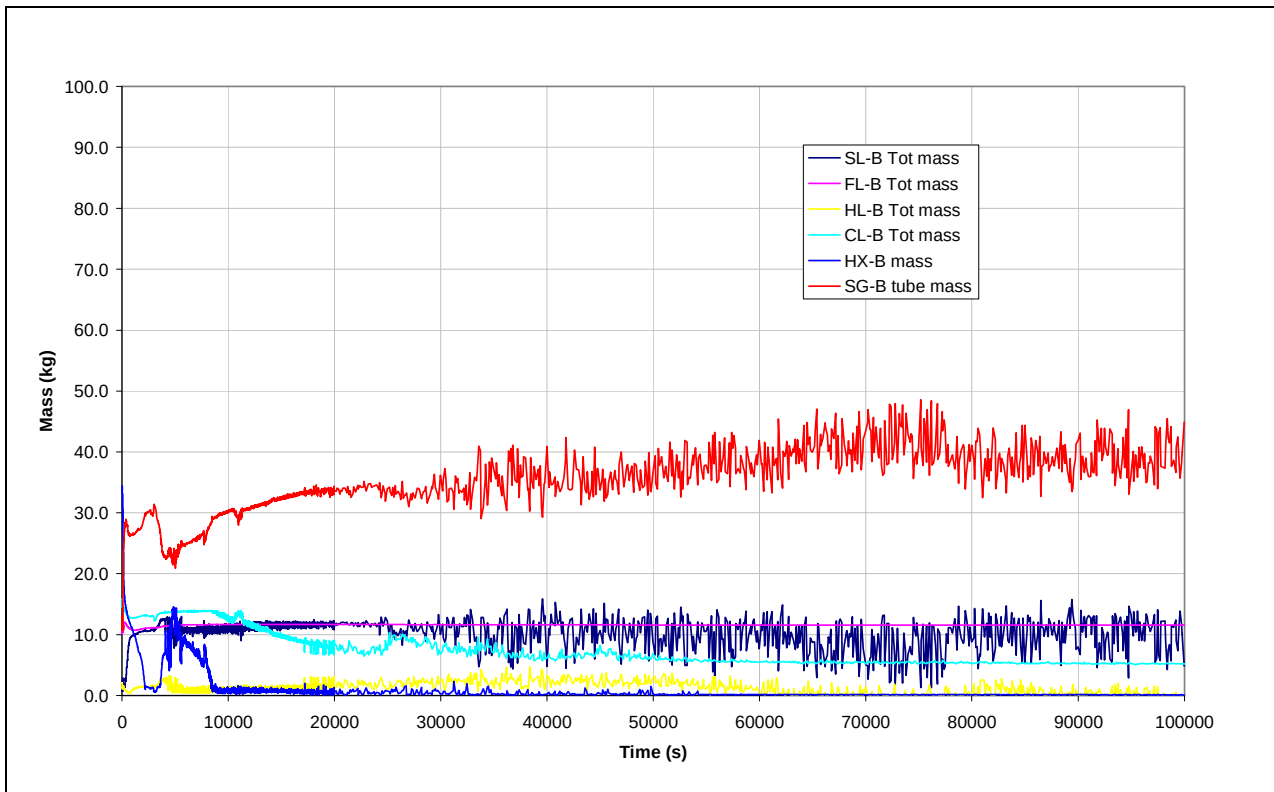
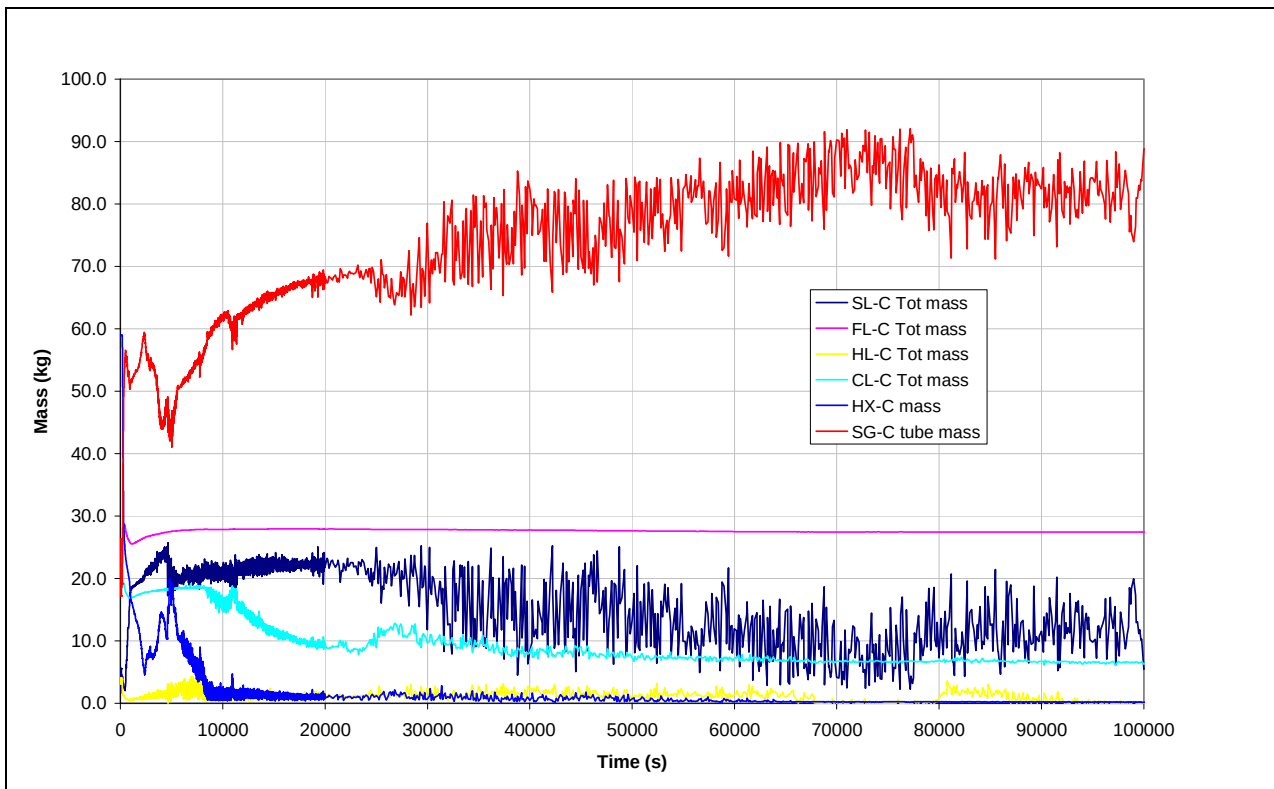
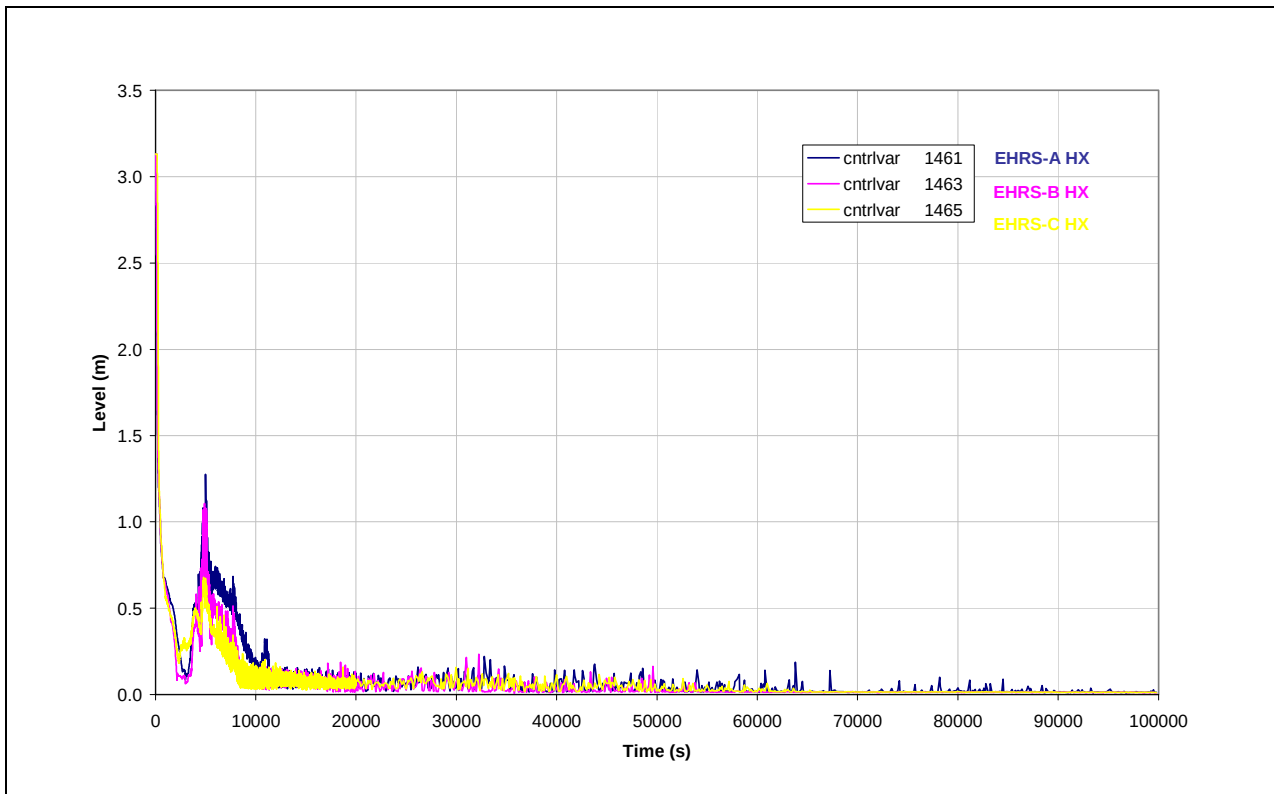


Fig.7. 6 - SPES3-130: SG-EHRS loop C partial masses



**Fig.7. 7 - SPES3-130: EHRS heat exchanger collapsed level**



**Fig.7. 8 – RWST-EHRS stand alone model (nodalization)**

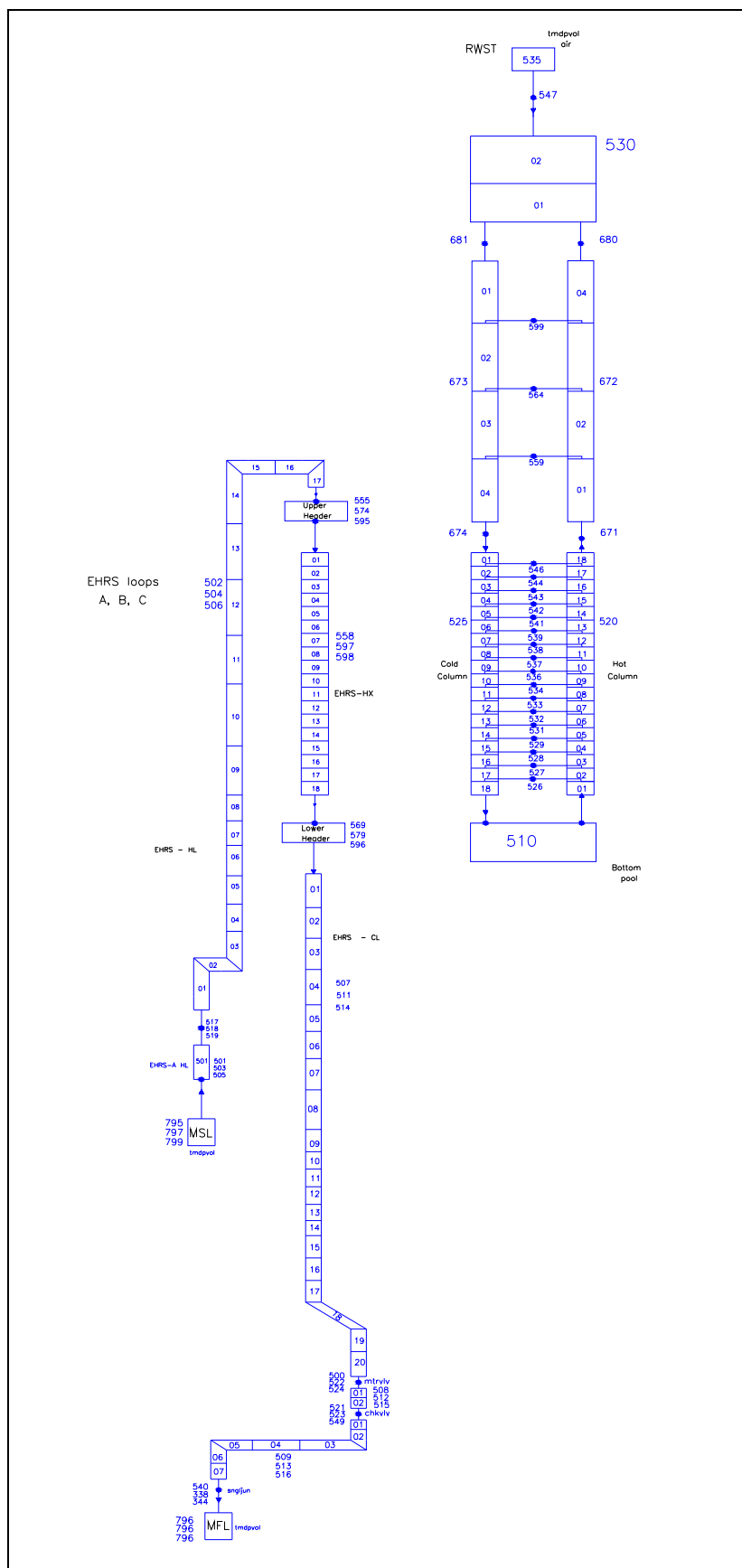


Fig.7. 9 – Inconel-600 and AISI 304 thermal conductivity

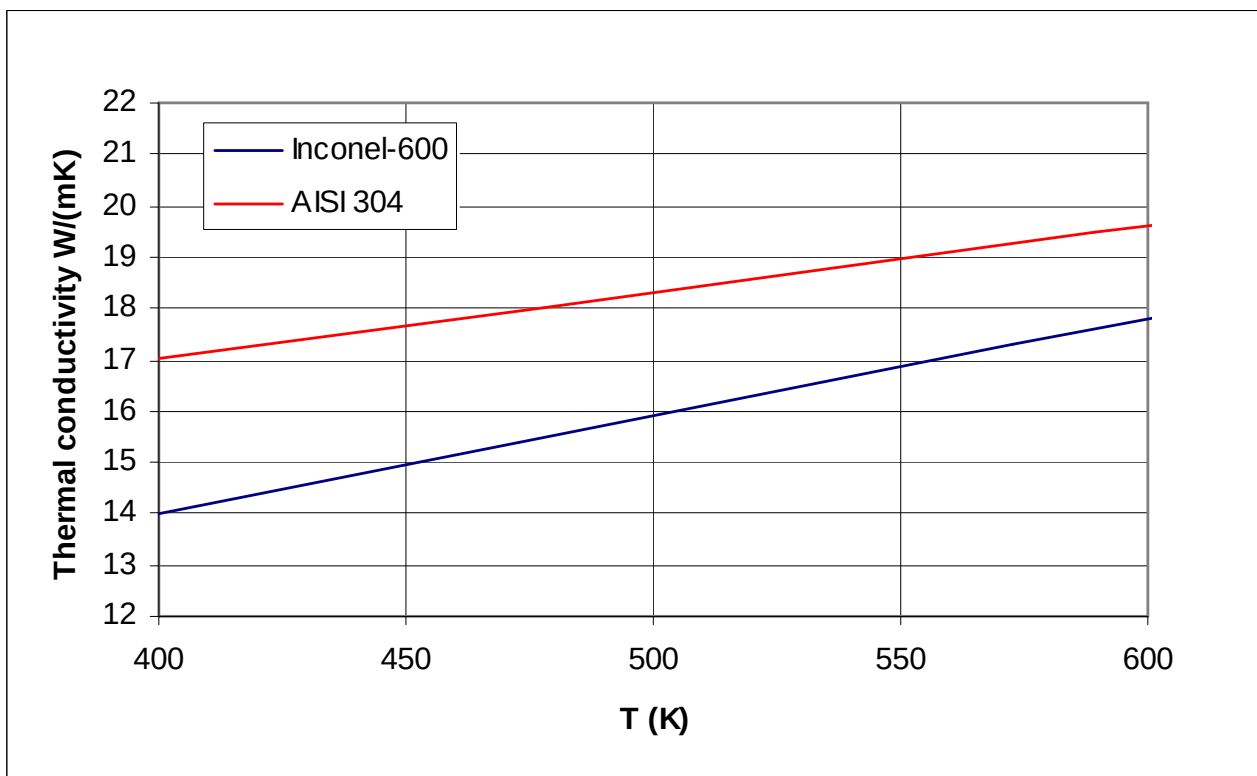
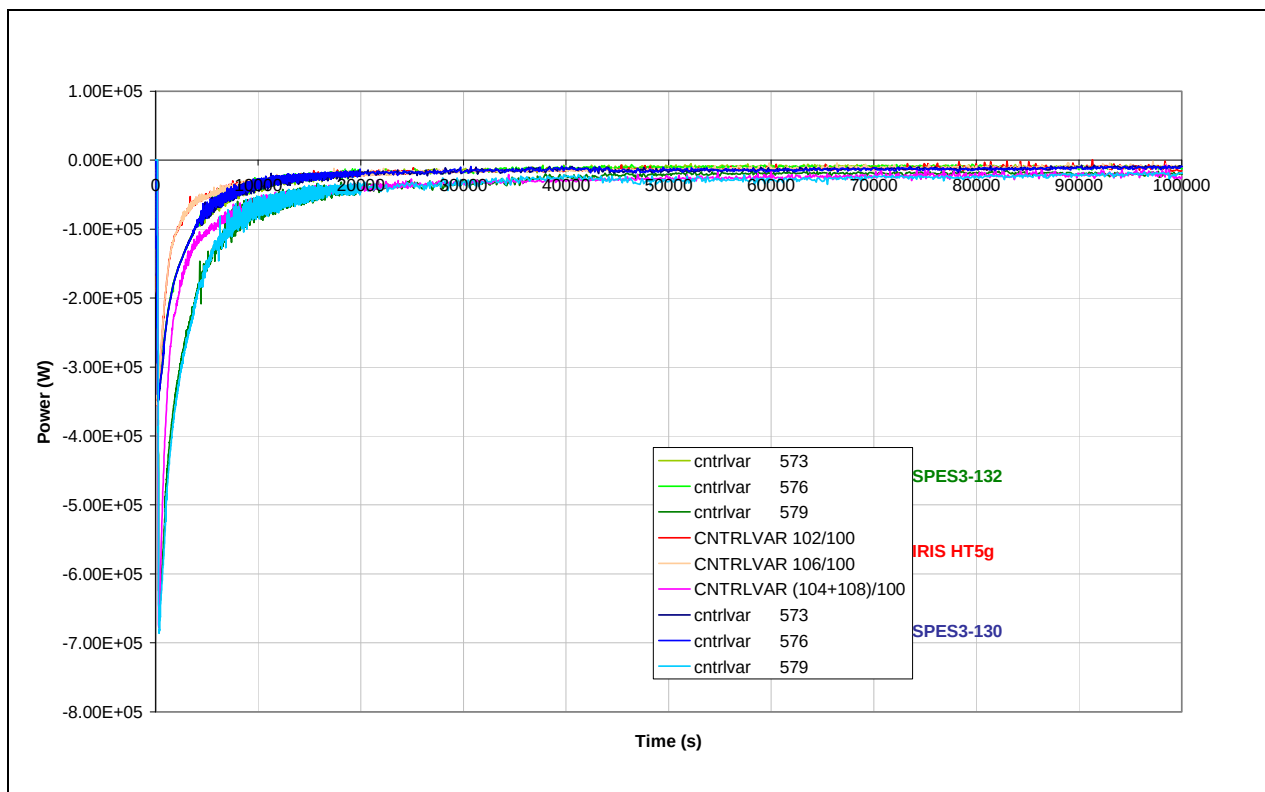
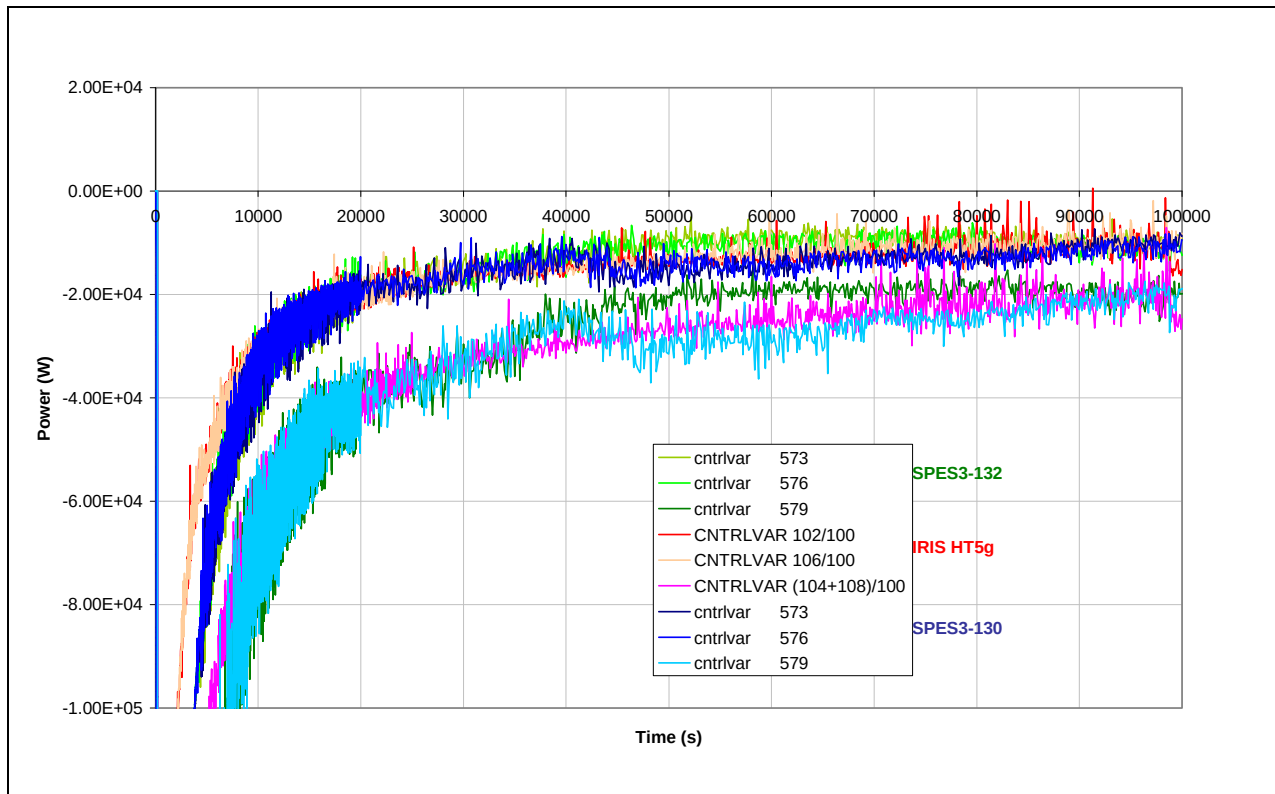


Fig.7. 10 – SPES3-132, 130 and IRIS HT5g EHRS power



**Fig.7. 11 – SPES3-132, 130 and IRIS HT5g EHRS power (window)**



**Fig.7. 12 – SPES3-132, 130 and IRIS HT5g DW pressure**

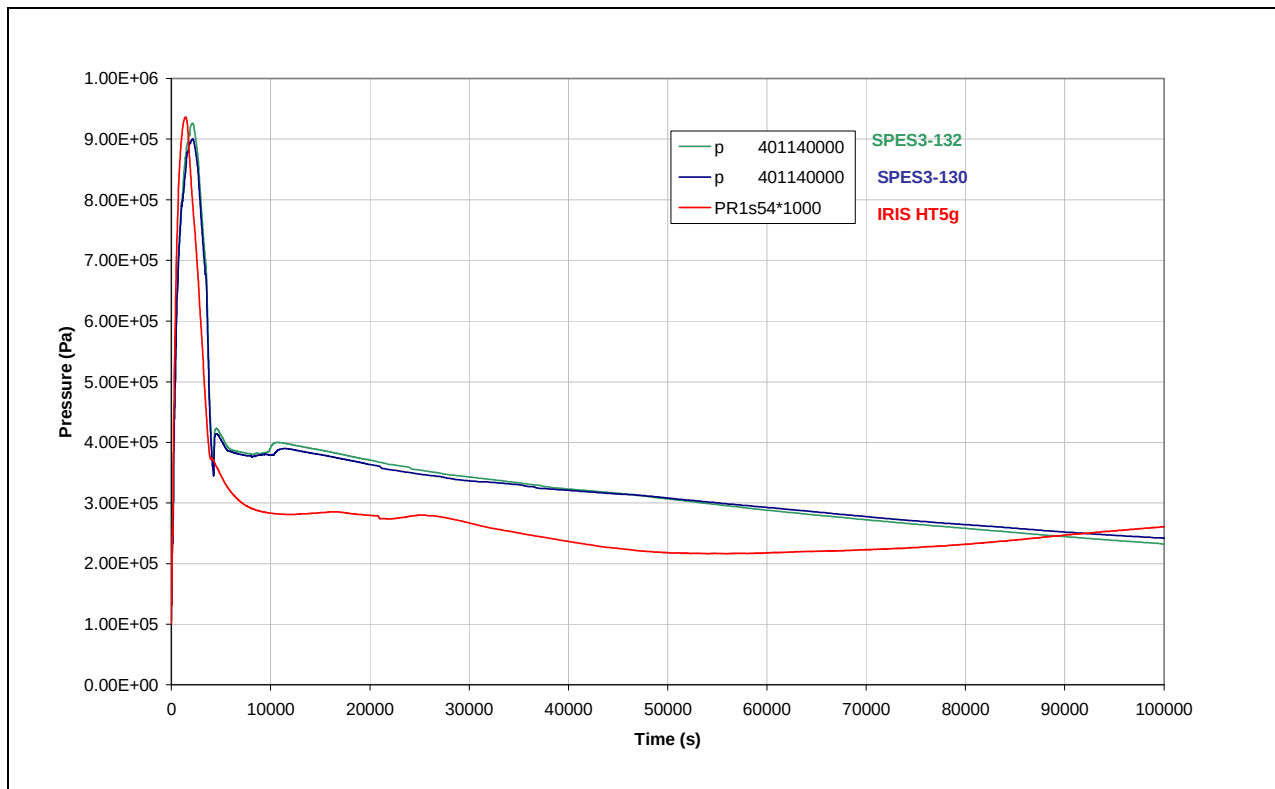


Fig.7. 13 – SPES3-132, 130 and IRIS HT5g: RWST temperature

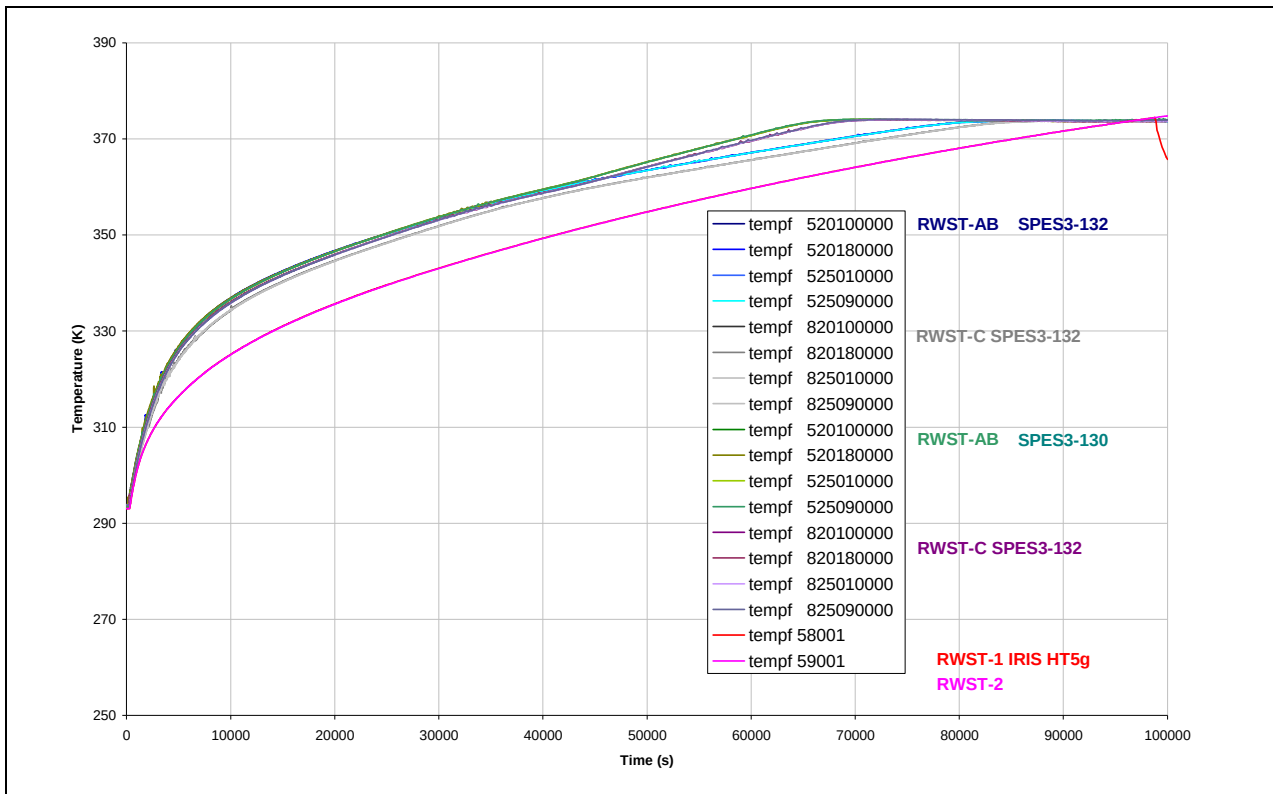
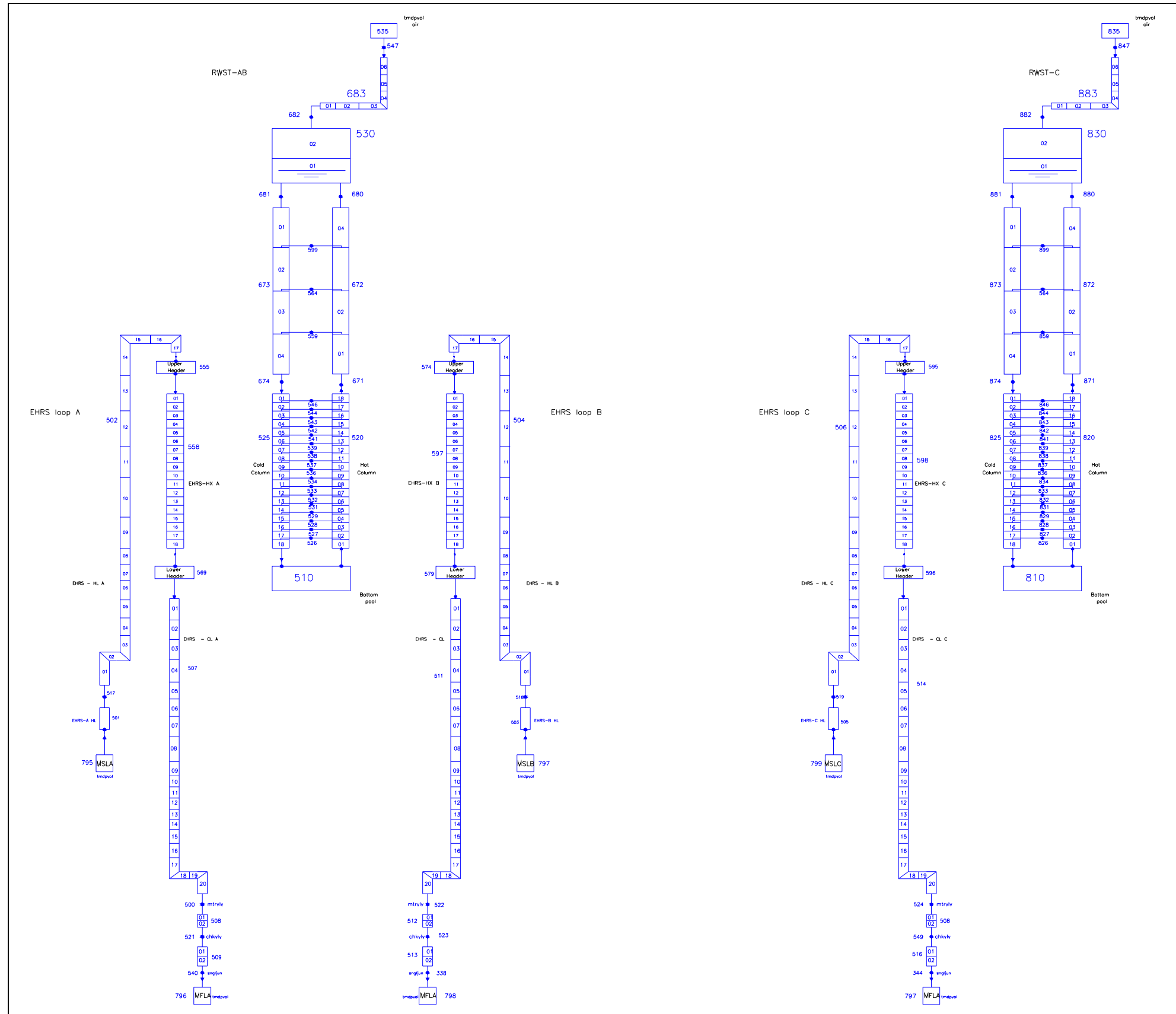
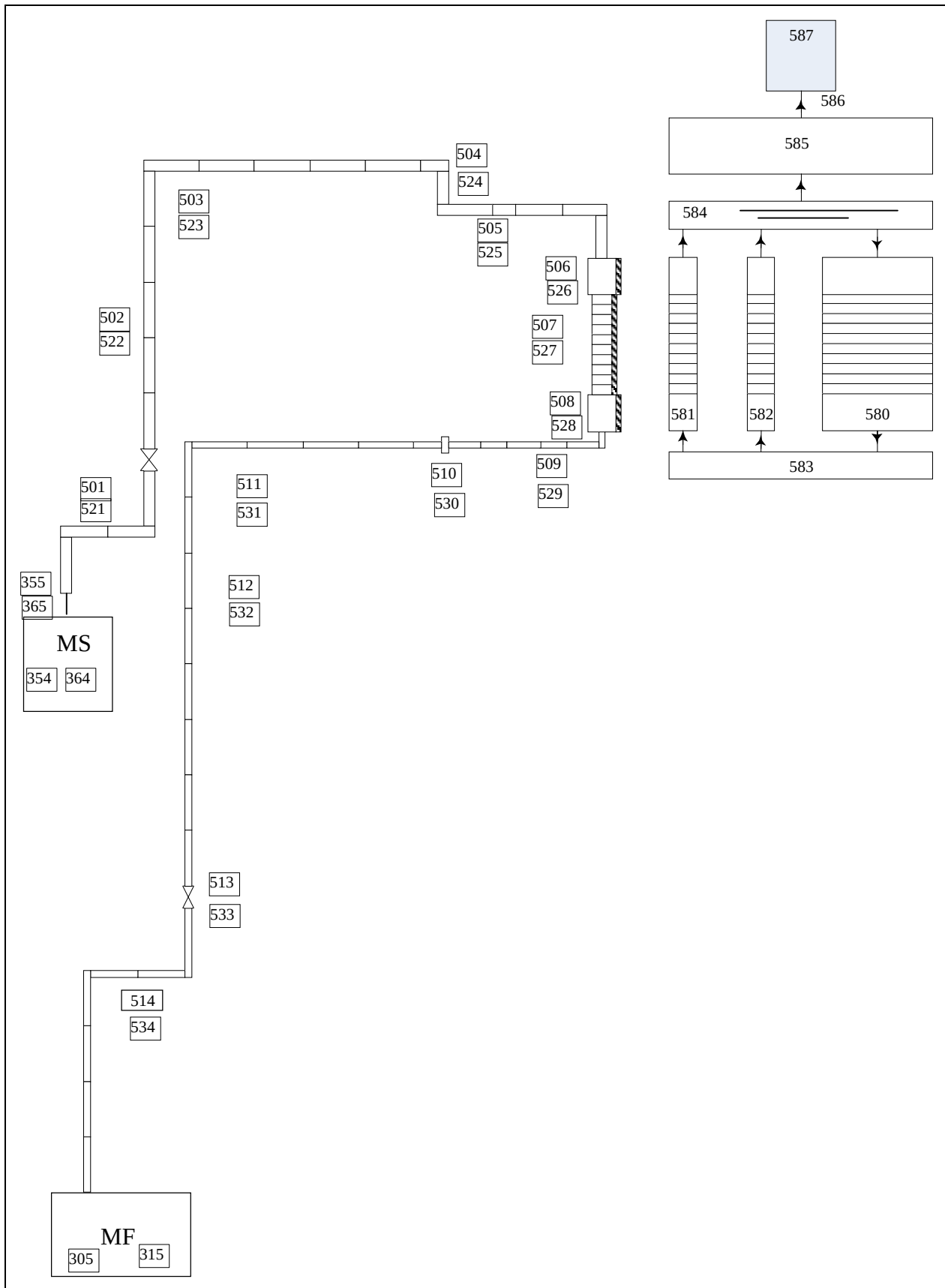


Fig.7. 14 – SPES3-AB and SPES3-C RWST-EHRS stand alone models (nodalization)

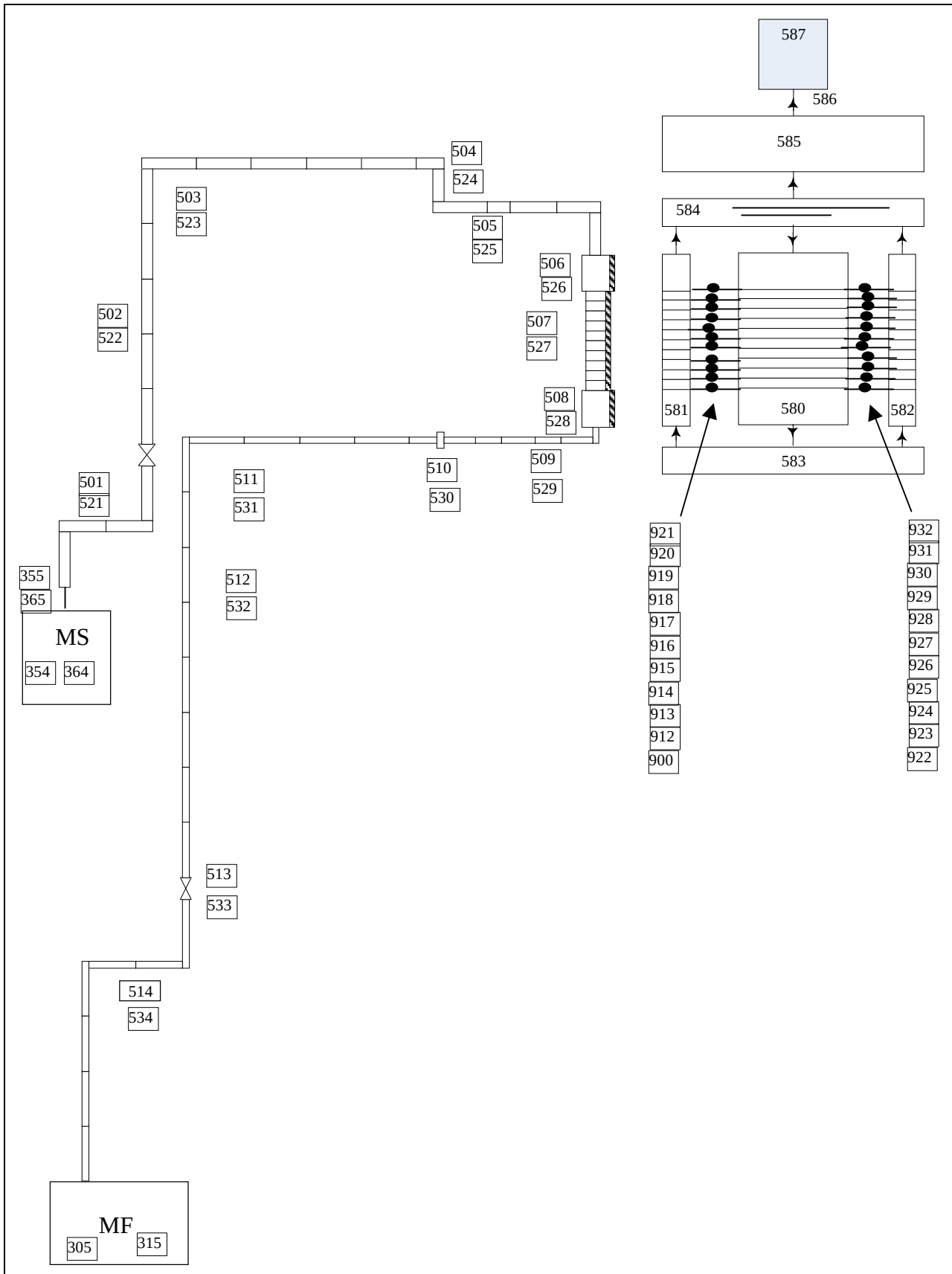




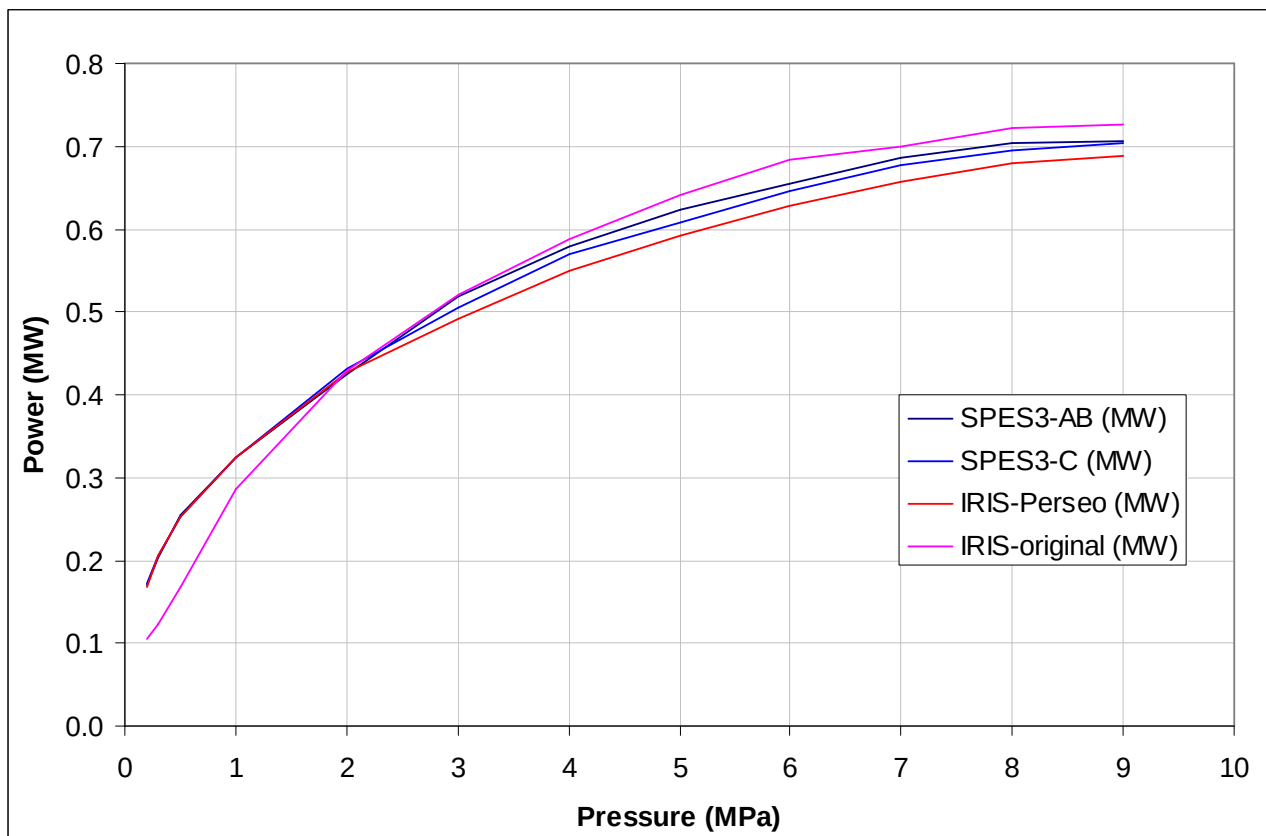
**Fig.7. 15 – IRIS Original RWST-EHRS stand alone model (nodalization)**



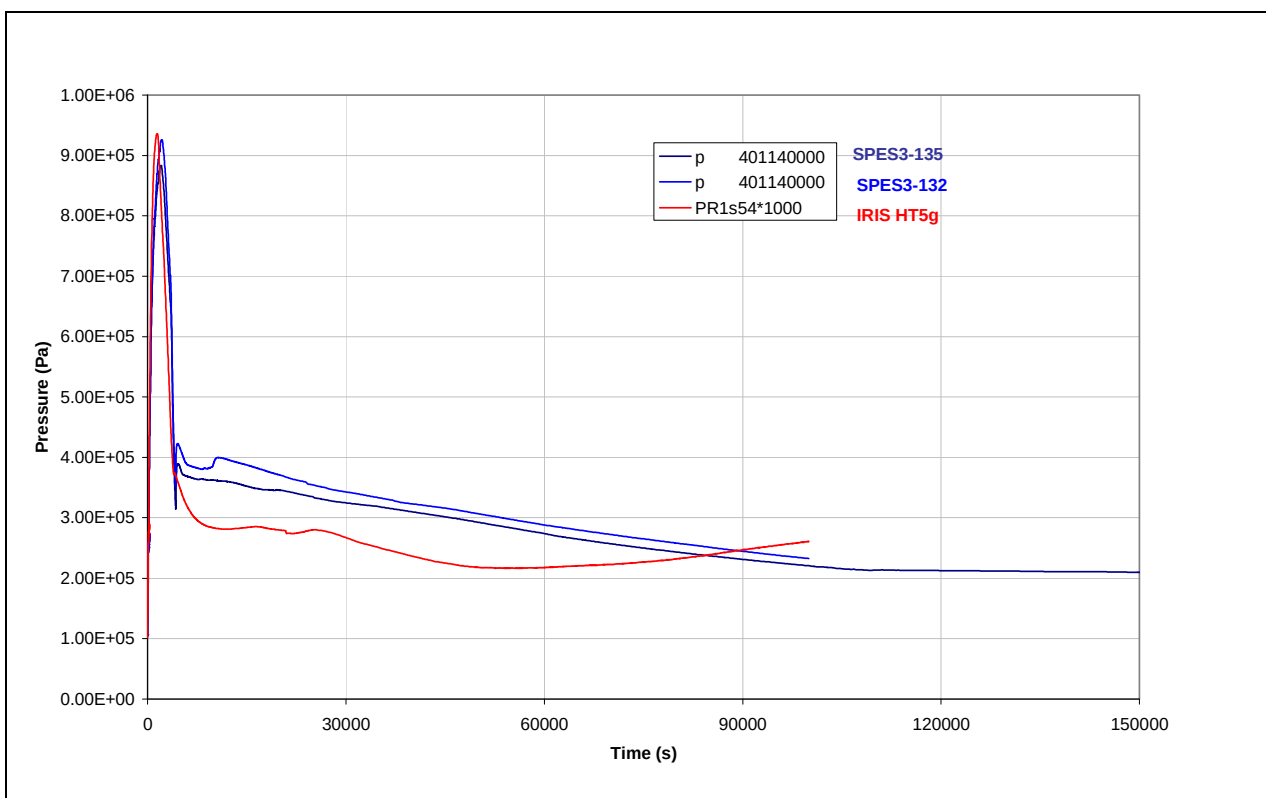
**Fig.7. 16 – IRIS Perseo RWST-EHRS stand alone model (nodalization)**



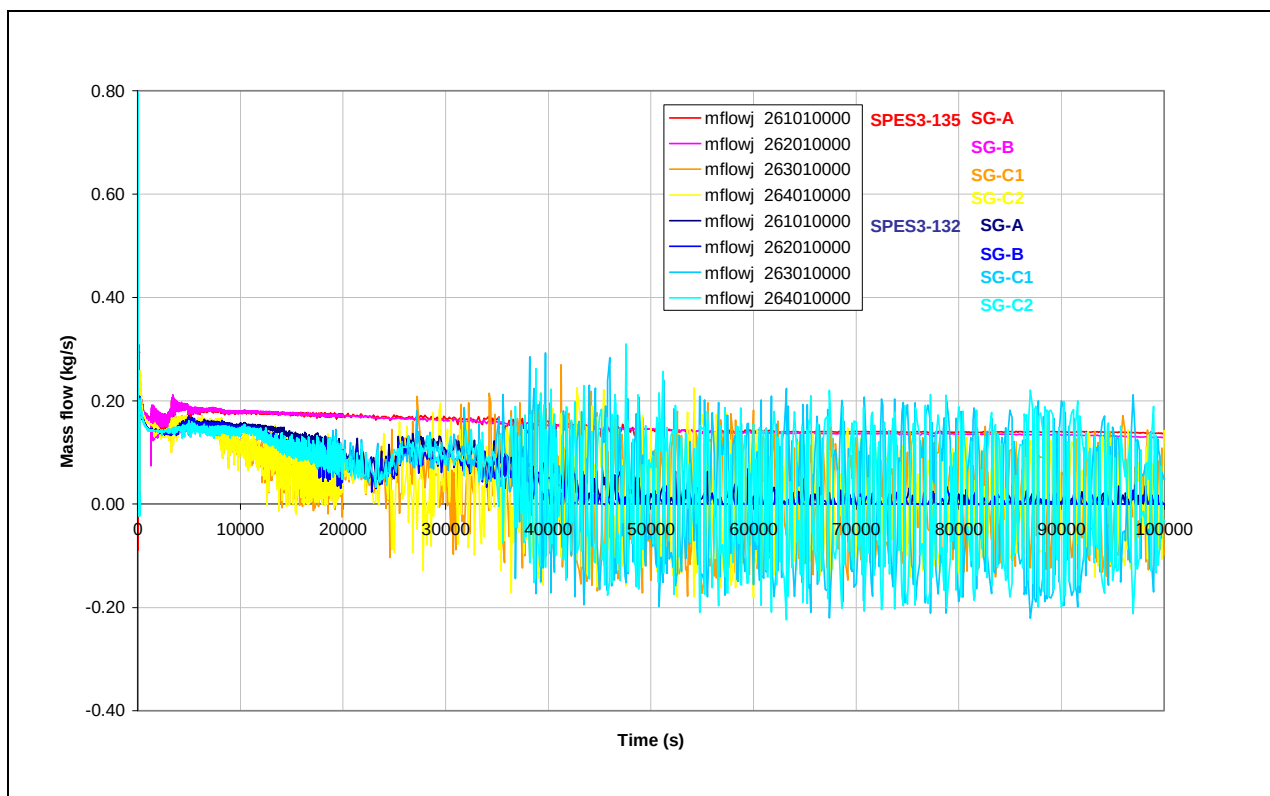
**Fig.7. 17 – SPES3 and IRIS EHRS-RWST parametric cases: power versus pressure**



**Fig.7. 18 – SPES3-135, SPES3-132 and IRIS HT5g DW pressure**



**Fig.7. 19 – SPES3-135 and SPES3-132 SG secondary side mass flow**



## 8. DVI DEG BREAK: DESIGN REVIEW SPES3-146 CASE AND IRIS HT6\_RWSTC

SPES3-146 and IRIS-HT6\_rwstc represent the base cases for SPES3 and IRIS, which can be utilized for the Fractional Scaling Analysis (FSA) application.

The SPES3-146 model includes all the design and model updates described in the previous chapters, in particular the review of the whole EHRS circuits with Hot and Cold Leg resizing, RWST slice area adjustment, Heat Exchanger heat transfer surface reduction and Fouling Factor updates as described in Paragraph 7.4. It includes the input-deck mistake correction as evidenced in Paragraph 7.6, the SG inlet orifice resizing to reduce SG parallel tube row oscillations, the correction of the input-deck mistake on PSS sparger hole area and the resizing of the PSS-DW vent pipe extension orifice to compensate for pressure drop variations in the pipe due to sparger area correction.

The IRIS HT6\_rwstc model includes the following modifications: the removal of the Fouling simulation in the SG tubes that in IRIS HT5g reduced the tube inner diameter and added a further thermal resistance; the ADS Stage-II actuation signal adjustment to correctly actuate when LGMS mass reaches 20%; the RWST slice model resizing according to PERSEO area ratio and the EHRS heat transfer parameter set-up according to PERSEO calibration, as described in Paragraph 7.4, the RWST top remodelling to avoid water-air solution and loss of mass before pool water boiling; the correction of some energy transfer parameters at the GOTHIC and RELAP5 code coupling [13].

The main SPES3-146 characteristics are reported below:

### *SPES3-146: DVI break base case*

- As in case SPES3-135:

DW volume 32.27 m<sup>3</sup> (Di = 1.62 m);

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume 4.5 m<sup>3</sup> (Di top = 0.961 m; Di bot = 0.553 m);

RC thickness top 10 mm, bot 8 mm;

QT volume 0.336 m<sup>3</sup> (Di = 0.37 m);

QT thickness 6 mm;

PSS volume 4.59 m<sup>3</sup> (Di top = 1.182 m; Di bot = 0.679 m);

PSS thickness top 12 mm, bot 8 mm;

LGMS volume 1.5 m<sup>3</sup> (Di top and bot = 0.554 m; Di mid = 0.831 m);

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle 10 mm;

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHRS-A and B CL calibrated orifice diameter 5.9 mm (resized for pressure drop adjustment, original size 5 mm);

EHRS-C CL calibrated orifice diameter 8.3 mm (resized for pressure drop adjustment, original size 7 mm);

RC to DVI line calibrated orifice diameter 1 mm;

Main PSS vent pipe diameter 2 ½" Sch. 40 (Di = 62.7 mm) (from 2" Sch. 40);

Extension PSS vent pipe diameter 1" Sch. 40 (Di = 26.6 mm) (from ½" Sch. 40);

LGMS to DVI line calibrated orifice diameter 3.6 mm;

Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);

PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom);  
 PSS bottom modeled with two branches, Fig.3. 9;  
 RWST top pipe connection to atmosphere control volume, Fig.3. 10;  
 LGMS initial level set to have 1 m<sup>3</sup> water;  
 EHRS-A and B: 0.6 tubes out of 3 thermally insulated with Teflon to simulate 240 IRIS EHRS tubes; 4% total extra surface covered to compensate for AISI-304 instead of Inconel-600;  
 EHRS-C: 0.2 tubes out of 5 thermally insulated with Teflon to simulate 480 IRIS EHRS tubes; 4% total extra surface covered to compensate for AISI-304 instead of Inconel-600;  
 EHRS Hot Leg-A and B resized to 1 ¼" Sch. 80 (original size 2" Sch. 80); EHRS loops in Fig.3. 11.  
 EHRS Cold Leg-A and B resized to ½" Sch. 80 (original size 1 ¼" Sch. 80);  
 EHRS Hot Leg-C resized to 2" Sch. 80 (original size 2 ½" Sch. 80);  
 EHRS Cold Leg-C resized to ¾" Sch. 80 (original size 1 ½" Sch. 80);  
 EHRS HL-A and B added an orifice (D = 17 mm ) for pressure drop adjustment;  
 EHRS HL-C added an orifice (D = 24 mm ) for pressure drop adjustment;  
 EHRS tube Fouling Factor: Left 2.9 (original value 2.725); Right 2.77 (original value 3.54284);  
 RWST-AB slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.490494 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);  
 RWST-C slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.492521 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);  
 RWST-AB and C side junction area 0.134618 m<sup>2</sup> (original value 0.105772 m<sup>2</sup>).  
 DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C;

- New for this case

Corrected input mistakes on area of volumes 509 and 513, set to 1.4957E-4 m<sup>2</sup> (it was 1.4957 m2);  
 Corrected input mistake at PSS sparger area (sngljun 474 and 484), set to 2.0268E-3 m<sup>2</sup> (it was 5.067E-4 m<sup>2</sup>);  
 Resized orifice at PSS vent pipe extension (D = 17.5 mm) to compensate for pressure drops variation for PSS sparger area correction (original size 19 mm);  
 Resized orifice at SG inlet (D = 11.7 mm) for SG parallel tube row oscillation reduction (original size 12.5 mm)

## 8.1 SPES3-146 and IRIS HT6\_rwstc

The full power steady conditions, starting point for the transient, are summarized in Tab.8. 1 for SPES3 and IRIS.

The list of the main events occurring during the transient with timing and quantities is reported in Tab.8. 2.

### 8.1.1 Transient phases and description

The first 10 s of SPES3 data (-10 s to 0 s) are steady state conditions. The IRIS data start from the break occurrence.

All times of the events are given with respect to the break time assumed as time 0 s.

### Break

The break mass flow peaks and trends, RV side (identified as SPLIT), are very similar in SPES3 and IRIS until the ADS intervention (177 s in SPES3 and 174 s in IRIS), Fig.8. 1. Later, during the phase of critical flow, until the containment and primary pressure equalization (2350 s in SPES3 and 1730 s in IRIS), the SPES3 mass flow is greater than IRIS one, driven by the higher SPES3 primary side pressure (higher pressure probably due to the larger thermal inertia of RV metal structures), Fig.8. 1, Fig.8. 2, Fig.8. 3. When the break flow is no more critical, some differences are observed, mostly related to the containment-RV differential pressure that drives water in a sense or the opposite, Fig.8. 4, Fig.8. 5, Fig.8. 9, Fig.8. 10.

The break mass flow containment side (identified as DEG) is related to the safety injection of EBT (177 s in SPES3 and 174 s in IRIS) and later of LGMS (2236.6 s in SPES3 and 1585 s in IRIS), Fig.8. 2, Fig.8. 57, Fig.8. 68.

A reverse flow from containment to RV is observed through the SPLIT line, after the RC level has reached the DW elevation up to reach the DW, accordingly to phases when the containment pressure is higher than the RV pressure, Fig.8. 2, Fig.8. 3, Fig.8. 26, Fig.8. 27.

### Blowdown, RV depressurization, containment pressurization

The blowdown phase depressurises the RV with mass and energy transfer to the containment.

The SPES3 and IRIS PRZ pressures are shown in Fig.8. 6, Fig.8. 7, Fig.8. 8. The depressurization rate is very similar until the ADS intervention (177 s in SPES3 and 174 s in IRIS), then SPES3 pressure is higher than IRIS, probably due to the heat release from RV metal structures (oversized in SPES3), notwithstanding the larger mass discharged through the ADS in SPES3 after about 1000 s, Fig.8. 54. After the containment and RV pressures are coupled (2350 s in SPES3 and 1730 s in IRIS) the SPES3 PRZ pressure stays above, correspondingly to the SPES3 containment one, Fig.8. 9, Fig.8. 10. In the long term, SPES3 shows a larger depressurization rate than IRIS and, around 103000 s, SPES3 PRZ pressure is lower than IRIS one, Fig.8. 10.

While the PRZ depressurizes, the containment pressure increases as shown in Fig.8. 6, Fig.8. 7, Fig.8. 4, Fig.8. 5, Fig.8. 9. The SPES3 and IRIS DW pressurization trend is similar even if delayed in SPES3 due to the greater containment heat structures, Fig.8. 4, Fig.8. 5. The pressure increase around 175 s is due to the ADS Stage-I intervention that discharge mass and energy into the DW, Fig.8. 12. After that, pressure increases up to reach a peak of 0.910 MPa in SPES3 at 2230 s and 0.936 MPa in IRIS at 1405 s. When the RV and DW pressures equalize, the ADS Stage-I mass flow stops and the DW pressure decreases thanks to the LGMS injection into the RV (intact loop) and into the RC (broken loop), Fig.8. 9, Fig.8. 68.

A faster DW depressurization occurs when a reverse flow from the PSS to the RV starts through the vent lines, Fig.8. 14, at 3510 s (PSS-A) – 3580 s (PSS-B) s in SPES3 and 2310 s in IRIS.

### Steam dumping into PSS

The containment space (DW and RC) pressurization causes the transfer of a steam-gas mixture from the DW to the PSS through the vent lines (starting at 15 s in SPES3 and 22 s in IRIS) lasting until mass flow exits the ADS Stage-I, Fig.8. 14, Fig.8. 12. The mass transferred from PSS to the DW is shown in Fig.8. 15. Due to the different shape of the PSS in SPES3 and IRIS, starting with the same initial mass and ending the injection at the same final level (sparger elevation), the total mass injected from PSS to DW results about 124 kg greater in SPES3 than IRIS, Fig.8. 15, Fig.8. 16.

The non-condensable gas quality in the DW is shown in Fig.8. 17 and Fig.8. 18. The way steam sweeps away gas from the DW seems similar in SPES3 and IRIS, even if the air quality remains higher in IRIS containment than SPES3 one. Moreover, the DW air quality increases more in IRIS than SPES3 in the last

phase of PSS to DW injection as if a larger quantity of air were transferred back from the PSS, Fig.8. 18, Fig.8. 14.

Steam is dumped underwater through the PSS sparger and gas (air in SPES3 and N<sub>2</sub> in IRIS) pressurizes the PSS and LGMS gas space, Fig.8. 19, Fig.8. 20, Fig.8. 21, Fig.8. 22. The PSS and LGMS pressure follows the DW pressure trend and, after the containment depressurization for LGMS and PSS injection, it is lower in IRIS than SPES3 until about 103000 s when the situation reverts due to the larger SPES3 depressurization rate, Fig.8. 23, Fig.8. 24. Anyway, an important difference between SPES3 and IRIS occurs when the PSS injection into the DW stops. In SPES3, all containment volumes reach the same pressure while in IRIS, the LGMS and PSS remain more pressurized than the DW, Fig.8. 23, Fig.8. 24. In IRIS, the PSS and DW volumes remain separated, from the pressure point of view, as the PSS to DW vent pipes remain partially full of water after the PSS injection to the DW is over, preventing non-condensable gas flowing from PSS to DW and pressure equalization, Fig.8. 25, Fig.8. 14. In SPES3, the PSS to DW vent pipes empty after the injection is over and pressure equalizes. Fig.8. 16 shows the PSS levels. The initial value is different in SPES3 and IRIS due to the different tank shape with the same liquid mass contained. The final value of level, with respect to the PSS bottom, is the same and it corresponds to the PSS sparger elevation.

The PSS water temperature increases, thanks to the mass transfer from the DW, Fig.8. 28, Fig.8. 29, Fig.8. 14. Temperature increases more in SPES3 than IRIS notwithstanding the lower mass transferred from the DW to the PSS in SPES3, during the first phase of injection, Fig.8. 30. This can be explained considering the higher SPES3 PRZ pressure and the consequently higher energy fluid exiting the RV and entering the DW and PSS, Fig.8. 6.

Both the liquid and gas temperatures are reported in Fig.8. 28, Fig.8. 29. In IRIS, the top gas temperature is generally higher than the liquid one (Gothic code results not clearly explainable here), while in the PSS lower part, the gas temperature is closer to liquid one than in SPES3. This can be explained by the initial heat structure preheating in the gas zone of SPES3 PSS that limits the gas temperature decrease.

Temperatures always remain below saturation at the maximum PSS pressure and also when pressure decreases (maximum temperature reached in SPES3 is 116 °C at 0.74 MPa and in IRIS 94 °C at 0.25 MPa). In the long term, the SPES3 PSS temperature decreases more than IRIS one, being related to the containment pressure and probably due to the higher heat losses to the environment.

#### *S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation*

The high containment pressure set-point (1.7e5 Pa) is reached at 31.6 s in SPES3 and 30 s in IRIS and it triggers the S-signal.

The S-signal (Safeguard) starts the reactor SCRAM, isolates the three secondary loops and actuates the EHRS-A and B.

Power released to the fluid in the core is shown in Fig.8. 31 and Fig.8. 32 and very similar trends are observed between SPES3 and IRIS.

Power transferred to the steam generators is shown in Fig.8. 33 and Fig.8. 34. The peak of removed power occurs following the EHRS-C intervention with similar values in SPES3 and IRIS (1.7 MW at 307 s in SPES3 and 1.69 MW at 320 s in IRIS), after that, removed power in SPES3 is higher than in IRIS until about 7500 s to become very similar for the rest of the transient.

The MFIV and MSIV of the secondary loops are contemporarily closed in 5 s both in SPES3 and IRIS. The secondary loop mass flows are shown in Fig.8. 35 and Fig.8. 36. They stop at the secondary loop isolation and re-start at the EHRS actuation. The EHRS-A and B in SPES3 are actuated at the secondary side isolation and a natural circulation flow establishes. The corresponding EHRS-1 and 3 in IRIS are actuated with 10 s delay with respect to the secondary loop isolation, and a short pause in secondary loop flow is observed, Fig.8. 35. The EHRS-C in SPES3 is actuated at LM-signal, starting the secondary loop natural



circulation after about 150 s from the loop isolation. EHRS-2 and 4 in IRIS are actuated on LM-signal, Fig.8. 35. For a direct comparison of the eight SG mass flow in IRIS and three SGs in SPES3 (loop C consists of two tube rows), the SG mass flow curves have been summed in IRIS. It appears that, at the EHRS actuation, the SPES3 and IRIS mass flow peaks are similar.

The SPES3 EHRS-A and B and the EHRS-1 and 3 in IRIS are actuated by opening in 2 s the related isolation valves. The peak flowrate of 0.261 kg/s is reached at 39 s in SPES3 while a peak of 0.287 kg/s is reached in IRIS at 45 s. Between 1000 s and 10000 s, a quite steady condition is reached with the SPES3 natural circulation about 20% higher and less oscillating than IRIS, Fig.8. 37. After 10000 s, larger oscillations appear in SPES3 and mass flows decrease getting closer to IRIS ones. After about 70000 s, mass flows are very similar in the two plants, Fig.8. 38.

Power removed by the EHRs is shown in Fig.8. 39 and Fig.8. 40. The SPES3 EHRS-A and B peaks of removed power occur at 218 s with a value of 371 kW each, while the IRIS EHRS-1 and 3 power peaks of 335 kW occur at 158 s. The average power removed by the SPES3 EHRS-A and B in the long term is around 10.5 kW each, while the IRIS EHRS-1 and 3 is about 9 kW each.

The secondary side pressures are shown in Fig.8. 41 and Fig.8. 42. After isolation, pressure increases due to the heat transfer from the primary side that makes water contained in the SG tubes evaporate. The SG tube levels decrease until water stored in EHRS heat exchangers is poured into the loops and power begins to be removed, Fig.8. 43, Fig.8. 44, Fig.8. 33. Similar trends are observed for SPES3 and IRIS, even if SPES3 level is about 1 m below, until 20000 s. After that, the SPES3 SG level slowly increases getting closer to IRIS. When SPES3 SG tube level is below the IRIS one, a larger surface is available for the heat transfer with the primary side and consequently a larger exchanged power results, Fig.8. 43, Fig.8. 34.

The SG pressure peaks are reached around 69 s in SPES3 and 57 s in IRIS, then pressure decreases after some oscillations lasting until about 200 s, Fig.8. 41. IRIS pressure decreases more than SPES3 one as power transferred through the SGs is lower, but they become very similar around 5000 s, when also SG power become similar, Fig.8. 34, Fig.8. 42.

#### *Pump coastdown and primary circulation through RI-DC check valves*

The PRZ levels of SPES3 and IRIS are shown in Fig.8. 45. The early phase of level decrease, until the ADS Stage-I intervention (176.7 s in SPES3 and 174 s in IRIS), is due to the loss of mass from the break. In this phase, mass lost from the break, RV side (DVI split) is very similar in IRIS and SPES3, Fig.8. 46. The observed difference in PRZ level can be explained hypothesizing flow instabilities due to steam bubbles at the PRZ surge holes in IRIS, not occurring in SPES3. The level increase after the ADS Stage-I actuation is similar in the two cases until the ADS stop when the containment and RV pressure equalize (2350 s in SPES3 and 1730 in IRIS). The liquid fraction at the pump inlet is reported in Fig.8. 47. Due to the loss of mass from the break, the pump uncovers soon. Water sucked at the ADS Stage-I maintains a certain liquid fraction at the pump suction until about 400 s in IRIS, while the SPES3 pump is uncovered soon after the PRZ early emptying. This can be explained considering the different position of the pump in the two plants, inside the RV in IRIS and outer and connected by piping in SPES3, less interested by the water path to the ADS through the PRZ surge holes.

The pump coastdown is triggered by a Low PRZ level signal delayed of 15 s (112.14 s in SPES3 and 145 s in IRIS). Soon after the pump suction is uncovered, the RV natural circulation through the pump interrupts.

The core outlet flow is shown in Fig.8. 48 and Fig.8. 49 and it is similar for IRIS and SPES3, except between 2500 s and 3000 s, when they have an opposite trend, probably caused by the void fraction of fluid at the check valves. After 3000 s, the values are very similar, even if IRIS shows stronger oscillations.

The pump stop and pressure decreasing in the DC, let the RI-DC check valves open at 129÷132 s in SPES3 and 185 s in IRIS and allow the natural circulation from riser to SG annuli at a lower level in the RV. The RI-DC check valve mass flows are shown in Fig.8. 50 and Fig.8. 51 for each SG (for SG-A in SPES3 it is the

sum of mass flows through the check valves 161 and 164, for SG-B of mass flow through the check valves 162 and 165 and for SG-C of mass flow through the check valves 163 and 166; for IRIS, the mass flows are combined for a direct comparison with SPES3). The trend and value of the RI-DC check valve mass flow is strictly related to the core flow, Fig.8. 49.

The fast RV depressurization, rapidly causes flashing of the primary circuit and void begins at the core outlet at 199 s in SPES3 and 186 s in IRIS, Fig.8. 52, Fig.8. 53. The low liquid fraction period in the core lasts until about 5000 s in IRIS and 6000 s in SPES3.

#### *LM-Signal: EHRS-C, ADS Stage-I and EBT actuation*

The LM-Signal (LOCA mitigation) occurs at 176.89 s in SPES3 and 174 s in IRIS when the low PRZ pressure set-point (11.72e6 Pa) is reached, Fig.8. 7.

The LM-signal actuates the EHRS-C in SPES3 and EHRS-2 and 4 in IRIS, opens the ADS stage-I, and opens the EBT actuation valves.

The SPES3 EHRS-C and the IRIS EHRS 2 and 4 are actuated by opening in 2 s the related isolation valves. on LM-signal. The peak flow rate of 0.540 kg/s is reached at 182 s in SPES3 while the IRIS peak of 0.580 kg/s is reached at 190 s. After the peak, a quite steady natural circulation flow of about 0.35 kg/s is reached in SPES3 between 700 s and 9000 s, while in IRIS the mass flow decreases until about 2000 s showing later strong oscillations around 0.2 kg/s until about 10000 s, Fig.8. 37, Fig.8. 38. The SPES3 and IRIS mass flows are similar in the long term, Fig.8. 38.

Power removed by SPES3 EHRS-C and IRIS EHRS 2 and 4 is shown in Fig.8. 39, Fig.8. 40. The SPES3 EHRS-C peak of removed power occurs at 315 s with a value of 723 kW, while the IRIS EHRS 2 and 4 power peak occurs at 325 s with a value of 636 kW. The average power removed by the SPES3 EHRS-C in the long term is 21.1 kW, while that removed by IRIS EHRS 2 and 4 is 18 kW.

The Stage-I of the ADS trains are actuated contemporarily on LM-signal (176.7 s in SPES3 and 174 s in IRIS) both in SPES3 and IRIS. The SPES3 mtrvlv 153 on the Single Train (ST) and 143 on the Double Train (DT) are fully open in 10 s and so do the IRIS three train ADS valves. The ADS Stage-I mass flows are shown in Fig.8. 12 and Fig.8. 13. For a direct comparison between SPES3 and IRIS, two of the IRS trains are condensed in one. SPES3 and IRIS show similar trends. Both IRIS and SPES3 show a two-peak trend flow, with the first SPES3 peak of 1.344 kg/s around 185 s and the second peak of 1.523 kg/s at 270 s and the first IRIS peak of 1.301 kg/s at 186 s and the second peak of 1.988 kg/s at 245 s.

When the ADS intervene, the PRZ is empty in SPES3 and almost empty in IRIS, Fig.8. 45, and the ADS flow peak is due to steam flowing toward the QT. At the ADS intervention, water is sucked upwards and the PRZ level increases. The second ADS mass flow peak is caused by an increasing liquid void fraction at the PRZ top that decreases when the PRZ empties.

The ADS integral flow is shown in Fig.8. 54 and mass exited from the RV through the ADS in IRIS is about 0.68 times that exited from SPES3. This justifies the difference in the RV mass trend observed in the early 1000 to 2500 s, Fig.8. 56. After the RV and containment pressure equalization and inversion (1730 s in IRIS and 2350 s in SPES3), Fig.8. 9, the differential pressure in SPES3 is sufficient to push back water into the RV through the ADS Stage-I pipe between 2590 s and 3800 s in SPES3 and 1970 s and 2550 s in IRIS, Fig.8. 12.

The LM-signal triggers the EBT actuation. Both in SPES3 and IRIS, the EBT actuation valves are fully open in 15 s. The EBT injection mass flows are shown in Fig.8. 57 and Fig.8. 58 and they are similar in SPES3 and IRIS until about 2000 s. The EBT injection into the broken DVI is initially about 14 times larger than injection into the intact DVI, due to the presence of the break. In SPES3, the EBT injection continues until both EBTs are empty, Fig.8. 60 while in IRIS the intact loop EBT interrupts its injection between 1950 s and 8540 s and between 17780 s and 22720 s to completely empty at 35490 s, Fig.8. 61. The trend of injection is

related to the RV mass that in IRIS increases more than in SPES3 thanks to the stronger LGMS injection until about 18000 s, Fig.8. 56, Fig.8. 68.

Soon after the EBT actuation, a liquid circulation from the RV toward the EBT starts at the EBT to RV connections, Fig.8. 59, then, after such connection is uncovered, steam replaces water contained in the EBT top lines and tanks. The SPES3 broken loop EBT is empty at 620 s while the corresponding IRIS EBT is empty at 625 s. The SPES3 intact loop EBT is empty at 3050 s while IRIS's one at 35490 s, Fig.8. 60, Fig.8. 61.

The EBT actuation, starting at 179 s in SPES3 and at 174 s in IRIS, is responsible for the mass flow through the break line, containment side, Fig.8. 1. The EBT injected mass enters the RV through the intact DVI, while a reverse flow occurs through the broken DVI towards the break, Fig.8. 62, Fig.8. 63. Such reverse flow lasts until the RV and containment pressures equalize, Fig.8. 9, Fig.8. 10. After that, the DVI mass flow in SPES3 and IRIS is driven by the differential pressure between RV and containment and by the amount of water in one or the other side of the plant.

### *RV saturation*

The RV mass decreases due to the loss of mass from the break, Fig.8. 56. The fast RV depressurization leads to reach the saturation conditions (core inlet T = core outlet T) at 316 s in SPES3 and 245 s in IRIS. Two-phase mixture occurs in the core, Fig.8. 52, but the natural circulation through the RI-DC check valves allows to remove the decay heat and a temperature difference establishes again between core inlet and outlet when the core is under liquid single-phase, after 5000 s in IRIS and 6000 s in SPES3. The inlet and outlet core temperatures are shown in Fig.8. 64 and Fig.8. 65. The SPES3 core temperatures establish at a higher value than IRIS when PRZ pressure is higher, then the situation reverts.

The core heater rod temperatures are shown in Fig.8. 66, Fig.8. 67. Notwithstanding the core liquid void fraction decrease, the rod surface temperatures never overcomes the maximum steady state temperature. Corresponding to the fluid temperature, also the heater rod temperatures stabilize at a higher value in SPES3 than IRIS when PRZ pressure is higher and vice-versa when pressure is lower.

### *Low DP RV-Containment signal, LGMS and RC to DVI valve actuation*

The containment pressure peak of 0.910 MPa occurs at 2230 s in SPES3 and of 0.936 MPa at 1405 s in IRIS, Fig.8. 4.

The "Low DP RV-Containment" signal set point of 50 kPa is reached at 2236.6 s in SPES3 and 1585 s in IRIS.

The combination of LM-signal AND Low DP RV-Containment signal actuates the LGMSs and opens the valves on the lines connecting the RC to the DVIs.

The SPES3 and IRIS LGMS isolation valves are fully open in 2 s as well as the RC to DVI line isolation valves.

LGMS injection is related both to gravity and to LGMS air space pressurization (through PSS to LGMS balance lines) by non-condensable gas entering the PSS from the DW. The broken loop LGMS injection into the DVI starts at 2236.6 s in SPES3 and 1585 in IRIS, while the intact loop LGMS injection into the DVI starts at 2250 s in SPES3 and 1670 in IRIS. The LGMS injection mass flow is shown in Fig.8. 68. Consequently to the LGMS injection into the broken DVI, a mass flow from the DEG break line restarts around 2250 s in SPES3 and 1585 s in IRIS, lasting until the LGMS is empty, Fig.8. 2, Fig.8. 3.

Fig.8. 68 shows that a difference exists between the IRIS and SPES3 LGMS injection trend. The SPES3 mass flow is stronger than IRIS in the first phase of injection (~0.14 kg/s in SPES3 and ~0.1 kg/s in IRIS) and then it decreases to about one fourth of its value until the LGMS are empty. In IRIS, the injection starts and then the mass flow decreases gradually until the LGMS are empty, Fig.8. 69. The reason is the different

pressurization of LGMS with respect to DVI due to the emptying of the PSS vent pipes in SPES3 and non-emptying of the same pipe in IRIS (see section *Steam dumping into PSS*), Fig.8. 70, Fig.8. 71.

*Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV*

The RV and containment pressure equalize at 2350 s in SPES3 and 1730 s in IRIS, Fig.8. 9. After this, the loss of mass through the break, RV side, depends on the periods when the RV pressure is higher than the containment pressure, Fig.8. 2, Fig.8. 3, Fig.8. 9, Fig.8. 10.

After the peak, the containment pressure decreases for steam condensation on the containment wall and for LGMS injection. After the RV and containment pressure are coupled, pressures decreases due to the EHRS heat removal from the primary side, Fig.8. 39. At 2660 s in SPES3 and 1650 s in IRIS, the DW pressure decreases below the PSS pressure, Fig.8. 23. When the differential pressure between PSS and DW is sufficient to overcome the hydrostatic head of the PSS vent pipes, a reverse flow starts from the PSS to the DW through the vent lines, lasting between 2310 s and 4050 s in IRIS and 3510 s to 4490 s in SPES3, Fig.8. 14.

The RC level, initially increased for break and ADS mass flow collection, rapidly increases in correspondence of the PSS injection up to the complete fill-up at 4470 s in SPES3 and 14891 s in IRIS (11 m level from bottom in SPES3 and 11.75 m in IRIS), Fig.8. 26.

When the RC level is above the DVI connection (4150 s in SPES3 and 5000 s in IRIS) and the containment pressure overcomes the RV pressure, water enters the RV through the RC to DVI connections, Fig.8. 72, Fig.8. 73. The mass injected from RC to DVI is shown in Fig.8. 74. In SPES3 the injection occurs soon after the RC to DVI valves are open, instead in IRIS it begins only around 70000 s, Fig.8. 72, when the containment pressure is higher than the RV pressure, Fig.8. 11. The total mass injected at the end of the transient is higher in IRIS than SPES3.

The QT, initially empty, is partially filled-up by the ADS discharge in SPES3, while in IRIS it is completely filled-up, Fig.8. 75. The later SPES3 fill-up around 10000 s is related to the rapid increase of the DW level after the RC fill-up, Fig.8. 26, Fig.8. 27.

#### *Low LGMS mass signal: ADS Stage-II actuation*

The intact loop LGMS low mass signal is reached at 17703.09 s in SPES3 (LGMS-A) when mass reaches 198 kg (20% of 1 m<sup>3</sup> water at 48.9 °C) and at 13171 s in IRIS (LGMS-2) when residual mass is 185 kg. The broken loop signal is reached at 24653.89 s in SPES3 (LGMS-B) and 14120 s in IRIS (LGMS-1), Fig.8. 69.

The reaching of both LGMS low mass signals actuates the ADS Stage-II valves, fully open in 10 s both in SPES3 and IRIS, to allow steam circulation between RV and DW in the upper part of the plant and enhance condensation on the SG tubes in the long term, Fig.8. 76, Fig.8. 77. According to the pressure difference between DW and RV, Fig.8. 11, a little and oscillating mass flow is observed in IRIS after about 60000 s, instead SPES3 shows oscillations around zero, as DW and RV pressure are very similar.

The SPES3 RWST-A/B begins to heat-up at 60 s (after the EHRS-A and B actuation at 31.63 s) while IRIS RWST-1 begins to heat up only at 256 s contemporarily to RWST-2 (after EHRS-2 and 4 actuation at 174 s). The SPES3 RWST-C begins to heat-up at 208 s (after the EHRS-C actuation at 176.89 s). In SPES3, water reaches saturation around 80000 s and in IRIS around 95000 s. Anyway, in IRIS saturation temperature establishes around 107 °C, corresponding to a higher RWST pressure, Fig.8. 78.

The RWST mass is shown in Fig.8. 79 and pressure in Fig.8. 80. Both in SPES3 and IRIS, the trend of mass is similar and both decrease sensibly when water reaches saturation. Actually, in SPES3 a loss of mass is evidenced even before saturation, Fig.8. 81, Fig.8. 82, for modeling reasons, but it is acceptably low as explained in Paragraph 7.1.

Power transferred from the EHRS to RWST is shown in Fig.8. 83 and Fig.8. 84. SPES3 RWST power is higher than IRIS one in the early 10000 s, but they are similar in the last part of the transient. In the long term, between 145000 s and 150000 s, total power transferred to the RWST in IRIS is 32.27 kW while total power in SPES3 is 41 kW. The difference is mostly related to the higher water temperature in IRIS.

The SPES3 and IRIS containment pressure is affected by the DW heat structures, larger in SPES3 than IRIS. Power transferred to the DW structures is reported in Fig.8. 85 and Fig.8. 86. Power transfer occurs until a thermal equilibrium is reached on the walls, Fig.8. 87 and Fig.8. 88. At the peak, the SPES3 power (1.2 MW) is about 11 times the IRIS power (0.112 MW) transferred to the DW structures putting in evidence the influence of the SPES3 larger heat transfer surface. This delays the SPES3 pressure rise that anyway is not so far from IRIS one, Fig.8. 4.

Fig.8. 87 and Fig.8. 88 show the SPES3 and IRIS DW wall temperatures at the inner and outer surface. In SPES3, inside temperatures are indicated with label 01 and outside ones with label 13. Moreover, temperatures are taken at various axial levels in the DW (lower 01, intermediate 07, and upper 17). In IRIS, TA is the inside temperature and TB the outside one with heat structure 01 for the lower shell, 02 for the concrete and 03 for the upper shell. The SPES3 DW is thermally insulated with the environment and the outer surface temperature is almost constant during the transient, while IRIS is not insulated and the inner and outer surface temperatures are very similar.

Starting from different heat structure initial temperature (48.9 °C in IRIS and 84°C in SPES3), the IRIS DW temperatures increase up to similar values around 2000 s, then the IRIS DW temperature decrease more rapidly due to heat losses to the environment and to lower pressure in the containment, Fig.8. 87, Fig.8. 88, Fig.8. 5.

### 8.1.2 Primary to secondary to RWST heat transfer

A general agreement between SPES3-146 and IRIS HT6\_rwstc sequence of events has come out of the transient analysis. Moreover, an improvement in SPES3 and IRIS heat transfer capabilities is evidenced with respect to the previous case SPES3-127, Paragraph 6.1.2.

Attention has been put on the heat transfer at the SG and at the EHRS, focusing in particular on the part of the transient after 40000 s.

As for SPES3-127, a sort of “global heat transfer coefficient” ( $h * S$ ) has been estimated for the Primary to Secondary side and for the EHRS to RWST heat transfer according to the following process.

#### Primary to Secondary circuit

The primary side saturation temperature has been obtained versus pressurizer pressure

$P (PRZ) \Rightarrow T_{sat} (P PRZ);$

The secondary side saturation temperature has been obtained versus steam generator pressure

$P (SG) \Rightarrow T_{sat} (PSG);$

The temperature difference between primary and secondary side has been obtained as difference of the above saturation temperatures

$DT1 = T (PRZ-SG);$

A global heat transfer coefficient has been obtained by the ratio between the SG total power and the above temperature difference

$SG \text{ tot power} / DT1 = h * S (SG) \quad \text{heat transfer coefficient} * \text{Surface}$



### EHRS to RWST

The EHRS saturation temperature has been obtained versus EHRS inlet pressure

$P \text{ (EHRS)} \Rightarrow T_{\text{sat}} (P \text{ EHRS});$

The RWST temperature is directly available

$T \text{ RWST};$

The temperature difference between EHRS and RWST has been obtained as difference of the above temperatures

$DT2 = T \text{ (EHRS-RWST)};$

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$\text{EHRS tot power} / DT2 = h * S \text{ (EHRS)} \quad \text{heat transfer coefficient} * \text{Surface}$

### Primary to RWST (global heat transfer)

The temperature difference between primary and RWST is obtained from the variables described above:

$DT3 = T \text{ (PRZ-RWST)}$

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$\text{EHRS tot power} / DT3 = h * S \text{ (Global)} \quad \text{heat transfer coefficient} * \text{Surface}$

Comparing SPES3 and IRIS:

- an opposite operation is observed at SG: in SPES3 there is higher DT and lower  $h*S$  than in IRIS between 30000 s and 100000 s, Fig.8. 89 and Fig.8. 90;
- the same behaviour is observed at EHRS where DT and  $h*S$  are very similar in SPES3 and IRIS, Fig.8. 91, Fig.8. 92;
- globally in SPES3 there is a higher DT and a lower  $h * S$  than in IRIS, Fig.8. 93 and Fig.8. 94, that makes removed power similar.

It appears that, after the EHRS and RWST remodelling according to achievements of Paragraphs 7.2, 7.4 and 7.5, the greatest difference in the heat transfer mode is related to the SG. Part of the difference could be reduced following a finer model synchronization, as for the EHRS-RWST, but part cannot be removed due to the actual geometric (thickness) and material (Inconel, AISI) configuration of the plants.

### 8.1.3 Case conclusions

The general good agreement of the SPES3-146 and IRIS HT6\_rwstc results leads to conclude the available data may constitute a suitable data base for the FSA final application.

**Tab.8. 1 – SPES3-146 and IRIS- HT6\_rwstc steady state conditions**

| <b>SPES3-146</b>         | <b>Primary/Core</b>              | <b>SG-A</b>       | <b>SG-B</b>       | <b>SG-C</b>       | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWSTAB</b> | <b>RWSTC</b> |
|--------------------------|----------------------------------|-------------------|-------------------|-------------------|---------------|-----------|-----------|---------------|-----------|----------------|---------------|--------------|
| Pressure (MPa)           | 15.55 (PRZ)<br>0.104 (pump head) | 5.83 (out)        | 5.83 (out)        | 5.88 (out)        | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013        | 0.1013       |
| Tin (°C)                 | 292.5                            | 223.9             | 223.9             | 223.9             | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20            | 20           |
| Tout (°C)                | 329.9                            | 322.3             | 320.5             | 320.1             |               |           |           |               |           |                |               |              |
| DT (°C)                  | 37.4                             | 98.4              | 96.6              | 96.2              |               |           |           |               |           |                |               |              |
| Superheating (°C)        |                                  | 48.6 (Tsat 273.7) | 46.8 (Tsat 273.7) | 45.9 (Tsat 274.2) |               |           |           |               |           |                |               |              |
| Mass flow (kg/s)         | 45.58<br>(2.13 in by-pass)       | 1.25              | 1.25              | 2.5               |               |           |           |               |           |                |               |              |
| Power (MW)               | 10                               | 2.506             | 2.499             | 4.992             |               |           |           |               |           |                |               |              |
| Level (m)<br>-collapsed- | 1.93 (PRZ)                       | 1.58              | 1.73              | 1.75              | 3.14 full     | empty     | empty     | 3.77<br>3.80  | empty     | 2.454          | 6.961         | 6.954        |
| Mass (kg)                | 3286 (RV)                        |                   |                   |                   | 127           |           |           | 1482          |           | 985            | 11869         | 11876        |

| <b>IRIS<br/>HT6_rwstc</b> | <b>Primary/Core</b>                | <b>SG 1</b>              | <b>SG 2</b>              | <b>SG 3</b>              | <b>SG 4</b>              | <b>SG 5</b>              | <b>SG 6</b>              | <b>SG 7</b>              | <b>SG 8</b>              | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWST1</b> | <b>RWST2</b> |
|---------------------------|------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|---------------|-----------|-----------|---------------|-----------|----------------|--------------|--------------|
| Pressure (MPa)            | 15.5 (PRZ)<br>0.129 (pump<br>head) | 5.81<br>(out)            | 5.79<br>(out)            | 5.79<br>(out)            | 5.78<br>(out)            | 5.78<br>(out)            | 5.79<br>(out)            | 5.79<br>(out)            | 5.81<br>(out)            | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013       | 0.1013       |
| Tin (°C)                  | 291                                | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20           | 20           |
| Tout (°C)                 | 329                                | 318.05                   | 316.24                   | 318.22                   | 316.52                   | 316.52                   | 318.22                   | 316.24                   | 318.05                   |               |           |           |               |           |                |              |              |
| DT (°C)                   | 38                                 | 94.35                    | 92.54                    | 94.52                    | 92.82                    | 92.82                    | 94.52                    | 92.54                    | 94.35                    |               |           |           |               |           |                |              |              |
| Superheating<br>(°C)      |                                    | 44.55<br>(Tsat<br>273.5) | 43.04<br>(Tsat<br>273.2) | 45.02<br>(Tsat<br>273.2) | 43.42<br>(Tsat<br>273.1) | 43.42<br>(Tsat<br>273.1) | 45.02<br>(Tsat<br>273.2) | 43.04<br>(Tsat<br>273.2) | 44.55<br>(Tsat<br>273.5) |               |           |           |               |           |                |              |              |
| Mass flow (kg/s)          | 45.24<br>(2.13 in by-<br>pass)     | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    |               |           |           |               |           |                |              |              |
| Power (MW)                | 10                                 | 1.24                     | 1.26                     | 1.24                     | 1.26                     | 1.26                     | 1.24                     | 1.26                     | 1.24                     |               |           |           |               |           |                |              |              |
| Level (m)<br>-collapsed-  | 2.019 (PRZ)                        | 1.93                     | 1.99                     | 1.92                     | 1.98                     | 1.98                     | 1.92                     | 1.99                     | 1.93                     | 3.14 full     | empty     | empty     | 3.00          | empty     | 2.668          | 9.099        | 9.099        |
| Mass (kg)                 | 3254 (RV)                          |                          |                          |                          |                          |                          |                          |                          |                          | 127           |           |           | 1453          |           | 989            | 11942        | 11942        |

Tab.8. 2 – SPES3-146 and IRIS HT6\_rwstc list of the main events

| DVI-B DEG break 2 inch equivalent                                                        |                                                         | SPES3-146      |                                        |                                                      | IRIS-HT6_rwstc |                          |                                                                    |
|------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------|----------------------------------------|------------------------------------------------------|----------------|--------------------------|--------------------------------------------------------------------|
| N.                                                                                       | Phases and events                                       | Time (s)       | Quantity                               | Notes                                                | Time (s)       | Quantity                 | Notes                                                              |
| <b>Break</b>                                                                             |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 1                                                                                        | Break initiation                                        | 0              |                                        | break valves stroke 2 s                              | 0              |                          | Instantaneous stroke 0.02 s delay                                  |
| 2                                                                                        | Break flow peak (Containment side)                      | 1              | 0.687 kg/s                             | Break flow = 0 kg/s at 11 s                          | 0.03           | 0.50 kg/s                | Break flow = 0 kg/s at 1.1 s                                       |
| 3                                                                                        | Break flow peak (RV side)                               | 2              | 1.33 kg/s                              |                                                      | 0.06           | 1.35 kg/s                |                                                                    |
| <b>Blowdown, RV depressurization, containment pressurization. Steam dumping into PSS</b> |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 4                                                                                        | Steam-air mixture begins to flow from DW to PSS         | 15             |                                        |                                                      | 22             |                          | 0 to 10 s water empties the vent pipe and moves into the PSS       |
| <b>S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation</b>         |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 5                                                                                        | High Containment pressure signal                        | 31.63          | 1.7e5 Pa                               | S-signal. Set-point for safety analyses              | 30             | 1.7e5 Pa                 | S-signal. Set-point for safety analyses                            |
| 6                                                                                        | SCRAM begins                                            | 31.63          |                                        |                                                      | 30             |                          |                                                                    |
| 7                                                                                        | MFIV-A,B,C closure start                                | 31.63          |                                        | MFIV-A,B,C stroke 5 s                                | 30             |                          | MFIV-1,2,3,4 stroke 5 s                                            |
| 8                                                                                        | MSIV-A-B-C closure start                                | 31.63          |                                        | MSIV-A,B,C stroke 5 s.                               | 30             |                          | MSIV-1,2,3,4 stroke 5 s.                                           |
| 9                                                                                        | EHRS-A and B opening start (EHRS 1 and 3 in IRIS)       | 31.63          |                                        | EHRS-A,B IV stroke 2 s.                              | 40             |                          | EHRS-1,3 IV stroke 2 s. S-signal + 10 s delay                      |
| 10                                                                                       | EHRS-A and B peak mass flow                             | 39             | 0.261 kg/s                             |                                                      | 45             | 0.287 kg/s               |                                                                    |
| 11                                                                                       | High SG pressure signal                                 | 45.38          | 9e6 Pa                                 |                                                      | 44             | 9e6 Pa                   |                                                                    |
| 12                                                                                       | SG-A high pressure reached                              | 45.38          |                                        |                                                      | 44             |                          |                                                                    |
| 13                                                                                       | SG-B high pressure reached                              | 46.23          |                                        |                                                      | 44             |                          |                                                                    |
| 14                                                                                       | SG-C high pressure reached                              | 46.25          |                                        |                                                      | 44             |                          |                                                                    |
| 15                                                                                       | RWST-A/B begins to heat-up                              | 60             |                                        |                                                      | 256            |                          | Same time as RWST-2                                                |
| 16                                                                                       | EHRS-A power peak                                       | 218            | 371 kW                                 |                                                      | 158            | 335 kW                   | EHRS-1                                                             |
| 17                                                                                       | EHRS-B power peak                                       | 218            | 371 kW                                 |                                                      | 158            | 335 kW                   | EHRS-3                                                             |
| <b>Pump coastdown and primary circulation through RI-DC check valves</b>                 |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 18                                                                                       | Low PRZ water level signal                              | 97.14          | 1.189 m                                |                                                      | 130            | 1.189 m                  |                                                                    |
| 19                                                                                       | RCP costdown starts                                     | 112.14         |                                        | Low PRZ level signal + 15 s delay                    | 145            |                          | Low PRZ level signal + 15 s delay                                  |
| 20                                                                                       | Secondary loop pressure peak                            | 68<br>69<br>70 | 105e5 Pa A<br>108e5 Pa B<br>113e5 Pa C |                                                      | 57             | 110.2e5 Pa<br>108.8e5 Pa | SG-1 to 4<br>SG-5 to 8                                             |
| 21                                                                                       | Natural circulation begins through shroud valves        | 129, 132       |                                        | SG-A,B 129 s,<br>SG-C 131 s                          | 185            |                          | SG-1+2, 5+6+7+8 185 s,<br>SG-3+4 185 s                             |
| 22                                                                                       | Flashing begins at core outlet                          | 199            | voidf 110 (core)                       | <1                                                   | 186            | voidf 110 (core)         | <1                                                                 |
| <b>LM-Signal: EHRS-C, ADS Stage-I and EBT actuation. RV saturation</b>                   |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 23                                                                                       | Low PRZ pressure signal                                 | 176.89         | 11.72e6 Pa                             | LM-Signal (High P cont + Low P PRZ)                  | 174            | 11.72e6 Pa               | LM-Signal (High P cont + Low P PRZ)                                |
| 24                                                                                       | EHRS-C opening start (EHRS 2 and 4 in IRIS)             | 176.89         |                                        | EHRS-C IV stroke 2 s.                                | 174            |                          | EHRS-2+4 IV stroke 2 s.                                            |
| 25                                                                                       | EHRS-C peak mass flow                                   | 182            | 0.540 kg/s                             |                                                      | 190            | 0.580 kg/s               | EHRS-2+4                                                           |
| 26                                                                                       | RWST-C begins to heat-up                                | 208            |                                        |                                                      | 256            |                          | Same time as RWST-1                                                |
| 27                                                                                       | EHRS-C power peak                                       | 315            | 723 kW                                 |                                                      | 325            | 636 kW                   |                                                                    |
| 28                                                                                       | ADS Stage I start opening (3 trains)                    | 176.89         |                                        | ADS valve stroke 10 s                                | 174            |                          | ADS valve stroke 10 s                                              |
| 29                                                                                       | ADS Stage I first peak flow (3 trains)                  | 182, 187       | 1.344 kg/s                             | ST 0.458 kg/s;<br>DT 0.886 kg/s                      | 186            | 1.301 kg/s               | ST (1) 0.432 kg/s;<br>DT (2+3) 0.869 kg/s                          |
| 30                                                                                       | ADS Stage I second peak flow (3 trains)                 | 270            | 1.523 kg/s                             | ST 0.483 kg/s; DT 1.04 kg/s. Due to liquid fraction. | 245            | 1.988 kg/s               | ST (1) 0.673 kg/s;<br>DT (2+3) 1.315 kg/s. Due to liquid fraction. |
| 31                                                                                       | EBT-A and B valve opening start                         | 176.89         |                                        | EBT valve stroke 15 s                                | 174            |                          | EBT valve stroke 15 s                                              |
| 32                                                                                       | Break flow peak (Containment side)                      | 197            | 0.701 kg/s                             | Due to EBT intervention                              | 203            | 0.633 kg/s               | Due to EBT intervention                                            |
| 33                                                                                       | EBT-RV connections uncovered                            | 218, 249       |                                        | EBT-B, EBT-A                                         | 385            |                          |                                                                    |
| 32                                                                                       | Natural circulation interrupted at SGs top              | 231            |                                        | Pump inlet uncovered (voidf 176-01 ~0)               | 265            |                          | Mass flow = 0 at SG top (mflowj 201-01 ~0)                         |
| 36                                                                                       | Core in saturation conditions                           | 316            |                                        |                                                      | 245            |                          |                                                                    |
| 37                                                                                       | EBT-B empty (broken loop)                               | 620            |                                        | 510 s almost empty (620 s completely empty)          | 625            |                          |                                                                    |
| <b>Low DP RV-Containment signal, LGMS and RC to DVI valve actuation</b>                  |                                                         |                |                                        |                                                      |                |                          |                                                                    |
| 38                                                                                       | Containment pressure peak                               | 2230           | 9.10e5 Pa                              |                                                      | 1405           | 9.36e5 Pa                |                                                                    |
| 39                                                                                       | Low DP RV-Containment                                   | 2236.58        | 50e3 Pa                                |                                                      | 1585           | 50e3 Pa                  |                                                                    |
| 40                                                                                       | LGMSA/B valve opening start                             | 2236.58        |                                        | LM + low DP RV-cont . LGMS valve stroke 2 s.         | 1585           |                          | LM + low DP RV-cont . LGMS valve stroke 2 s.                       |
| 41                                                                                       | RC to DVI line valve opening                            | 2236.58        |                                        | RC to DVI valve stroke 2 s.                          | 1585           |                          | RC to DVI valve stroke 2 s.                                        |
| 42                                                                                       | LGMS-B starts to inject into RC through DVI broken loop | 2236.58        |                                        |                                                      | 1585           |                          | LGMS-1 broken loop                                                 |
| 43                                                                                       | LGMS-A starts to inject into RV through DVI intact loop | 2250           |                                        |                                                      | 1670           |                          | LGMS-2 intact loop                                                 |

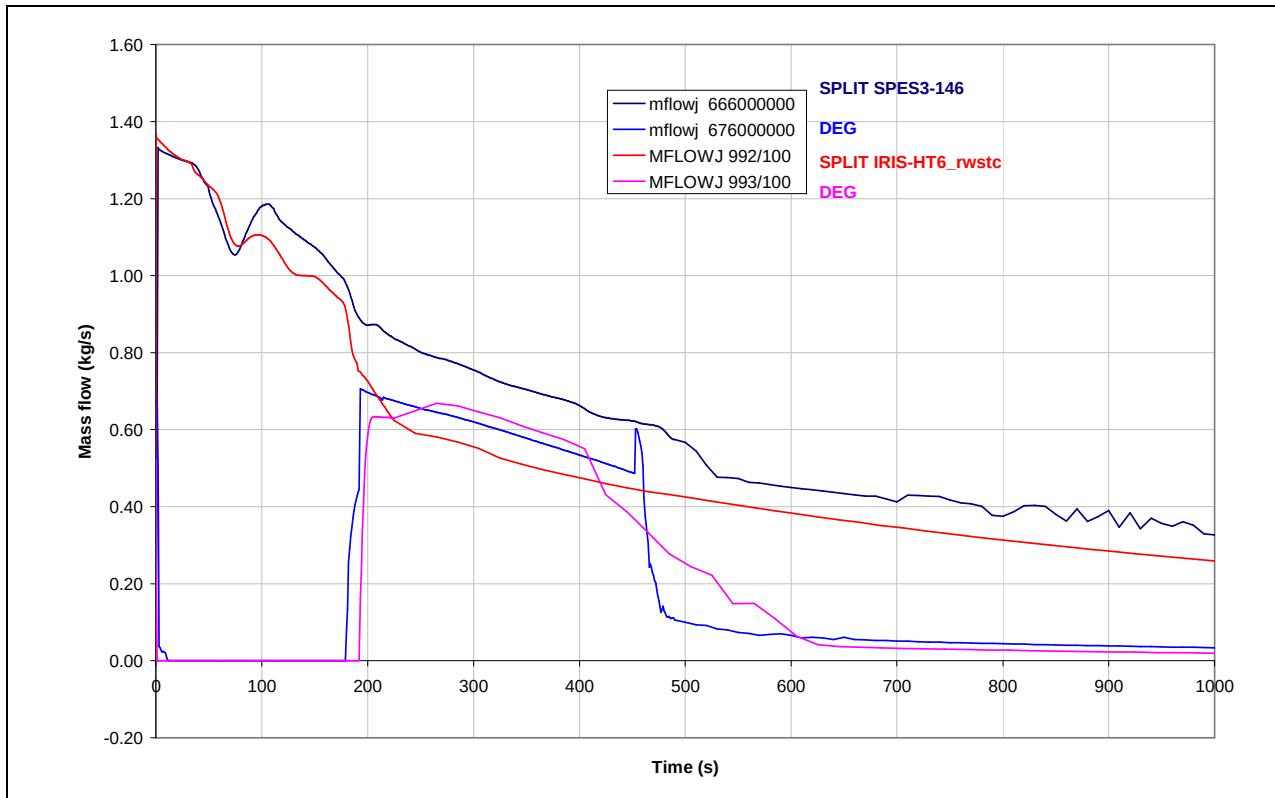
....continues



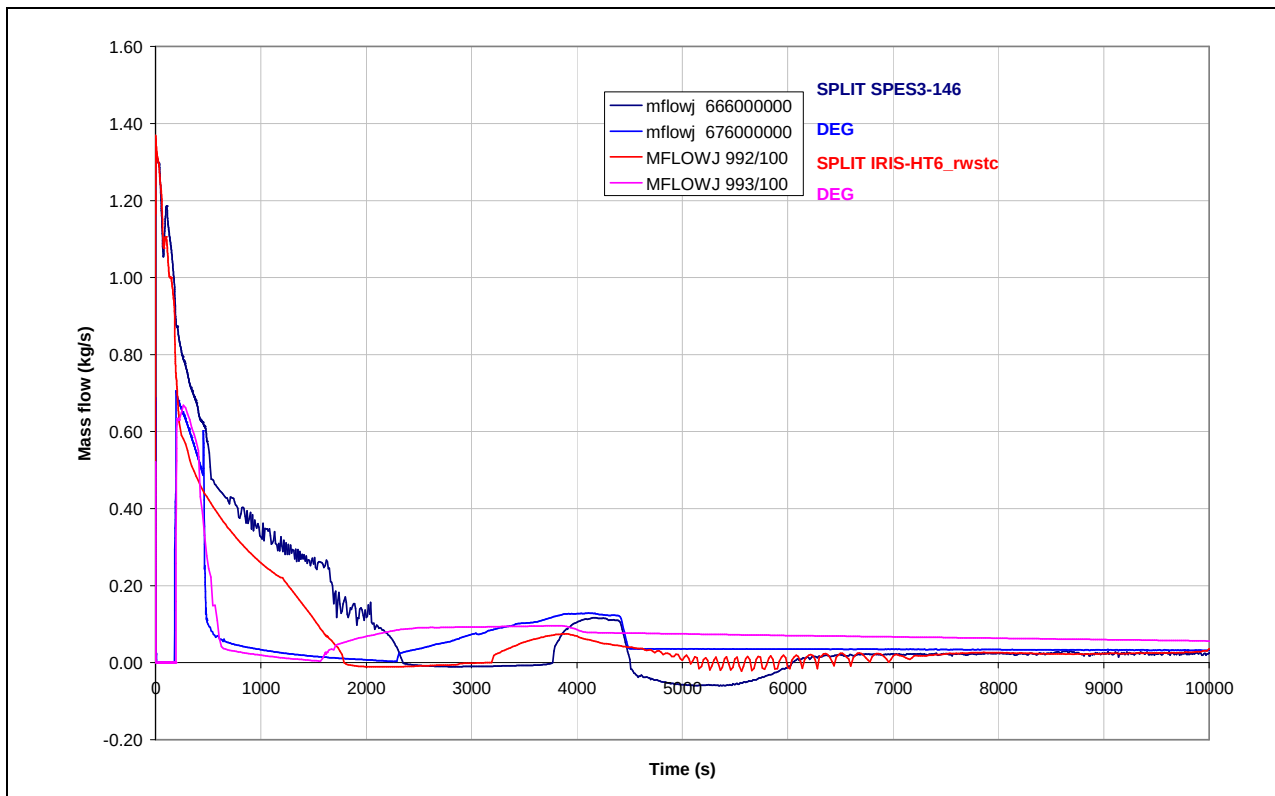
....continued

|                                                                                                                         | <b>DVI-B break 2 inch equivalent DEG</b>        | <b>SPES3-146</b> |                      |                                                                | <b>IRIS-<br/>HT6_rwstc</b> |          |                                                   |
|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|------------------|----------------------|----------------------------------------------------------------|----------------------------|----------|---------------------------------------------------|
| N.                                                                                                                      | Phases and events                               | Time (s)         | Quantity             | Notes                                                          | Time (s)                   | Quantity | Notes                                             |
| <b>Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV</b> |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 44                                                                                                                      | Containment and RV pressure equalization        | 2350             |                      |                                                                | 1730                       |          |                                                   |
| 45                                                                                                                      | Mixture starts to flow from RC to DVI-A         | 2350             |                      |                                                                | -                          |          | Negligible until 59000 s.                         |
| 46                                                                                                                      | DW pressure lower than PSS pressure             | 1980, 2660       |                      | A, B                                                           | 1650                       |          |                                                   |
| 47                                                                                                                      | EBT-A empty (intact loop)                       | 3050             |                      |                                                                | 35490                      |          |                                                   |
| 48                                                                                                                      | Water starts to flow from PSS to DW             | 3510, 3580       |                      | A, B                                                           | 2310                       |          |                                                   |
| 49                                                                                                                      | Steam and gas mixture flows again from RV to QT | 3790             |                      | 3790 to 4450 s<br>(RV P > DW P)                                | 3640                       |          | 3640 to 4100 s<br>(RV P > DW P). Negligible flow  |
| 50                                                                                                                      | RC level at DVI elevation                       | 4150             |                      |                                                                | 5000                       |          |                                                   |
| 51                                                                                                                      | RC full of water                                | 4470             |                      |                                                                | 14891                      |          |                                                   |
| 52                                                                                                                      | QT fill-up starts from DW connection            | 9640             |                      |                                                                | -                          |          | QT full at 2650 s for ADS Stage-I<br>intervention |
| <b>Low LGMS mass signal: ADS Stage-II actuation</b>                                                                     |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 53                                                                                                                      | <b>Low LGMS mass</b>                            | 17703.09         | 20% mass<br>(198 kg) | LGMS A (intact loop)                                           | 13171                      | (185 kg) | LGMS-2 (intact loop)                              |
| 54                                                                                                                      |                                                 | 24653.89         | 20% mass<br>(198 kg) | LGMS B (broken loop)                                           | 14120                      | (185 kg) | LGMS-1 (broken loop)                              |
| 55                                                                                                                      | ADS stage-II start opening                      | 24653.89         |                      | ADS stage II valve<br>stroke 10 s.                             | 14120                      |          | ADS stage II valve stroke 10 s.                   |
| 56                                                                                                                      | LGMS-A empty (intact loop)                      | 37990            |                      |                                                                | 20450                      |          | LGMS-2 (intact loop).                             |
| 56                                                                                                                      | LGMS-B empty (broken loop)                      | 40000            |                      | 35 kg at 40000 s.<br>~20kg residual mass<br>70000 to 150000 s. | 20450                      |          | LGMS-1 (broken loop).                             |
| 57                                                                                                                      | Flow from RC to RV (intact loop) stable         | 33240            |                      |                                                                | 65414                      |          | Strong oscillations                               |
| <b>Long Term conditions</b>                                                                                             |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 58                                                                                                                      | Core power (kW)                                 | 100000           | 45.95                | Aver 95000 - 100000 s                                          | 100000                     | 52.04    | Aver 95000 - 100000 s                             |
| 59                                                                                                                      | SG tot power (kW)                               | 100000           | 43.18                |                                                                | 100000                     | 38.91    |                                                   |
| 60                                                                                                                      | RWST tot power (kW)                             | 100000           | 42.31                |                                                                | 100000                     | 36.01    |                                                   |
| 61                                                                                                                      | RWST-A/B temperature (°C)                       | 100000           | 101                  | saturated                                                      | 1 00000                    | 107      | Saturated at 97300 s                              |
| 62                                                                                                                      | RWST-C temperature (°C)                         | 100000           | 101                  | saturated                                                      | 100 000                    | 107      | Saturated at 97300 s                              |
|                                                                                                                         |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 63                                                                                                                      | Core power                                      | 150000           | 46.03                | Aver. 145000-150000 s                                          | 150000                     | 47.05    | Aver. 145000-150000 s                             |
| 64                                                                                                                      | SG tot power                                    | 150000           | 42.69                |                                                                | 150000                     | 34.06    |                                                   |
| 65                                                                                                                      | RWST tot power                                  | 150000           | 41.00                |                                                                | 150000                     | 32.27    |                                                   |
| 66                                                                                                                      | RWST-A/B temperature                            | 150000           | 100                  | saturated                                                      | 150000                     | 107      | saturated                                         |
| 67                                                                                                                      | RWST-C temperature                              | 150000           | 100                  | saturated                                                      | 150000                     | 107      | saturated                                         |

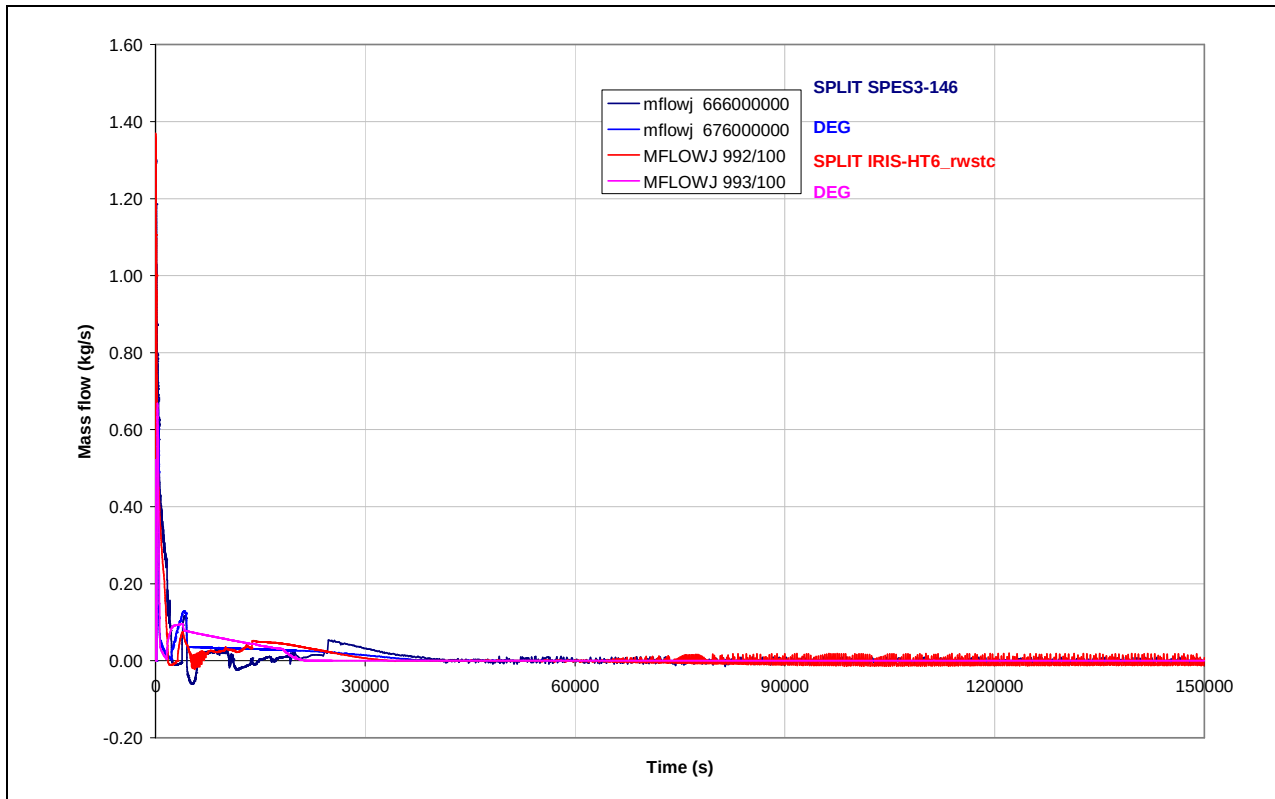
**Fig.8. 1 – SPES3-146 and IRIS HT6\_rwstc DVI break flow (window)**



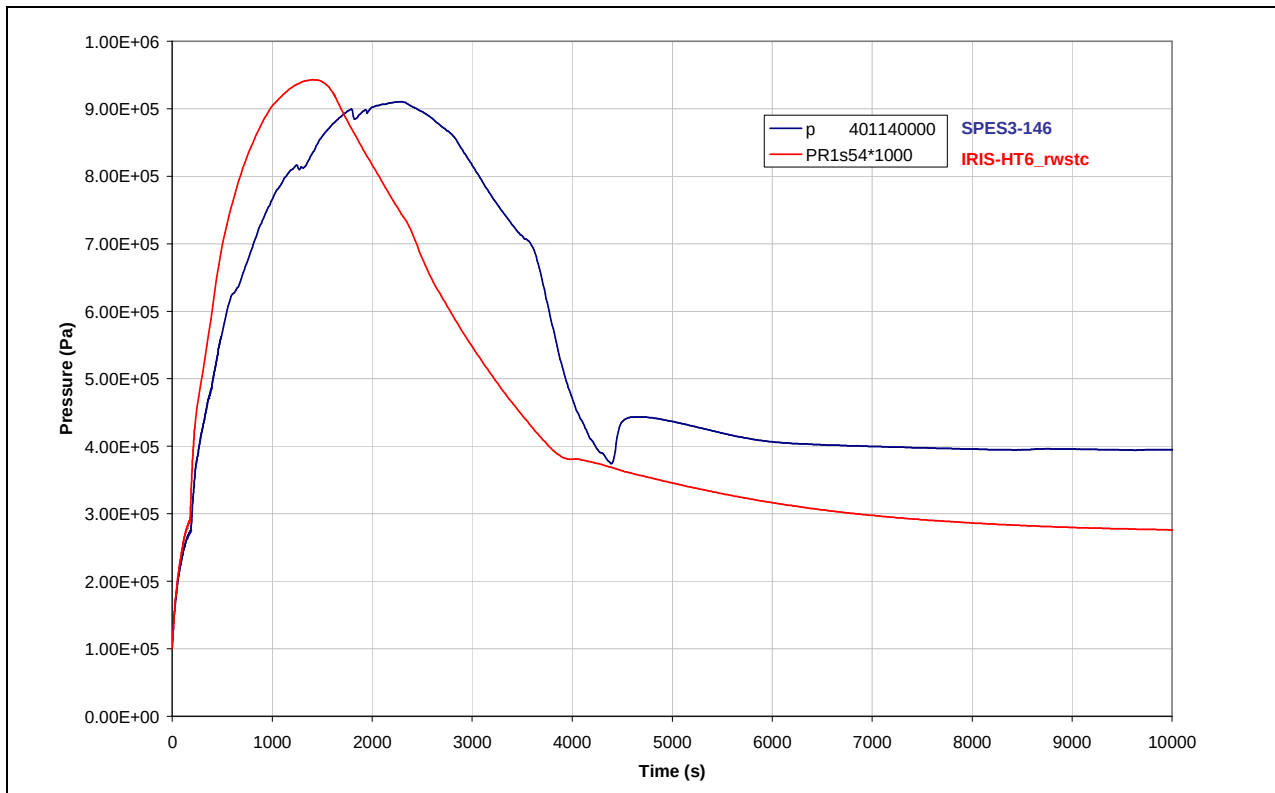
**Fig.8. 2 – SPES3-146 and IRIS HT6\_rwstc DVI break flow (window)**



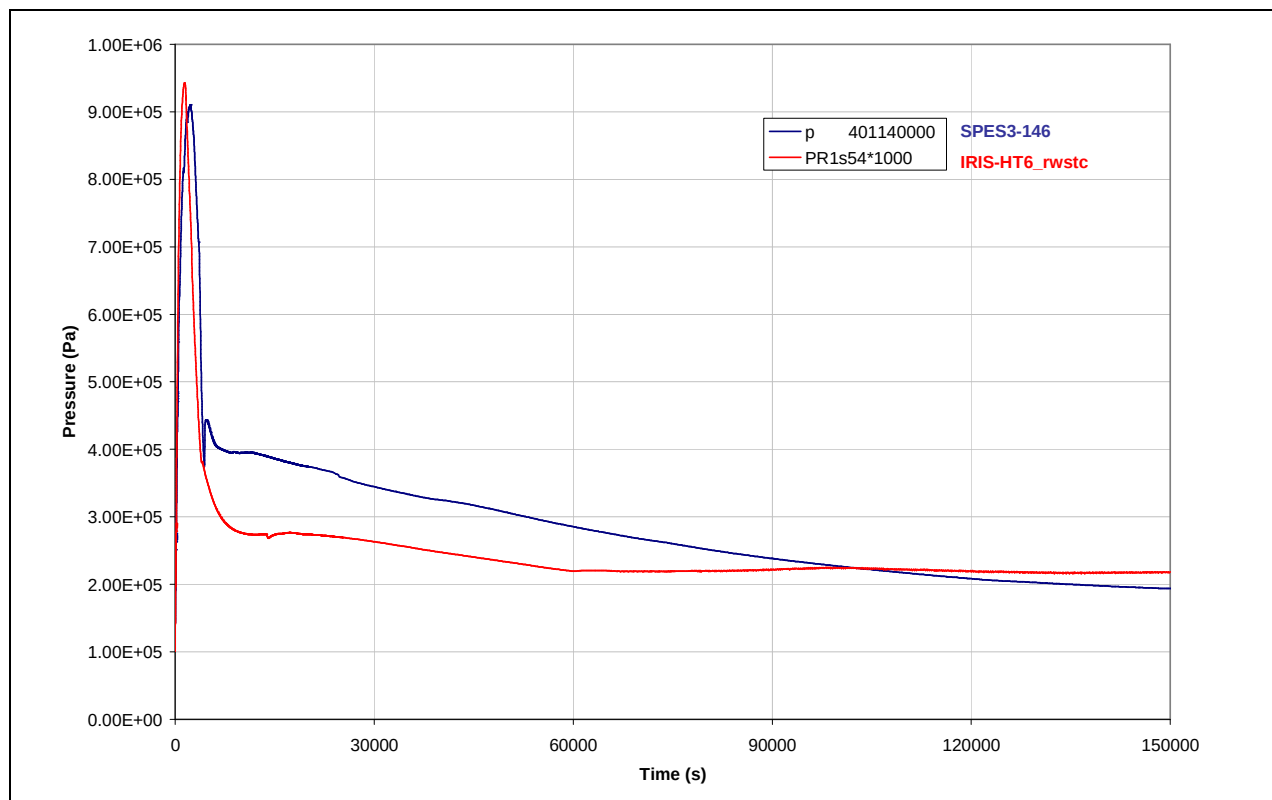
**Fig.8. 3 – SPES3-146 and IRIS HT6\_rwstc DVI break flow**



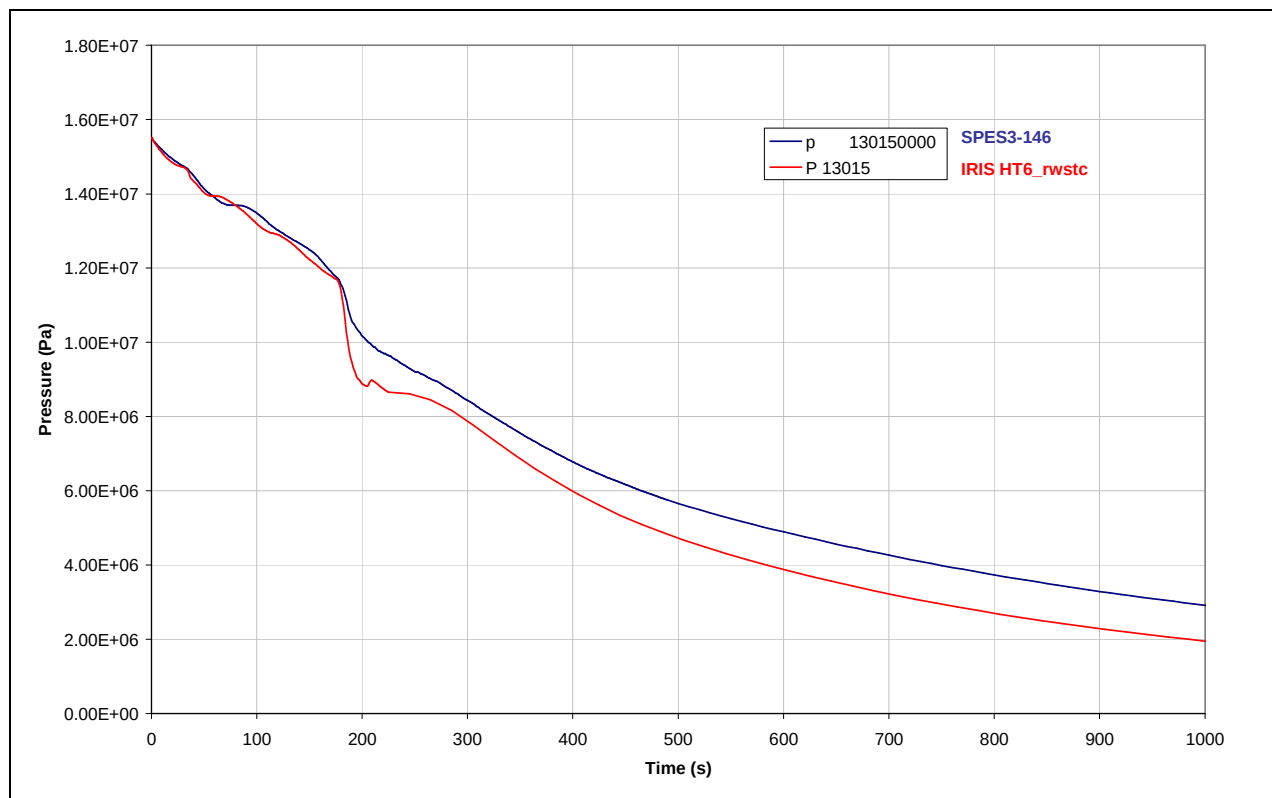
**Fig.8. 4 – SPES3-146 and IRIS HT6\_rwstc DW pressure (window)**



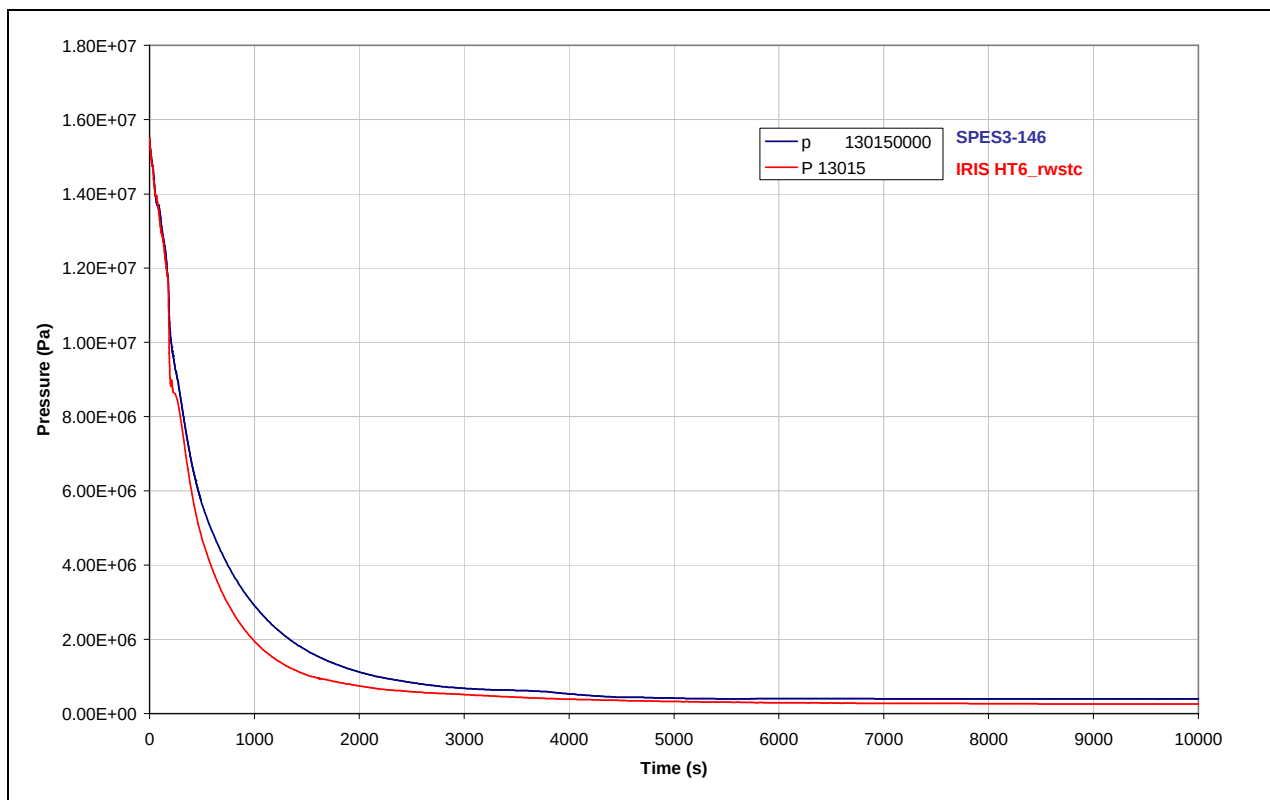
**Fig.8. 5 – SPES3-146 and IRIS HT6\_rwstc DW pressure**



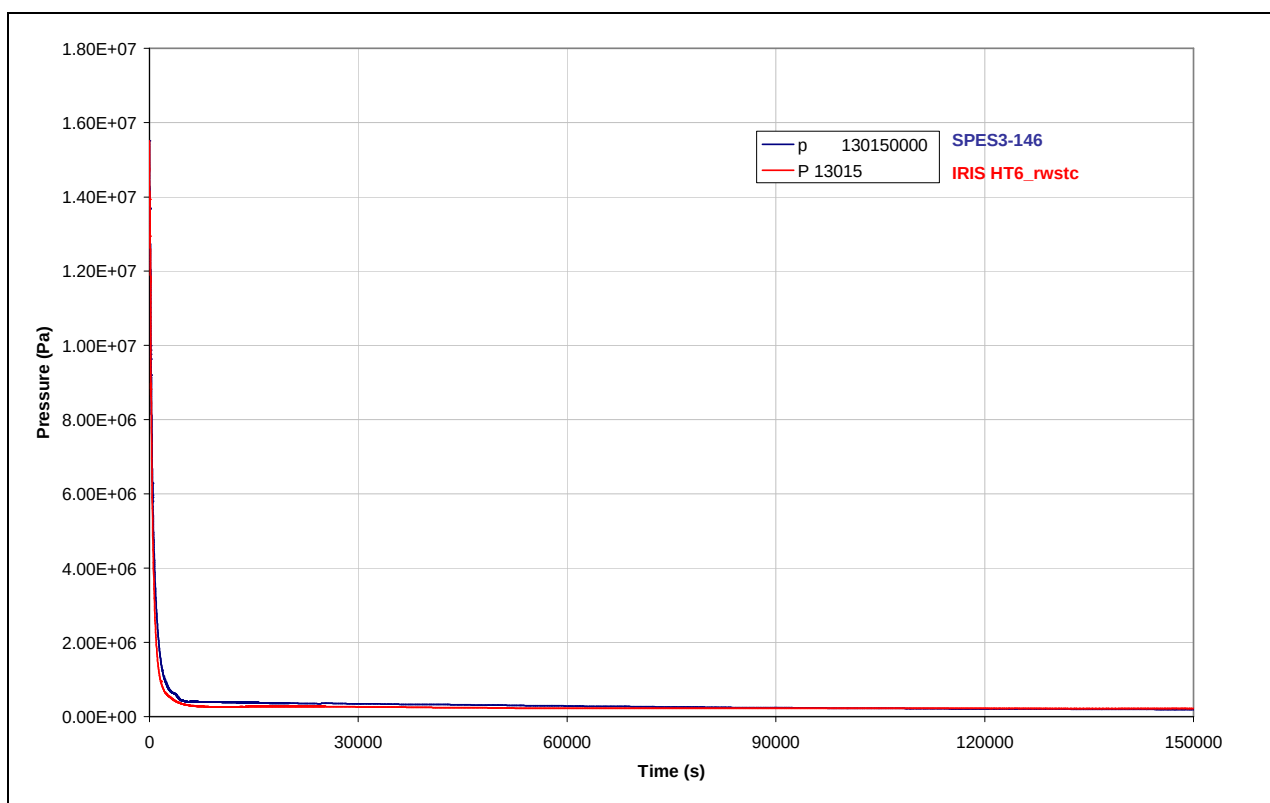
**Fig.8. 6 – SPES3-146 and IRIS HT6\_rwstc PRZ pressure (window)**



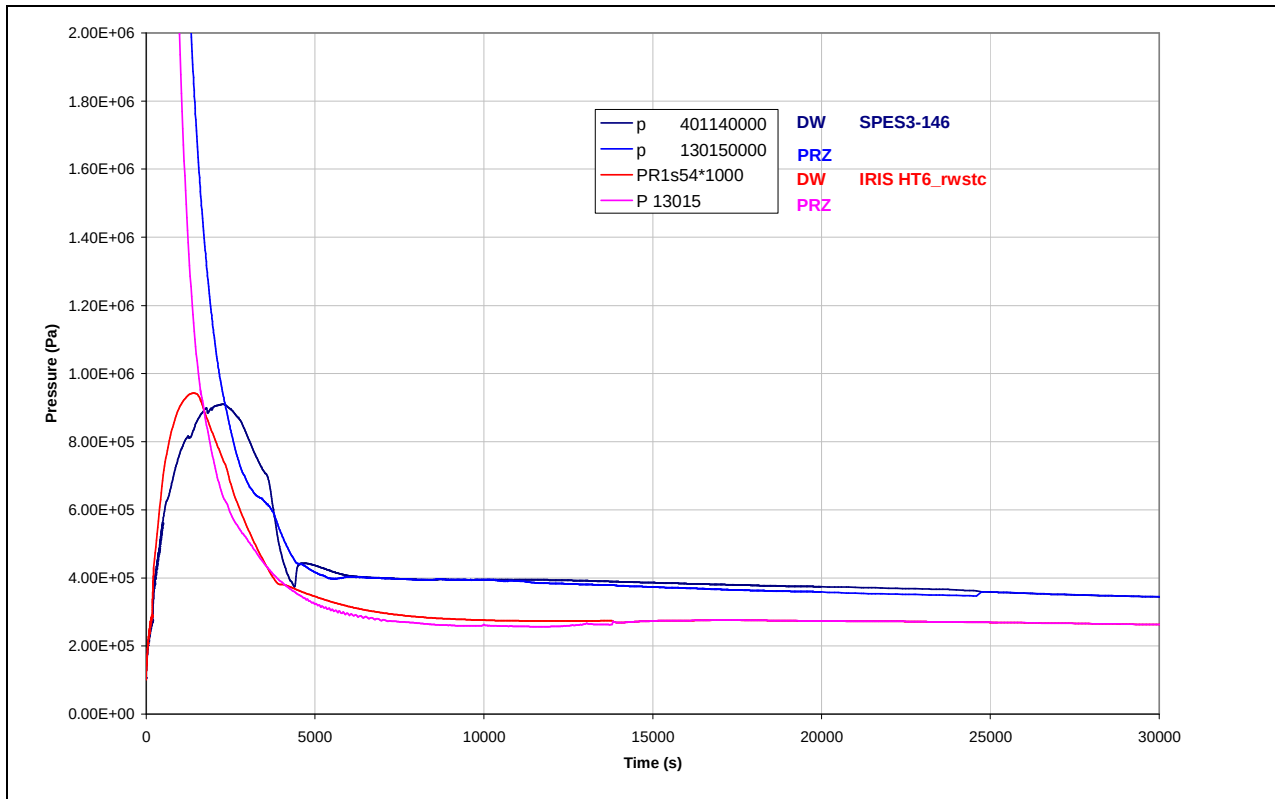
**Fig.8. 7 – SPES3-146 and IRIS HT6\_rwstc PRZ pressure (windows)**



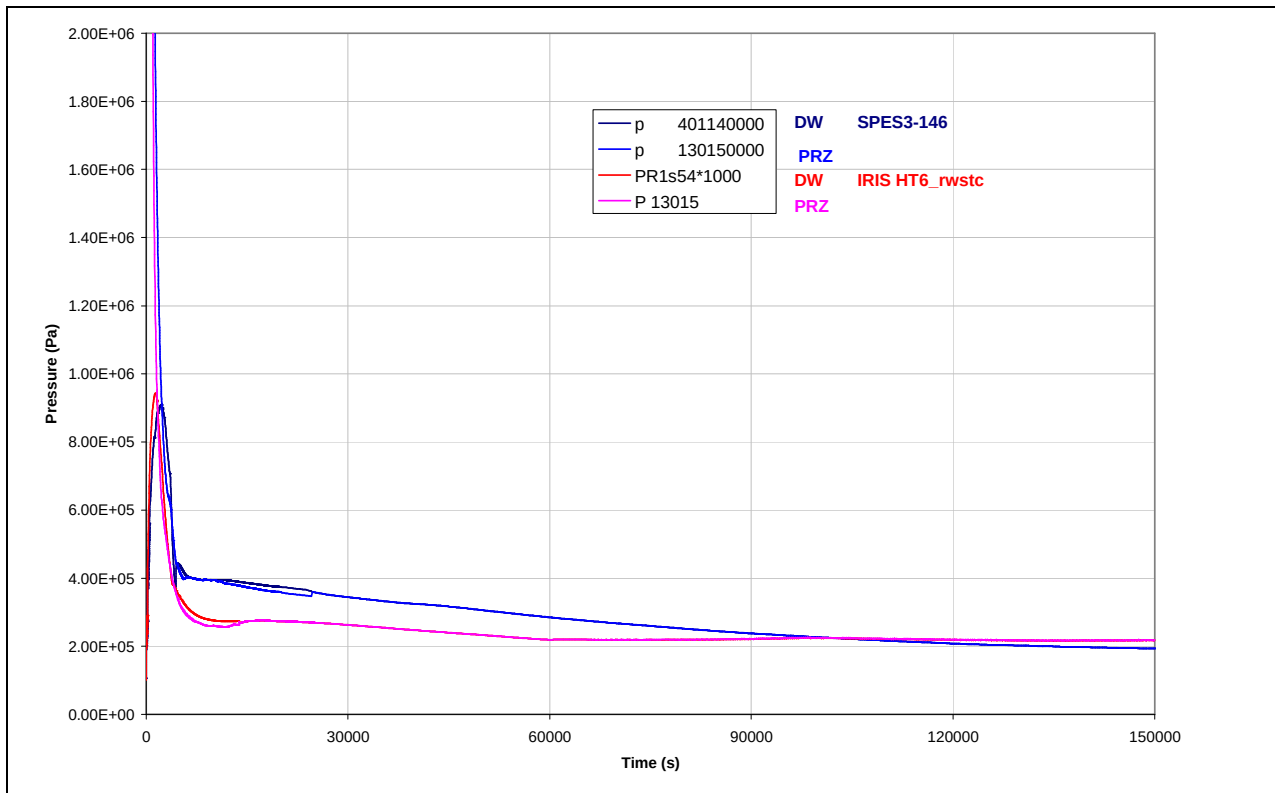
**Fig.8. 8 – SPES3-146 and IRIS HT6\_rwstc PRZ pressure (windows)**



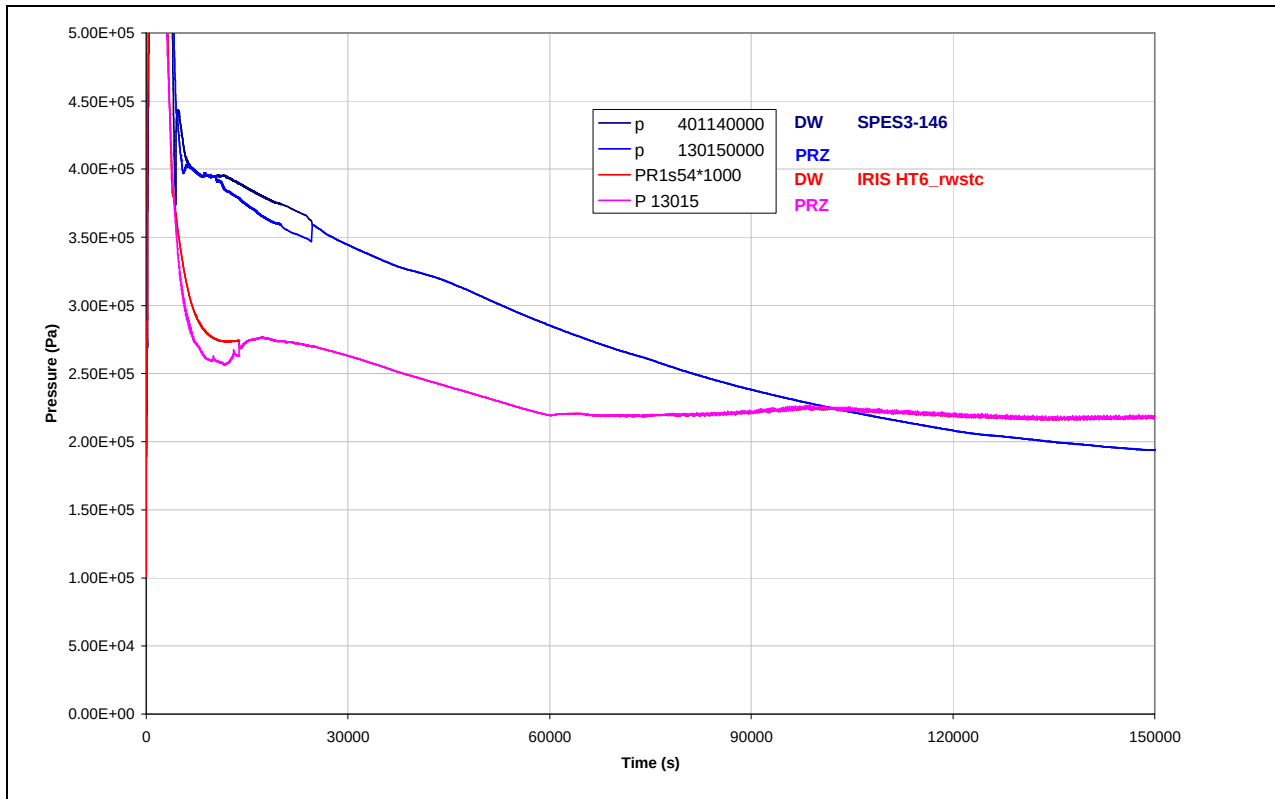
**Fig.8. 9 – SPES3-146 and IRIS HT6\_rwstc PRZ and DW pressures (window)**



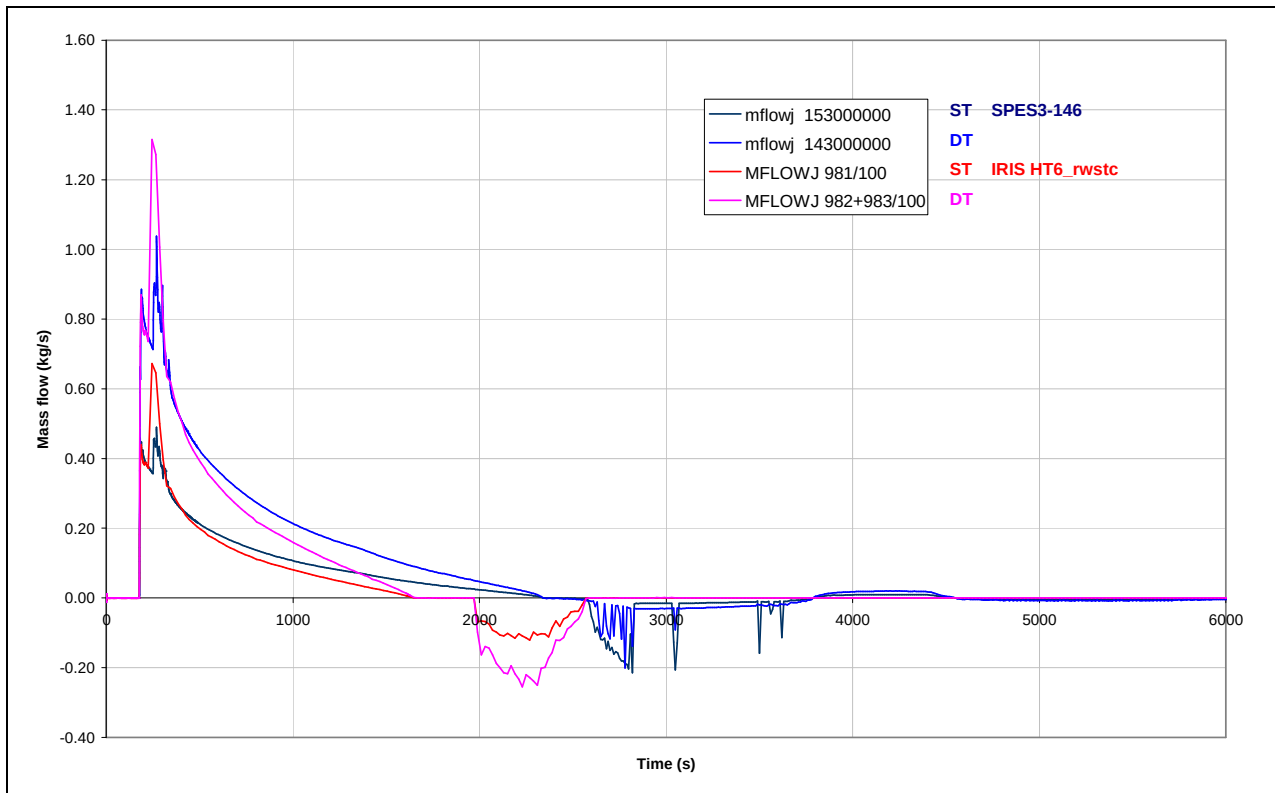
**Fig.8. 10 – SPES3-146 and IRIS HT6\_rwstc PRZ and DW pressures**



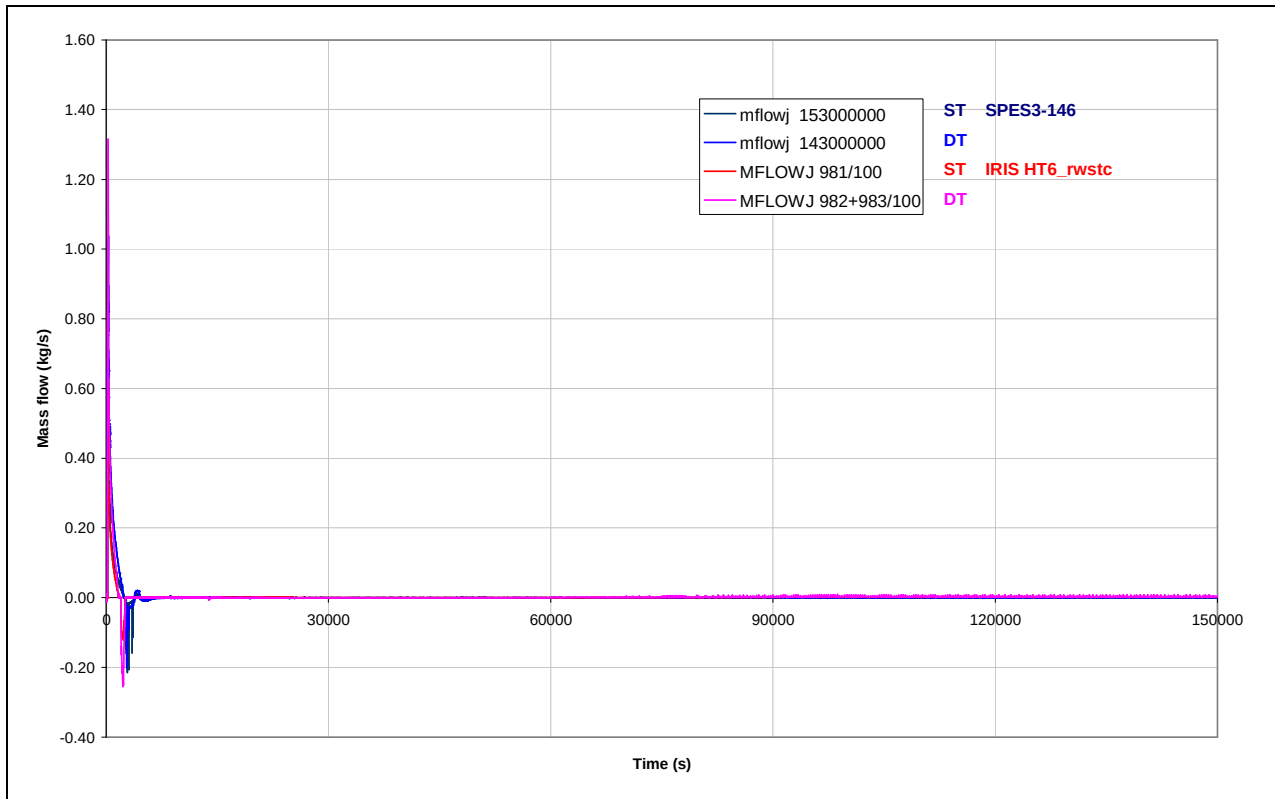
**Fig.8. 11 – SPES3-146 and IRIS HT6\_rwstc PRZ and DW pressures (detail)**



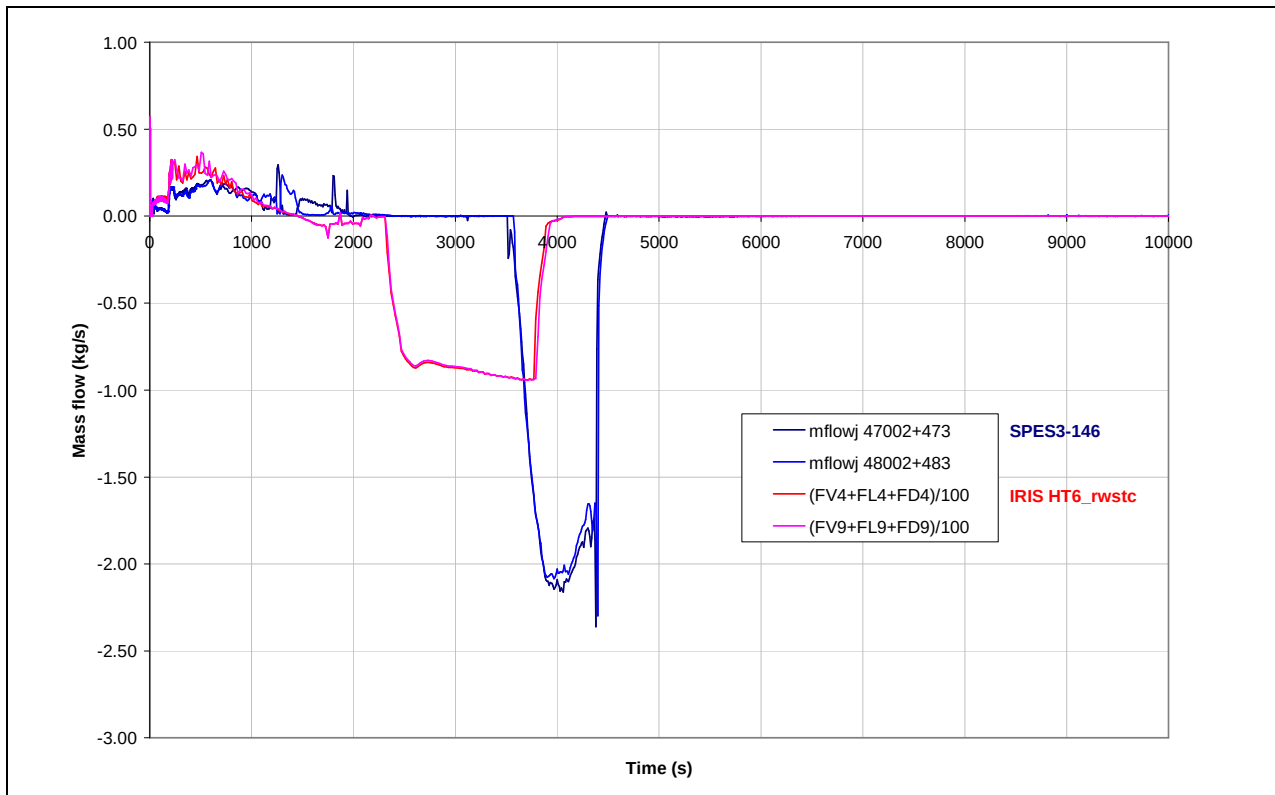
**Fig.8. 12 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-I mass flow (window)**



**Fig.8. 13 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-I mass flow**

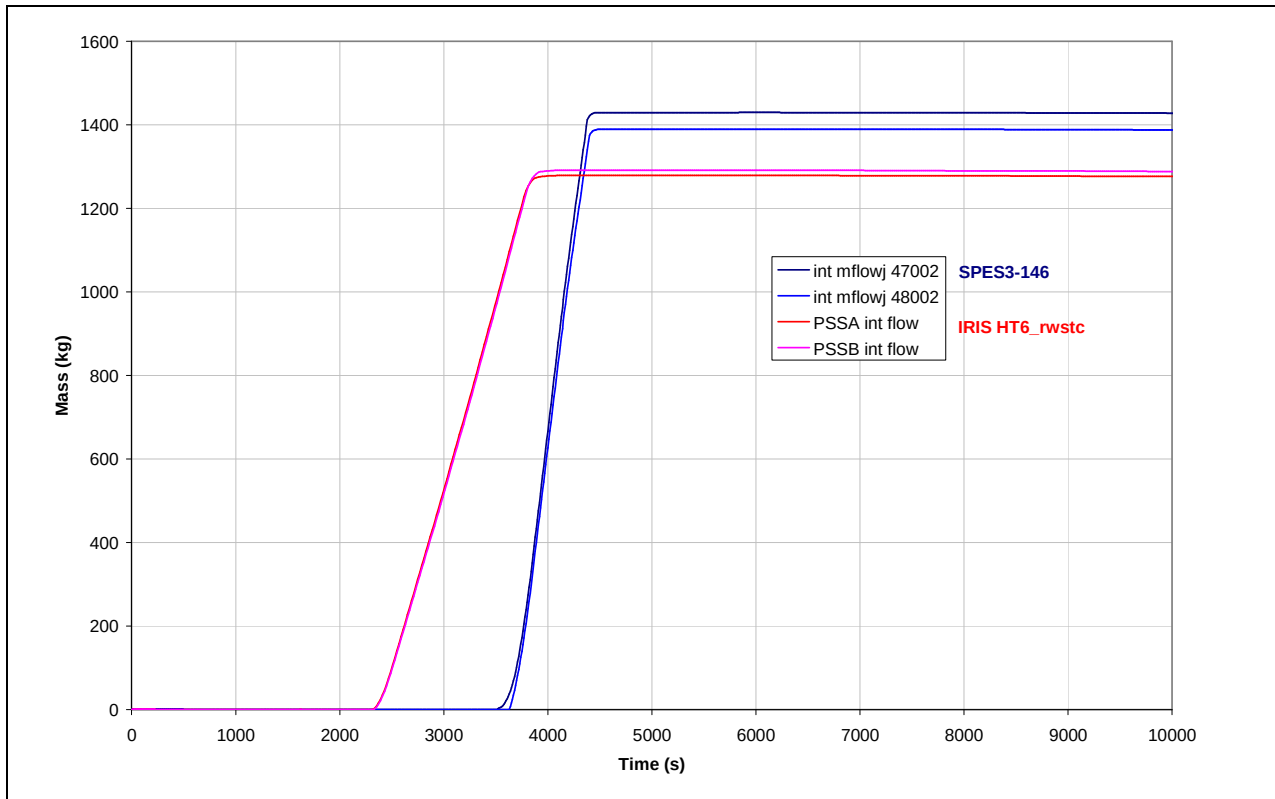


**Fig.8. 14 – SPES3-146 and IRIS HT6\_rwstc DW to PSS mass flow (window)**

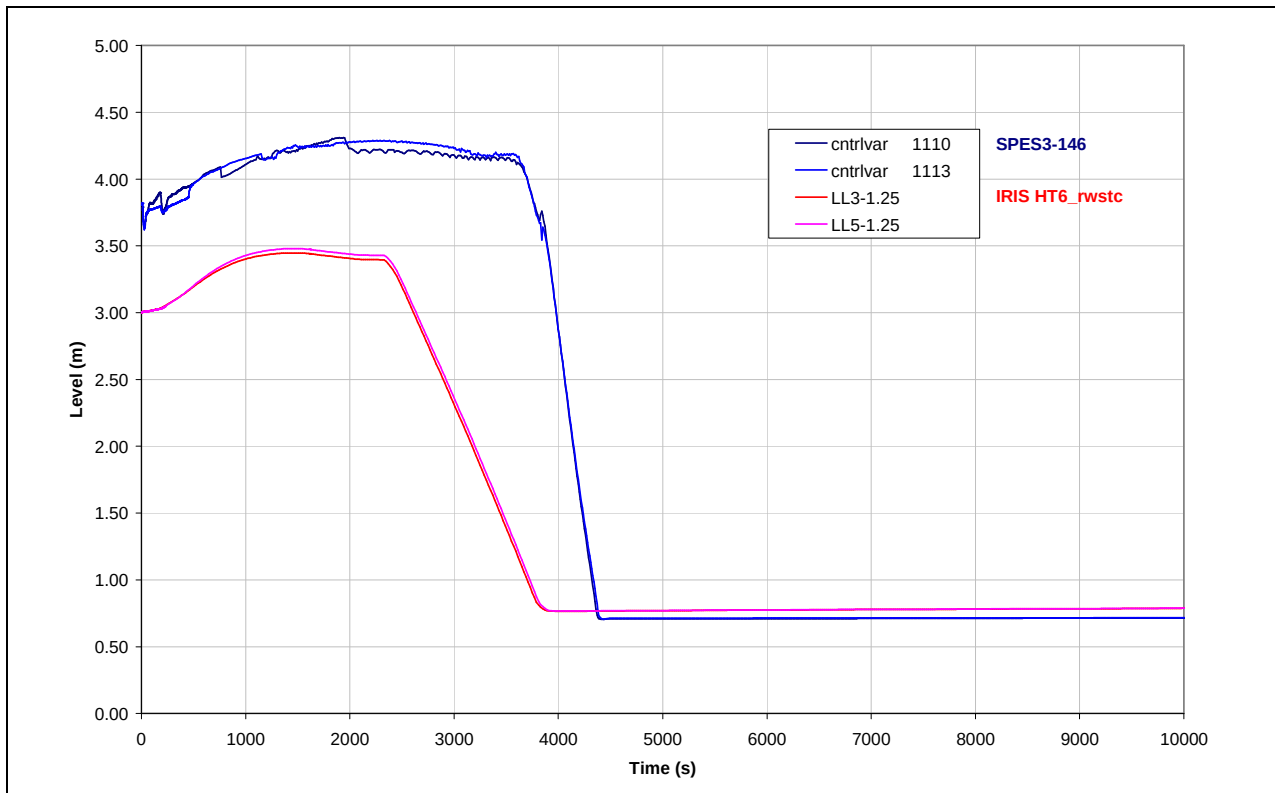




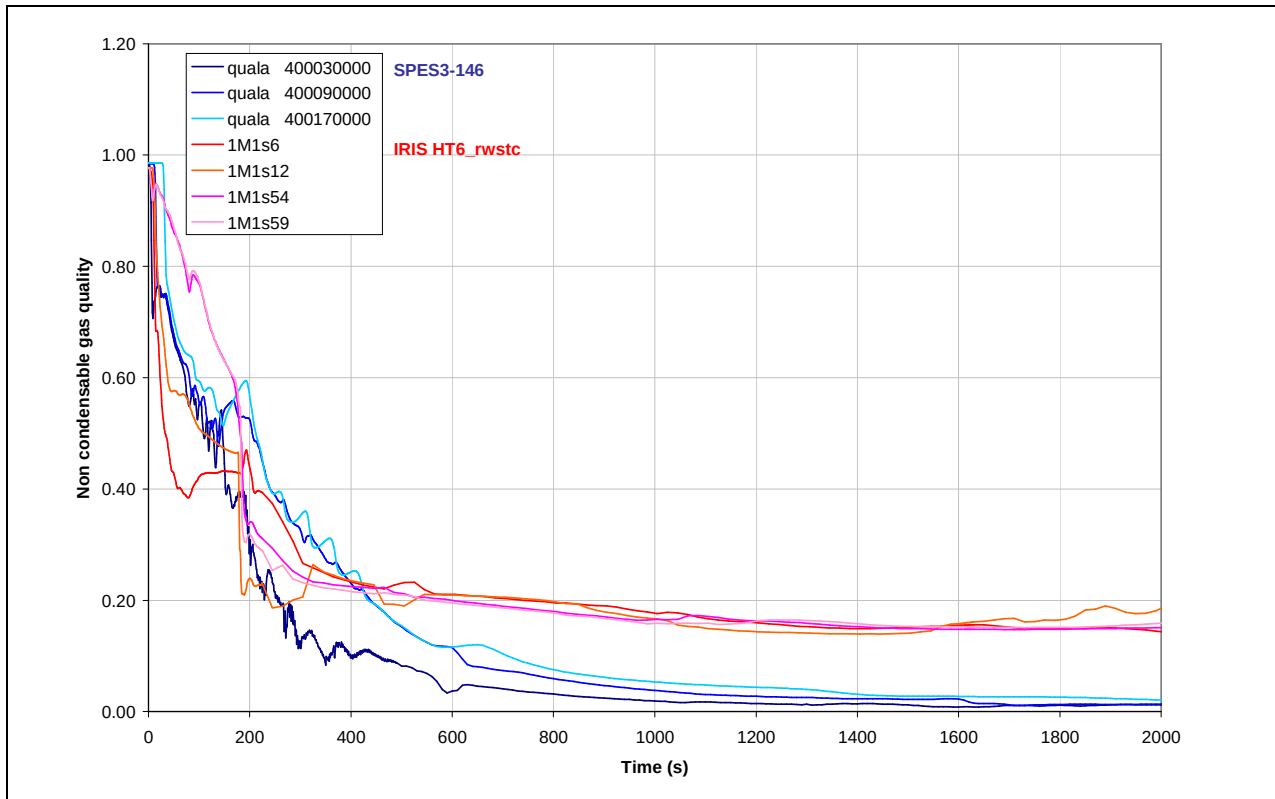
**Fig.8. 15 – SPES3-146 and IRIS HT6\_rwstc PSS to DW integral flow (window)**



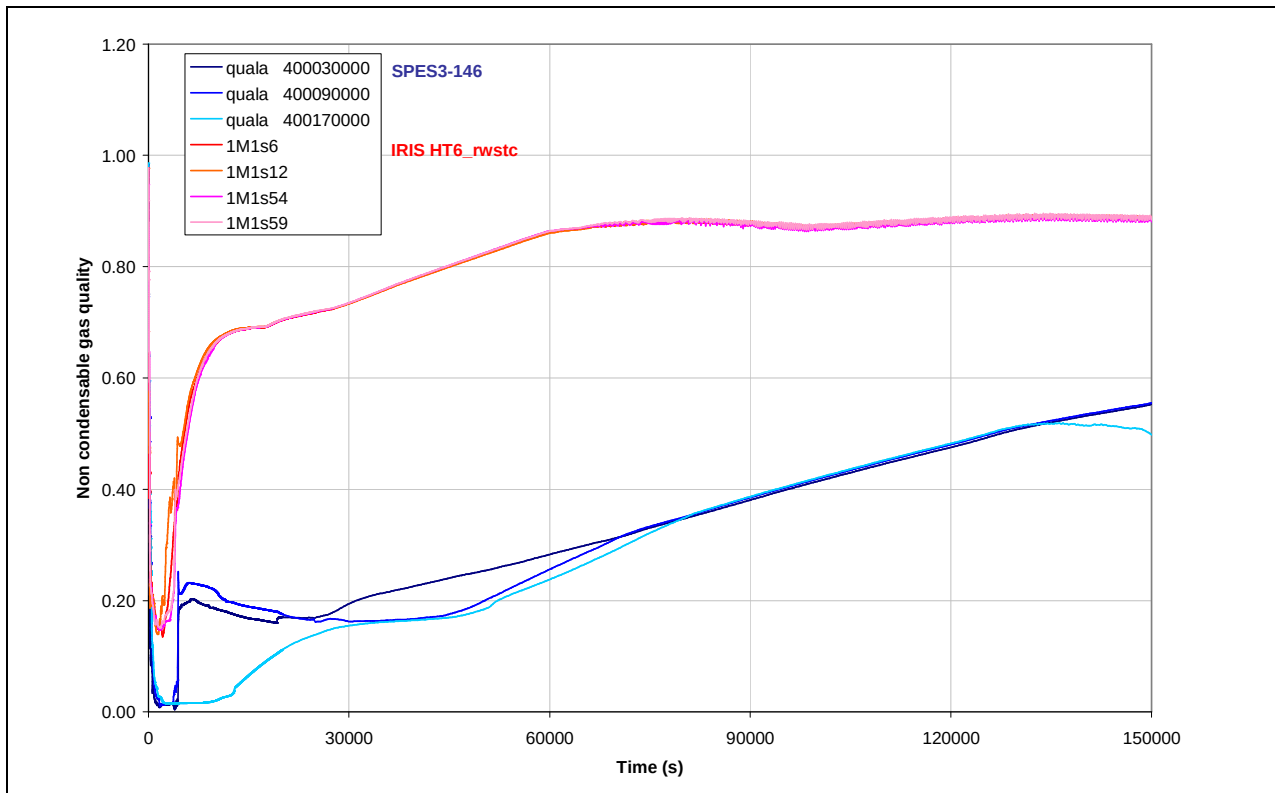
**Fig.8. 16 – SPES3-146 and IRIS HT6\_rwstc PSS level (window)**



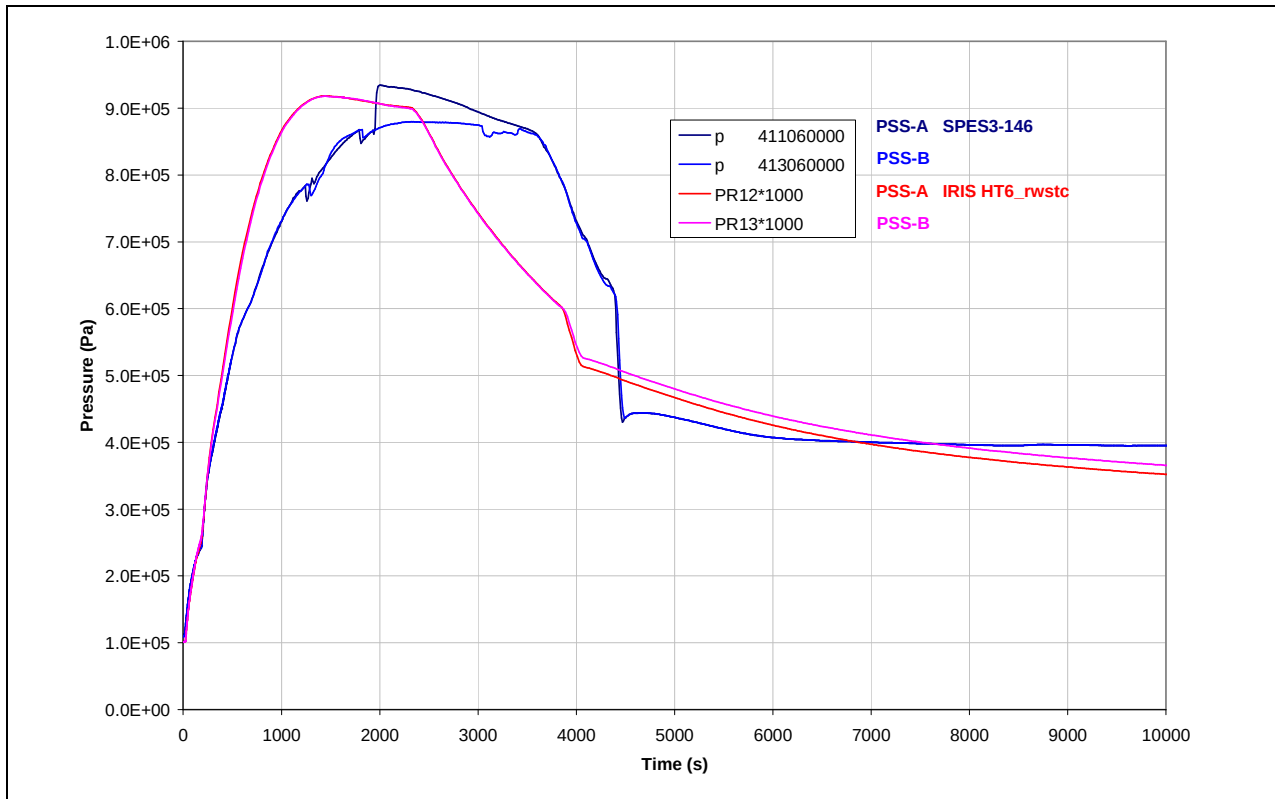
**Fig.8. 17 – SPES3-146 and IRIS HT6\_rwstc DW non-condensable gas quality (window)**



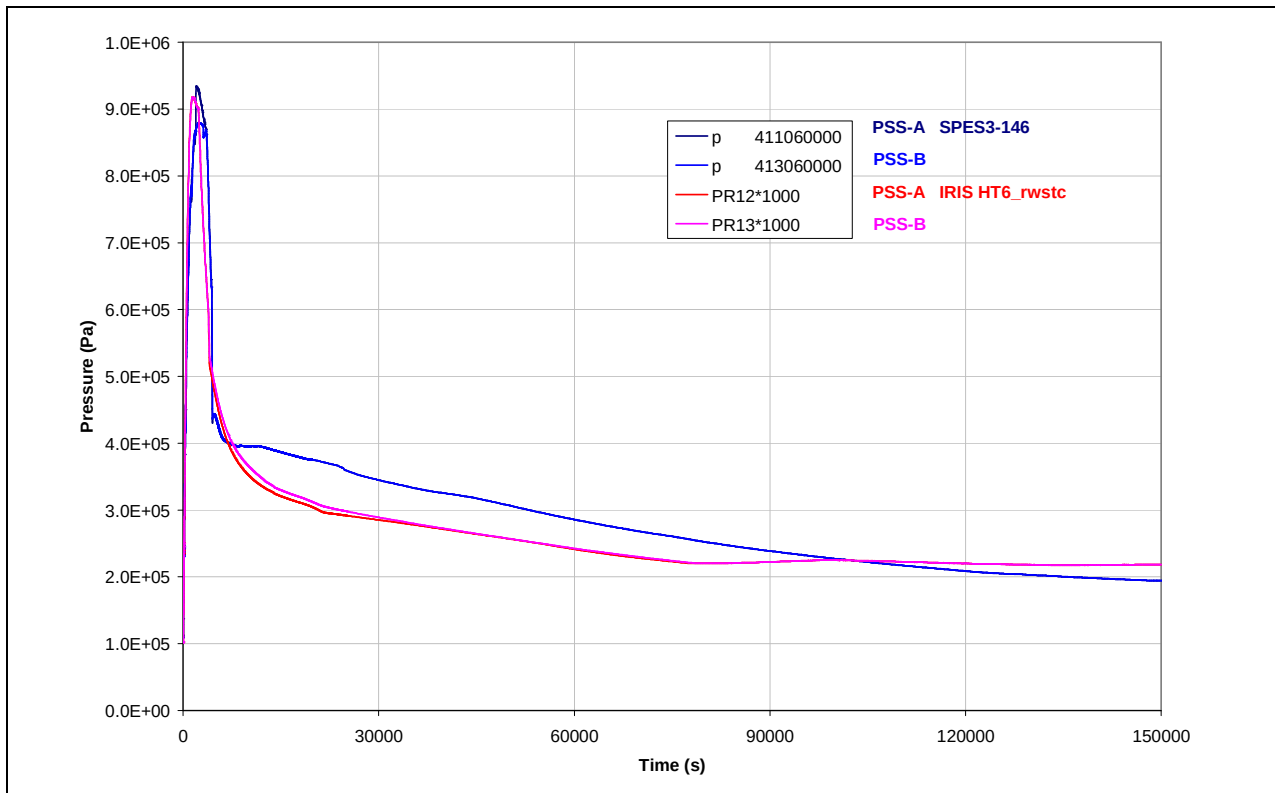
**Fig.8. 18 – SPES3-146 and IRIS HT6\_rwstc DW non-condensable gas quality**



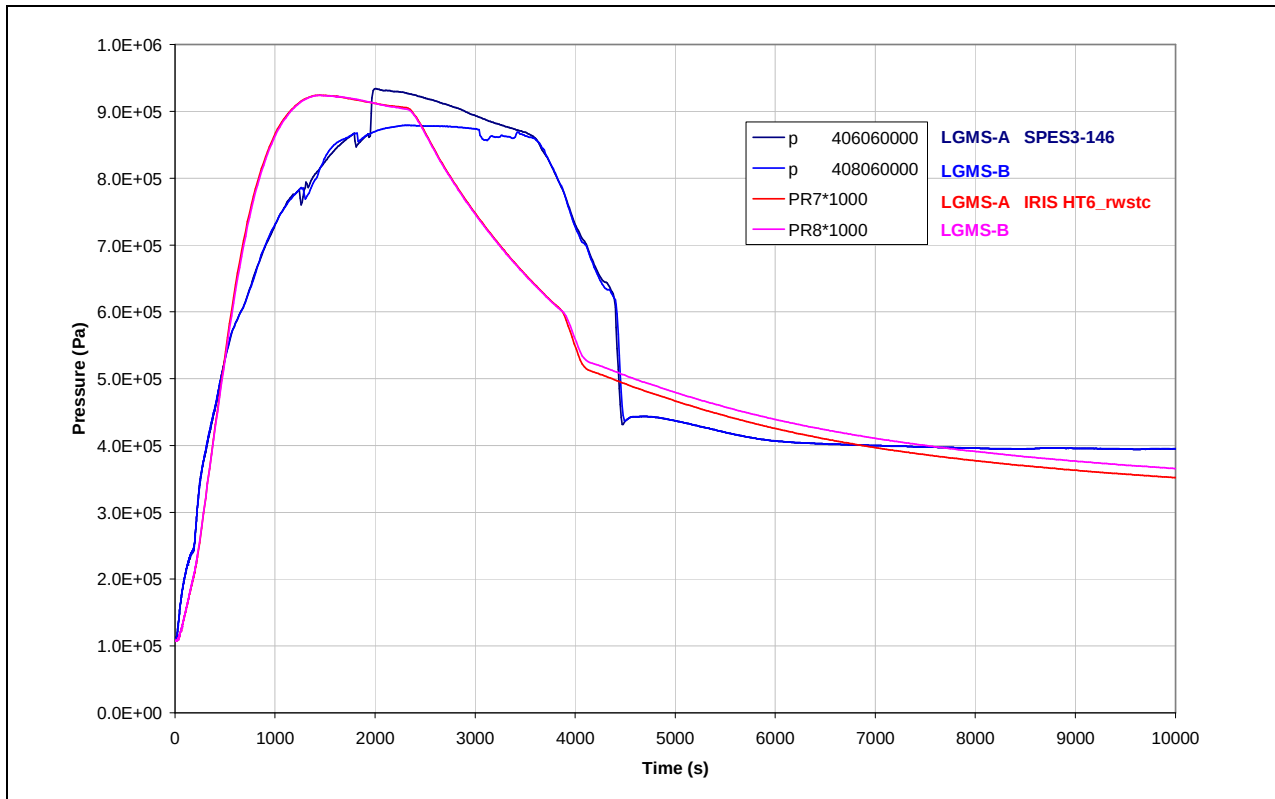
**Fig.8. 19 – SPES3-146 and IRIS HT6\_rwstc PSS pressure (window)**



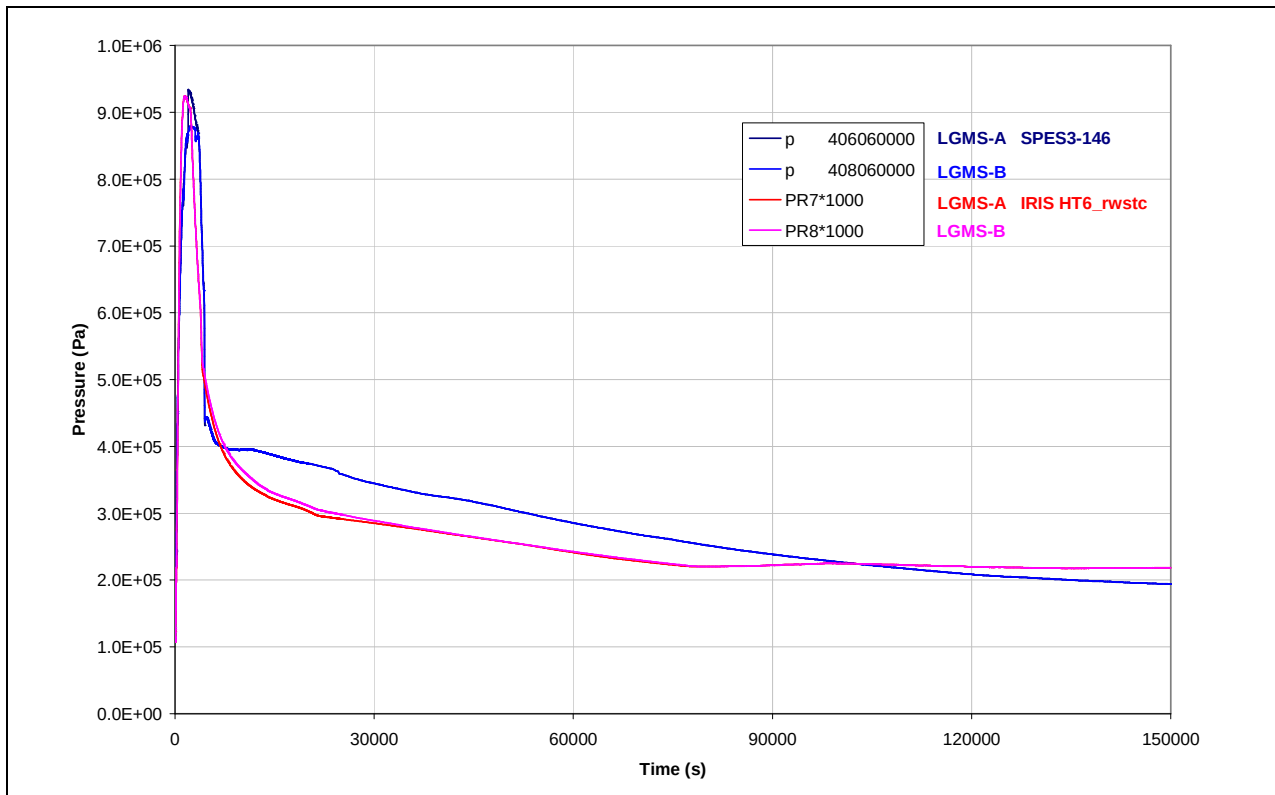
**Fig.8. 20 – SPES3-146 and IRIS HT6\_rwstc PSS pressure**



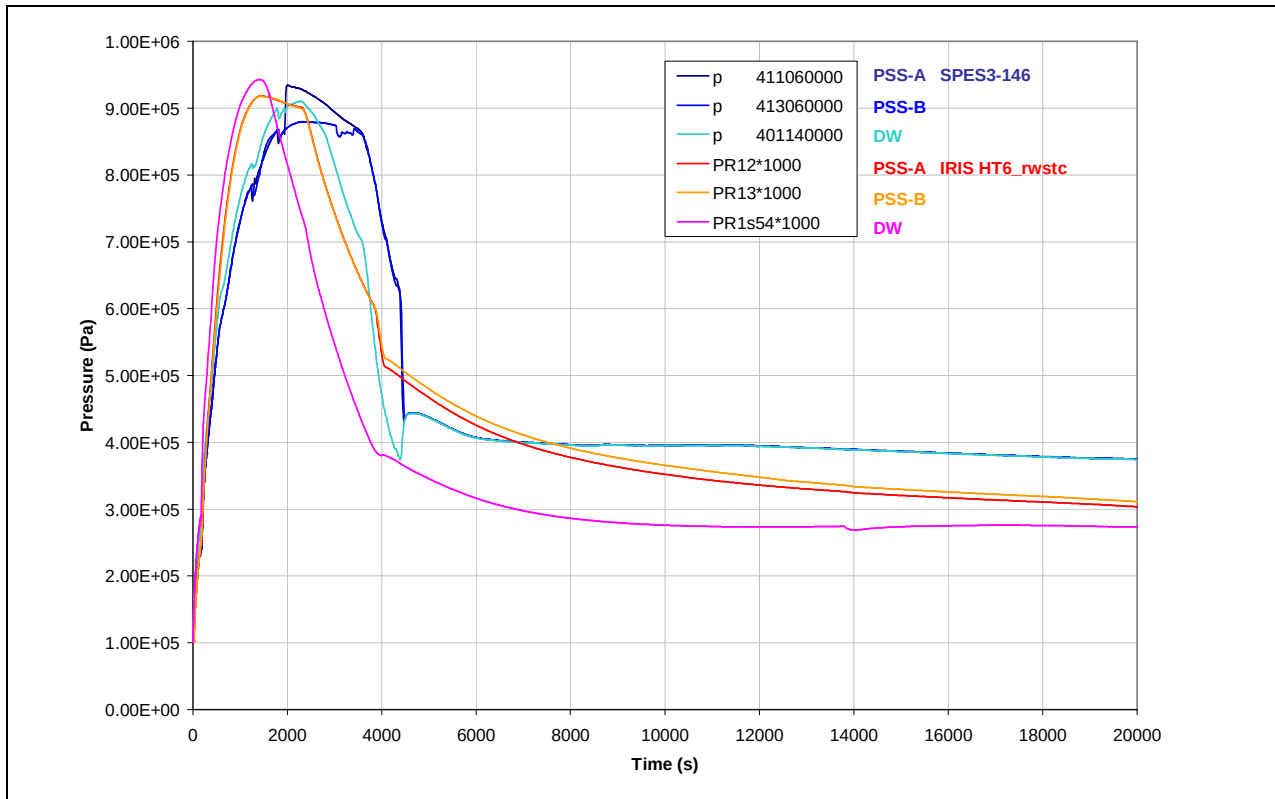
**Fig.8. 21 – SPES3-146 and IRIS HT6\_rwstc LGMS pressure (window)**



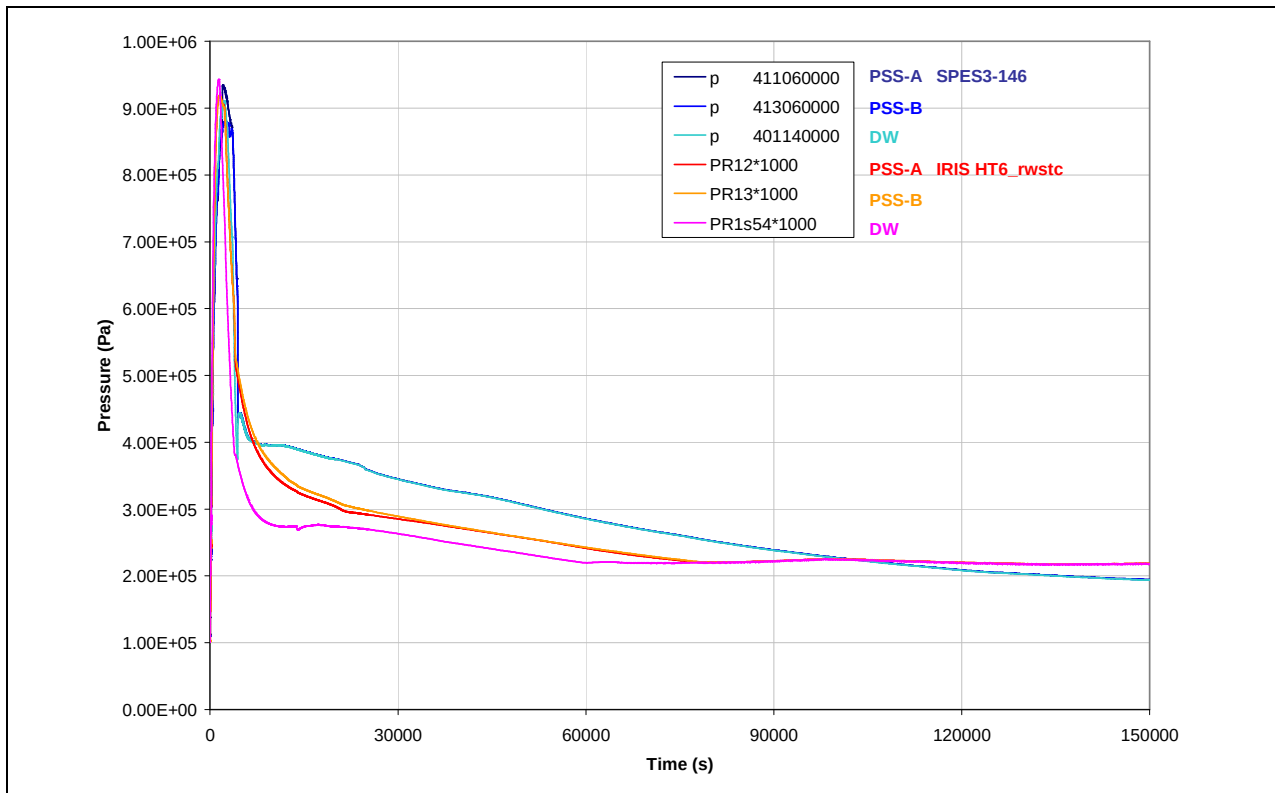
**Fig.8. 22 – SPES3-146 and IRIS HT6\_rwstc LGMS pressure**



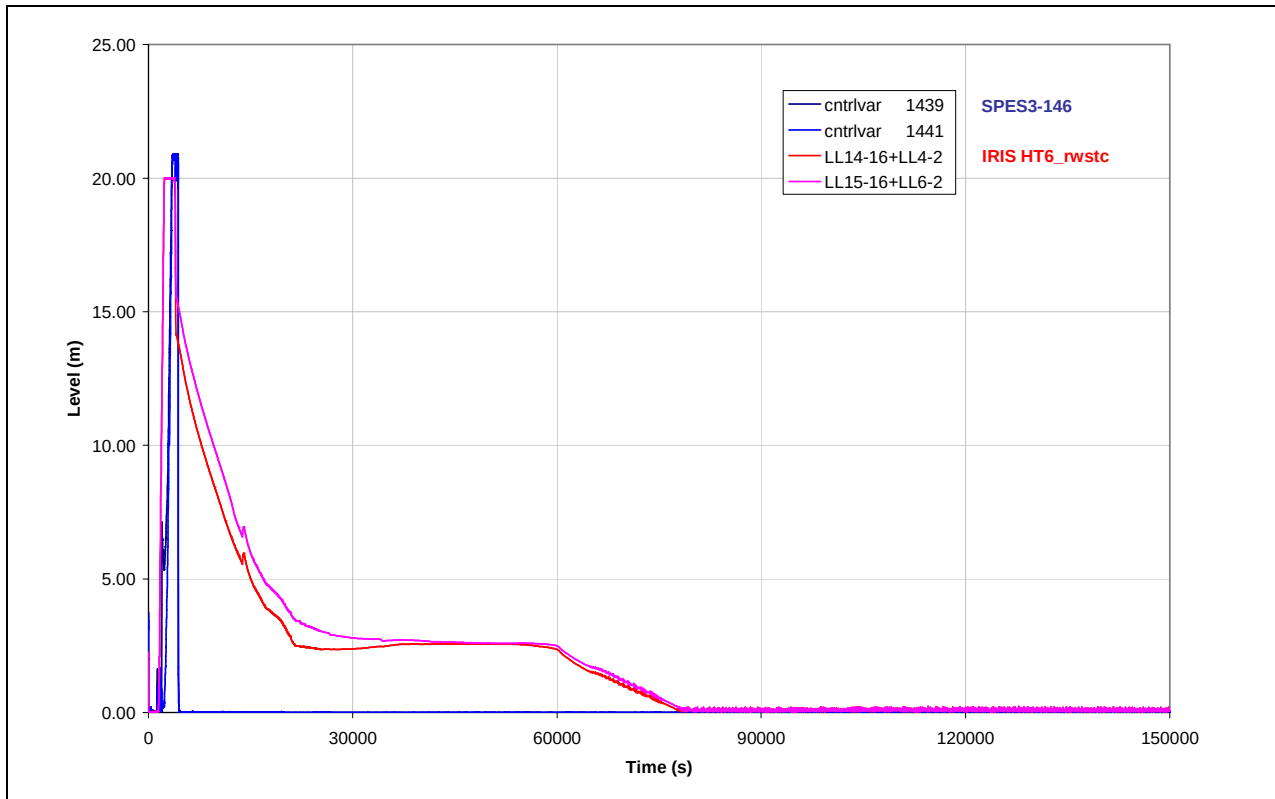
**Fig.8. 23 – SPES3-146 and IRIS HT6\_rwstc DW and PSS pressure (window)**



**Fig.8. 24 – SPES3-146 and IRIS HT6\_rwstc DW and PSS pressure**



**Fig.8. 25 – SPES3-146 and IRIS HT6\_rwstc PSS to DW pipe level**



**Fig.8. 26 – SPES3-146 and IRIS HT6\_rwstc RC level (window)**

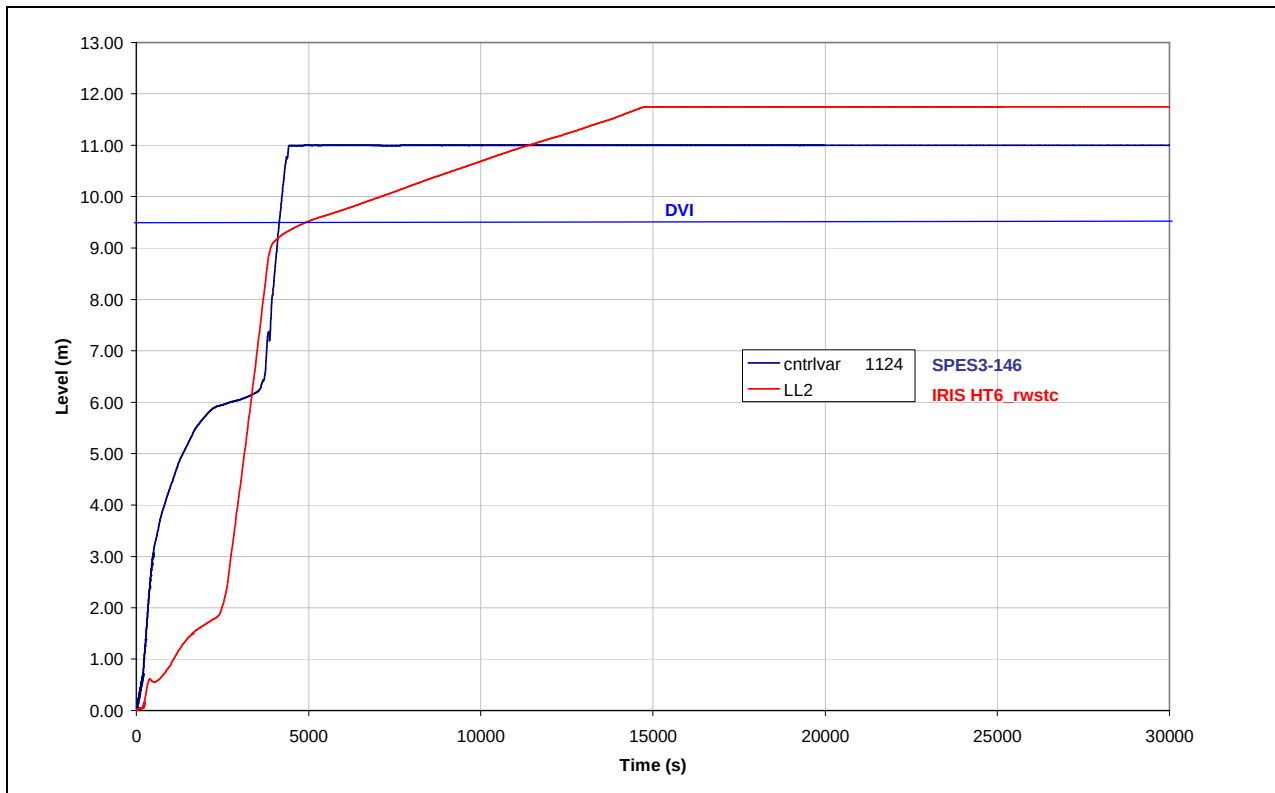


Fig.8. 27 – SPES3-146 and IRIS HT6\_rwstc DW level

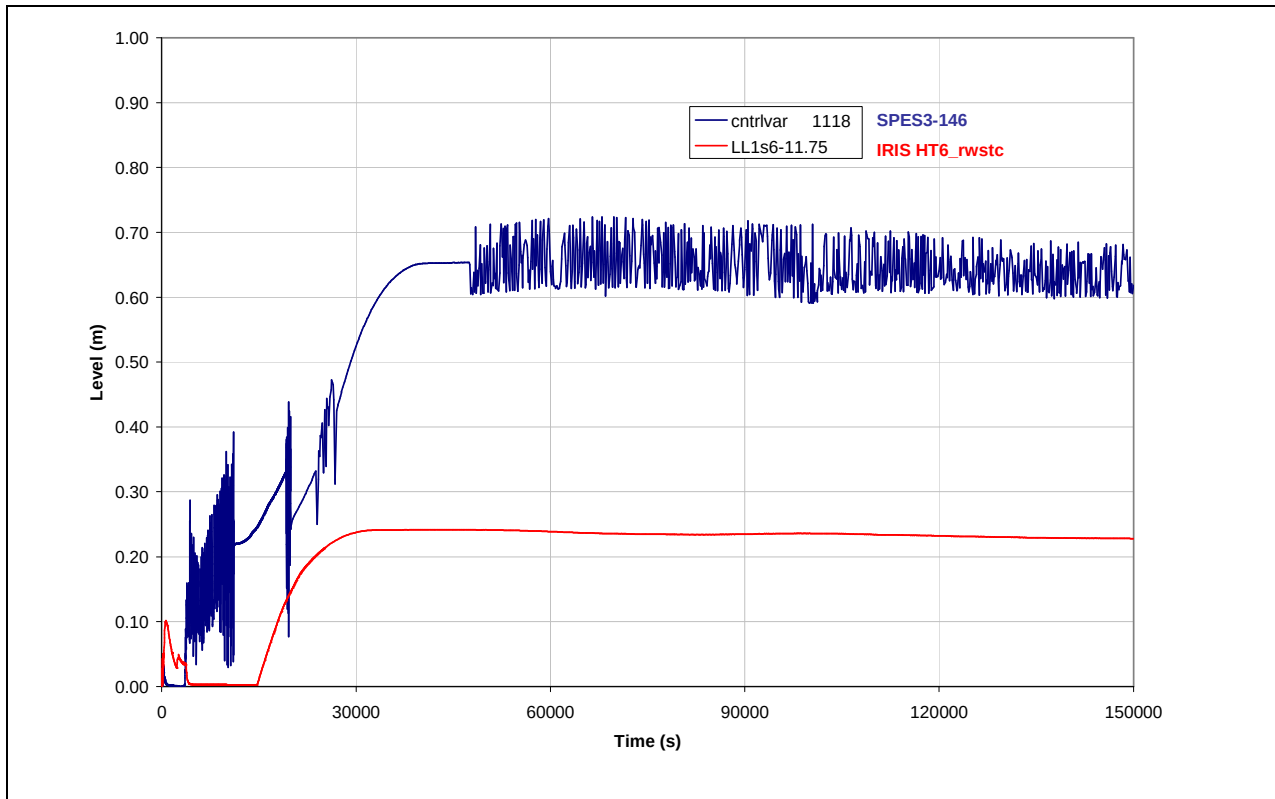


Fig.8. 28 – SPES3-146 and IRIS HT6\_rwstc PSS liquid and gas temperature (window)

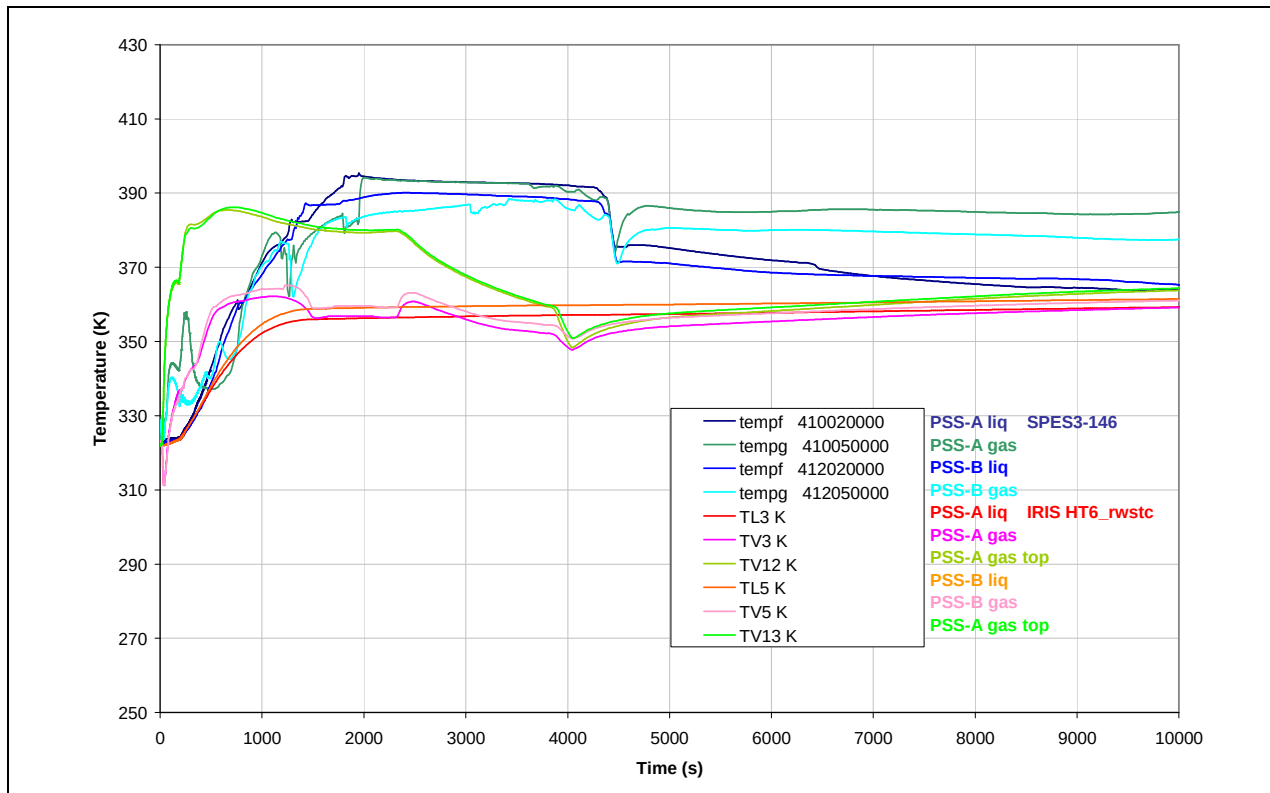


Fig.8. 29 – SPES3-146 and IRIS HT6\_rwstc PSS liquid and gas temperature

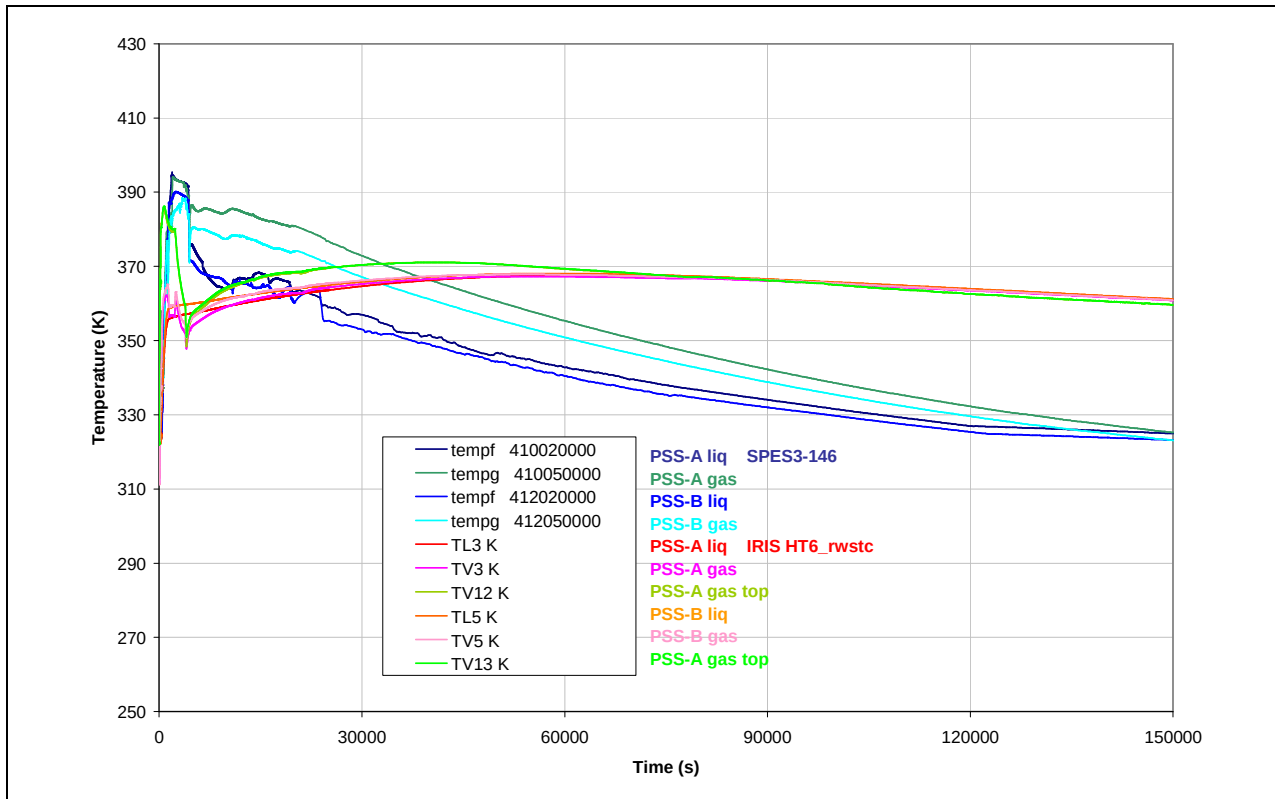
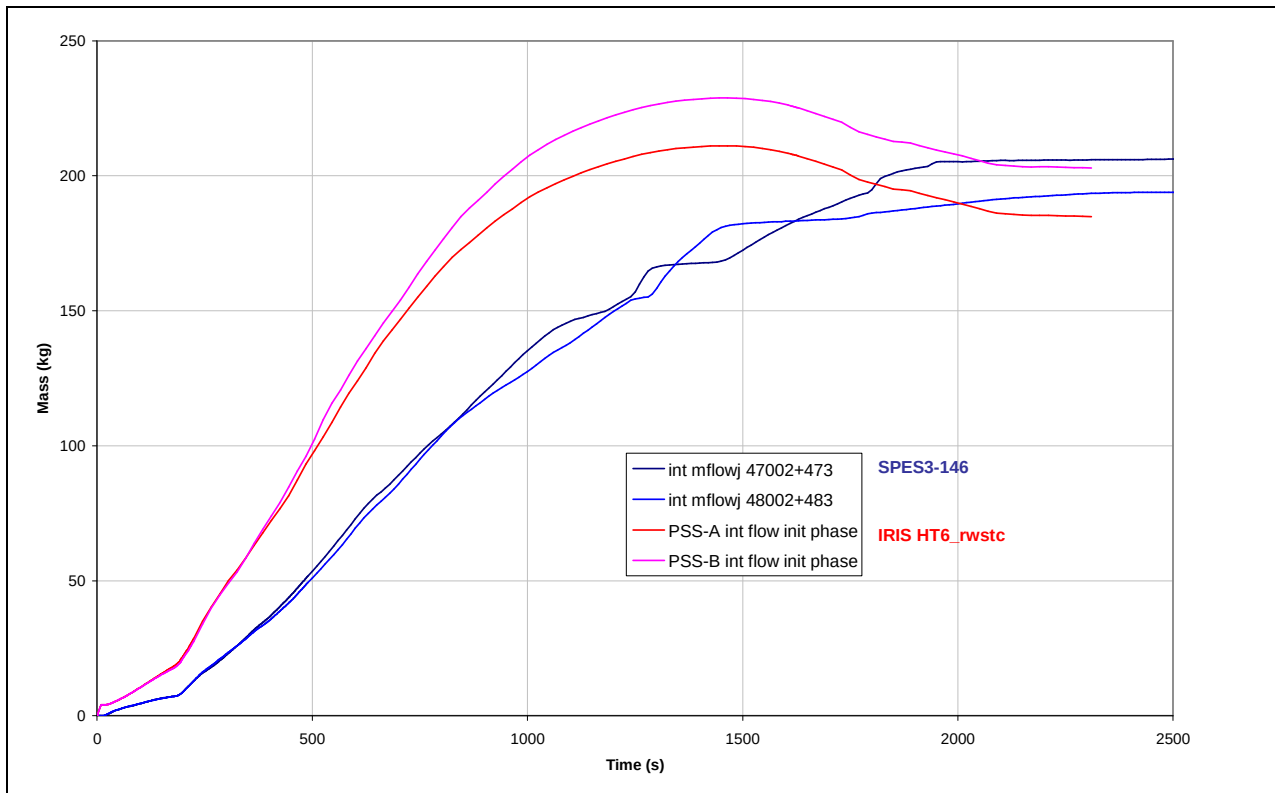
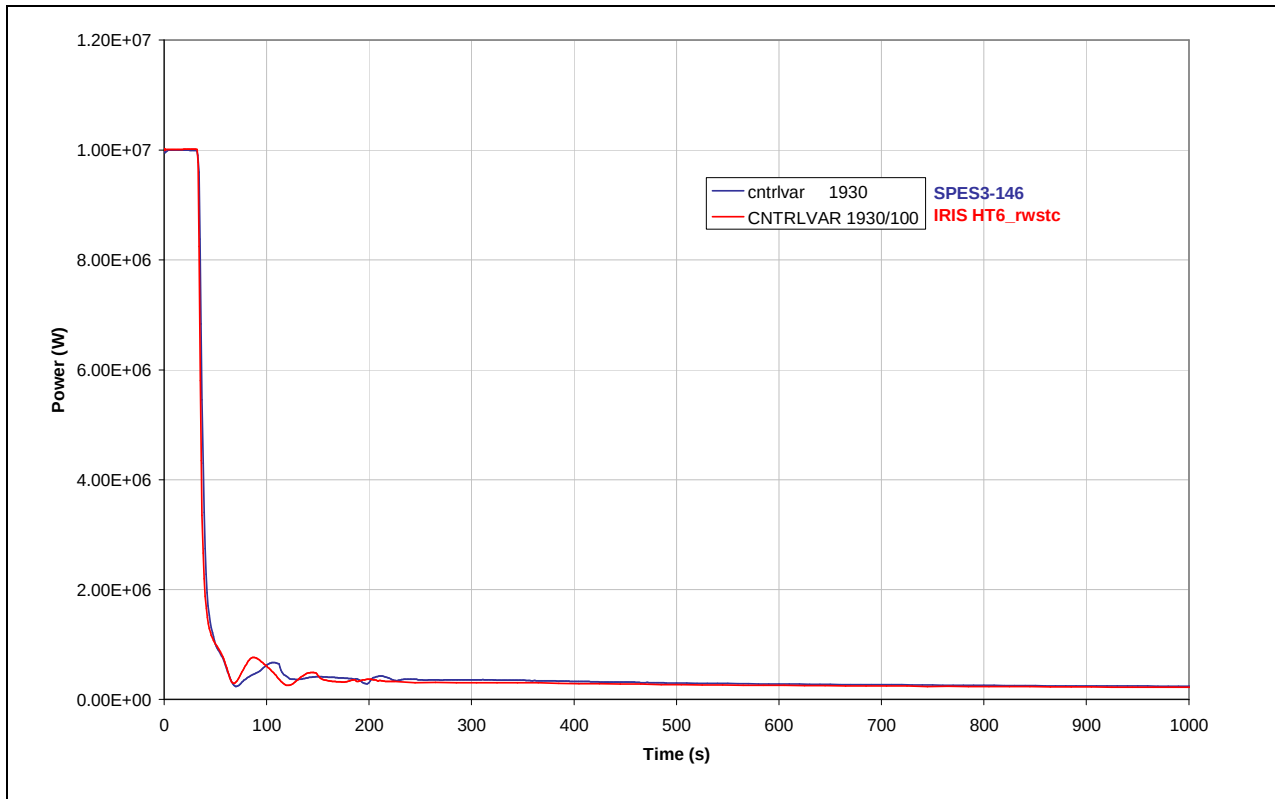


Fig.8. 30 – SPES3-146 and IRIS HT6\_rwstc DW to PSS integral flow (first phase of injection)

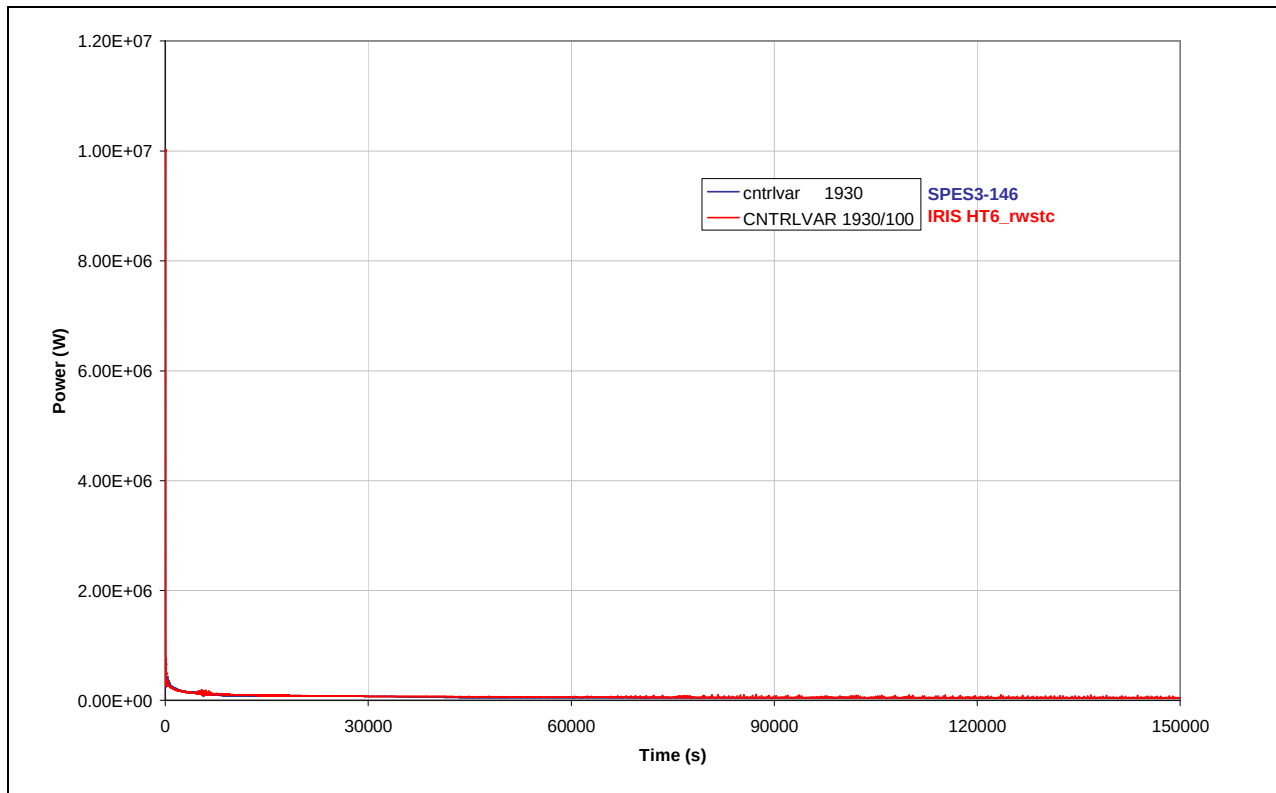




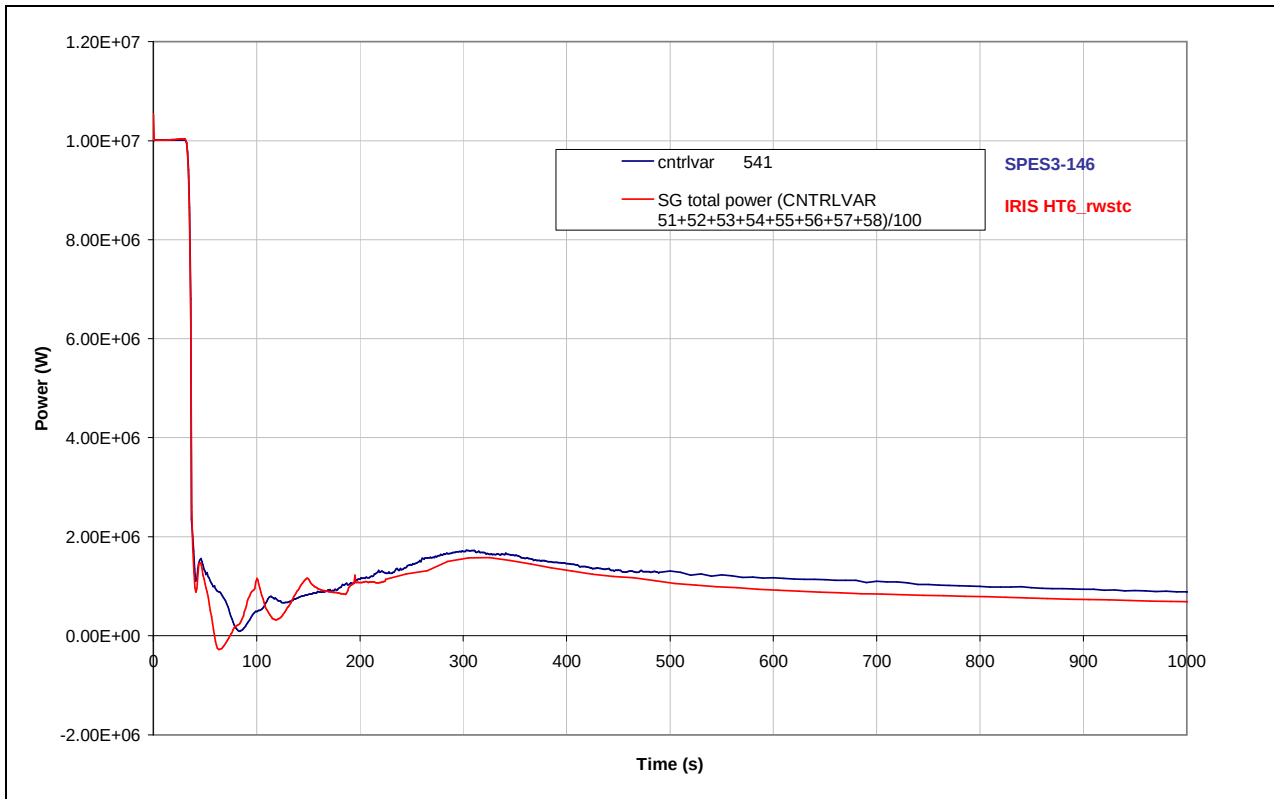
**Fig.8. 31 – SPES3-146 and IRIS HT6\_rwstc core power (window)**



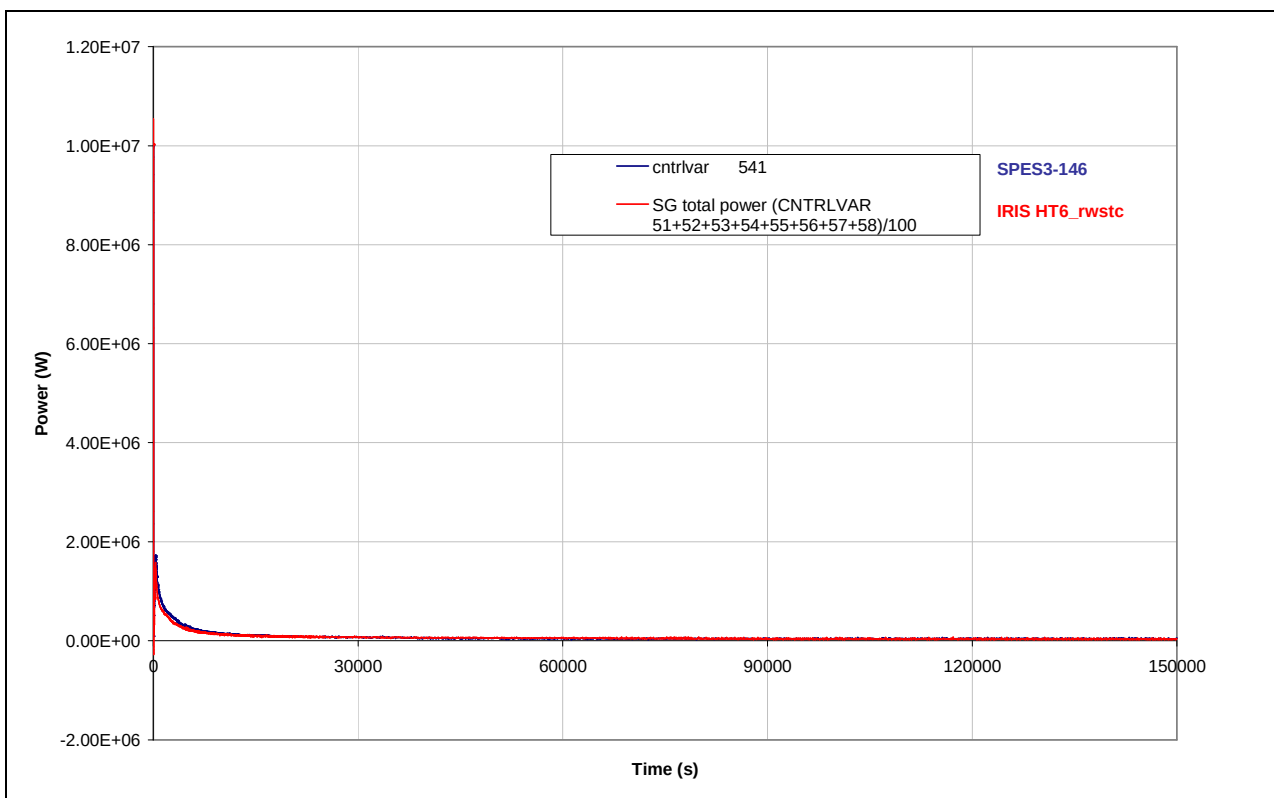
**Fig.8. 32 – SPES3-146 and IRIS HT6\_rwstc core power**



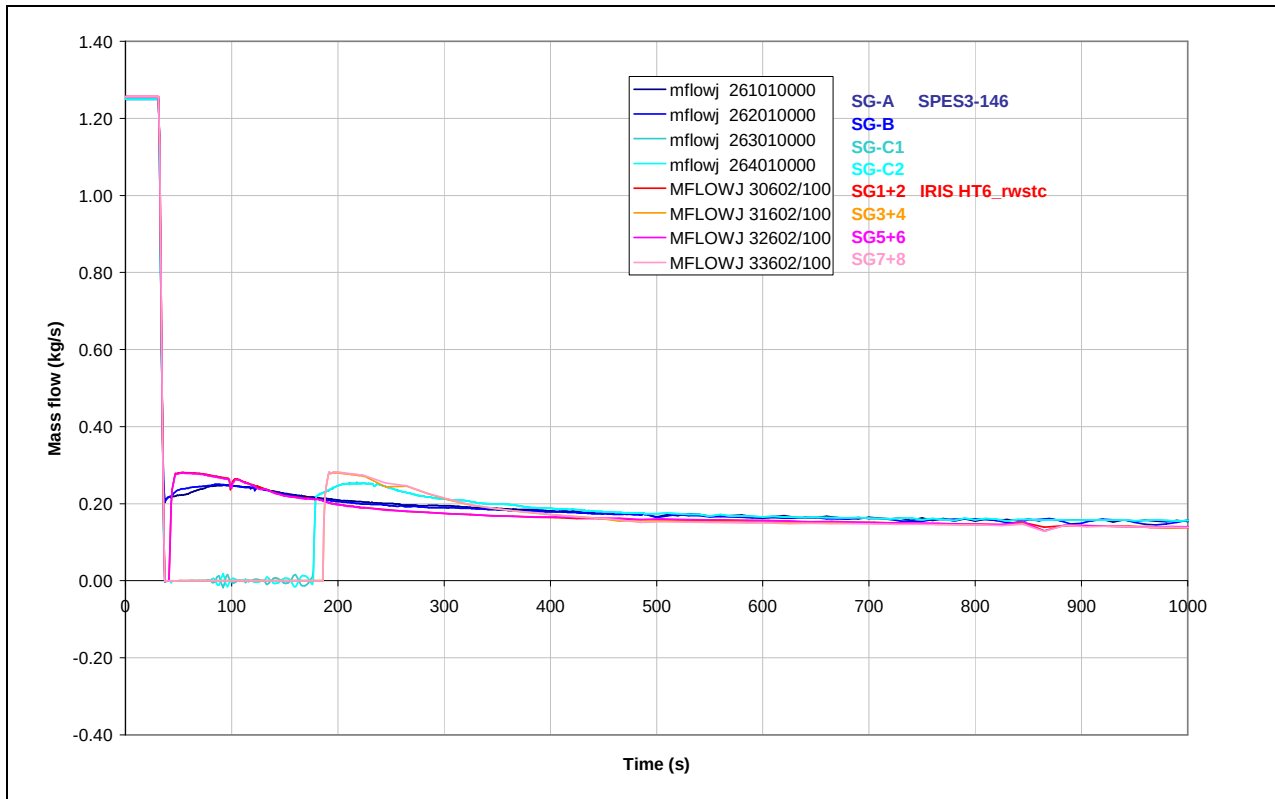
**Fig.8. 33 – SPES3-146 and IRIS HT6\_rwstc SG power (window)**



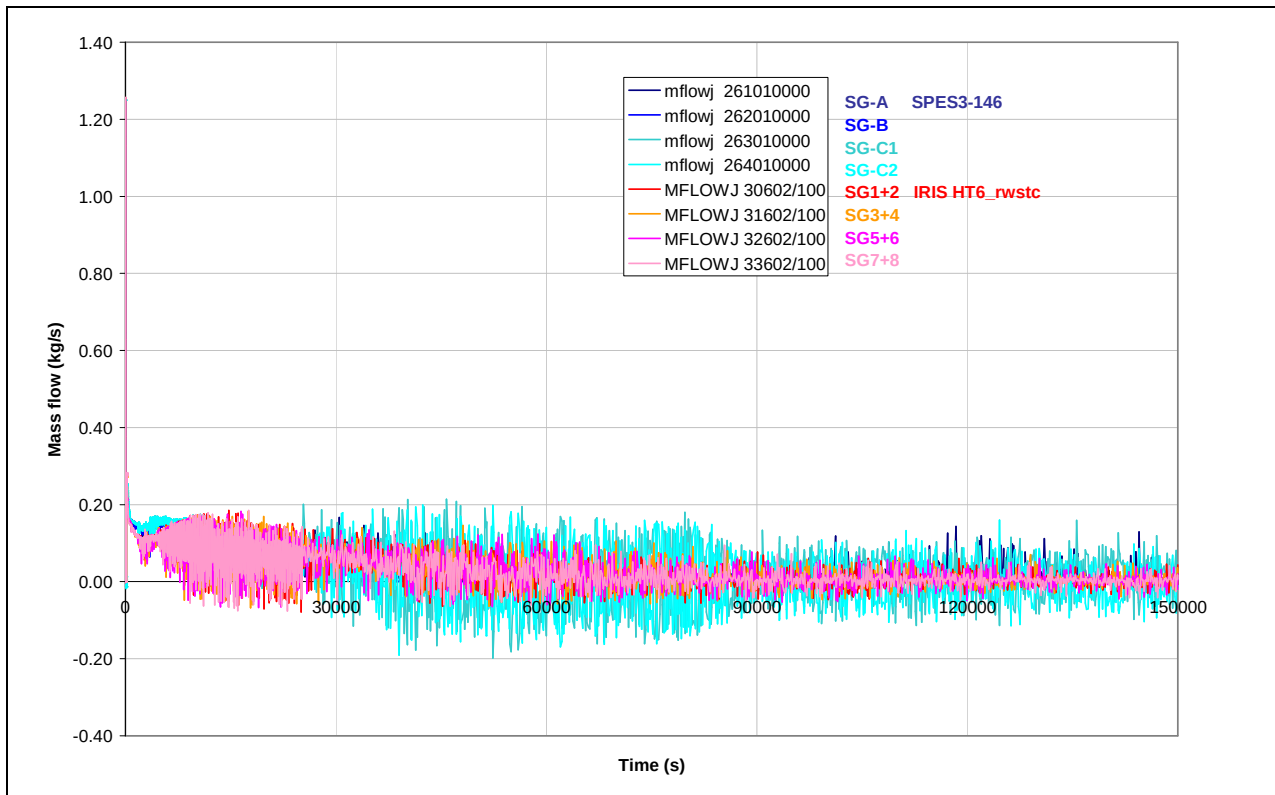
**Fig.8. 34 – SPES3-146 and IRIS HT6\_rwstc SG power**



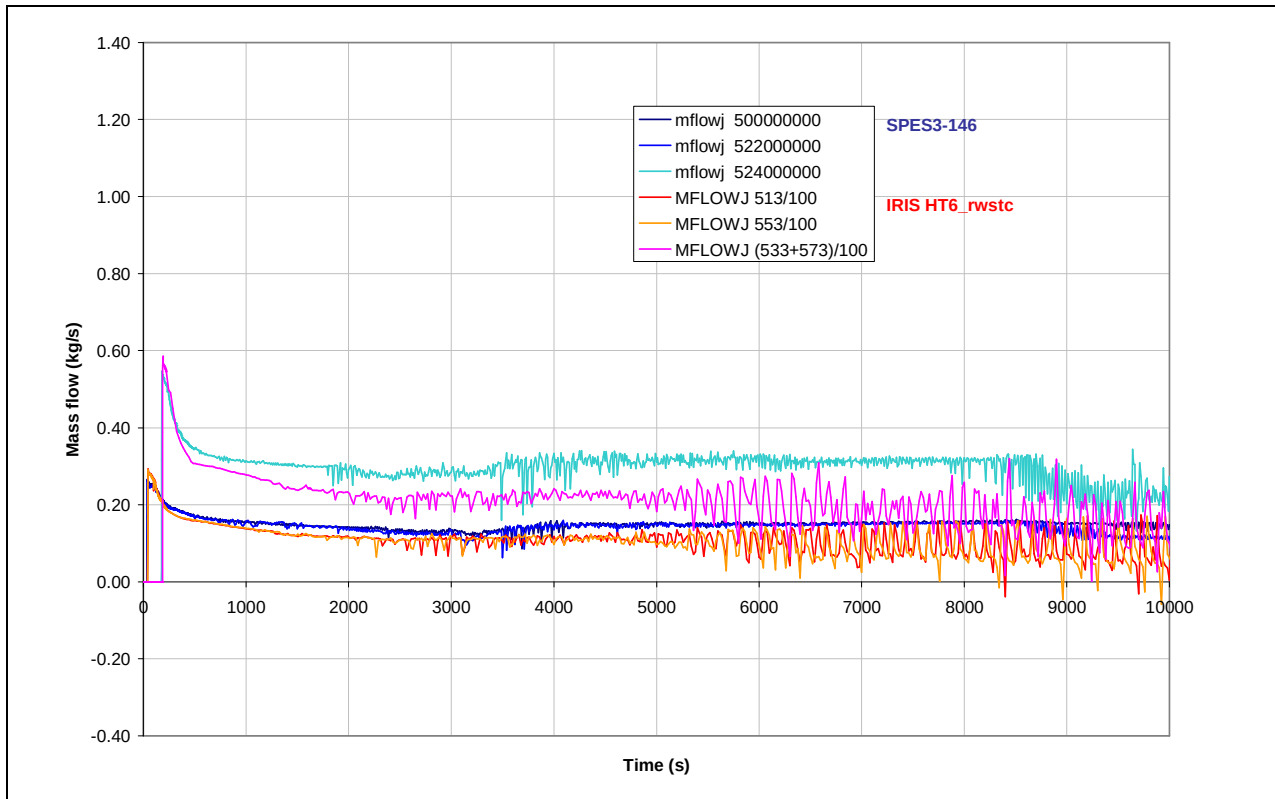
**Fig.8. 35 – SPES3-146 and IRIS HT6\_rwstc SG ss mass flow (window)**



**Fig.8. 36 – SPES3-146 and IRIS HT6\_rwstc SG ss mass flow**



**Fig.8. 37 – SPES3-146 and IRIS HT6\_rwstc EHRS cold leg mass flow (window)**



**Fig.8. 38 – SPES3-146 and IRIS HT6\_rwstc EHRS cold leg mass flow**

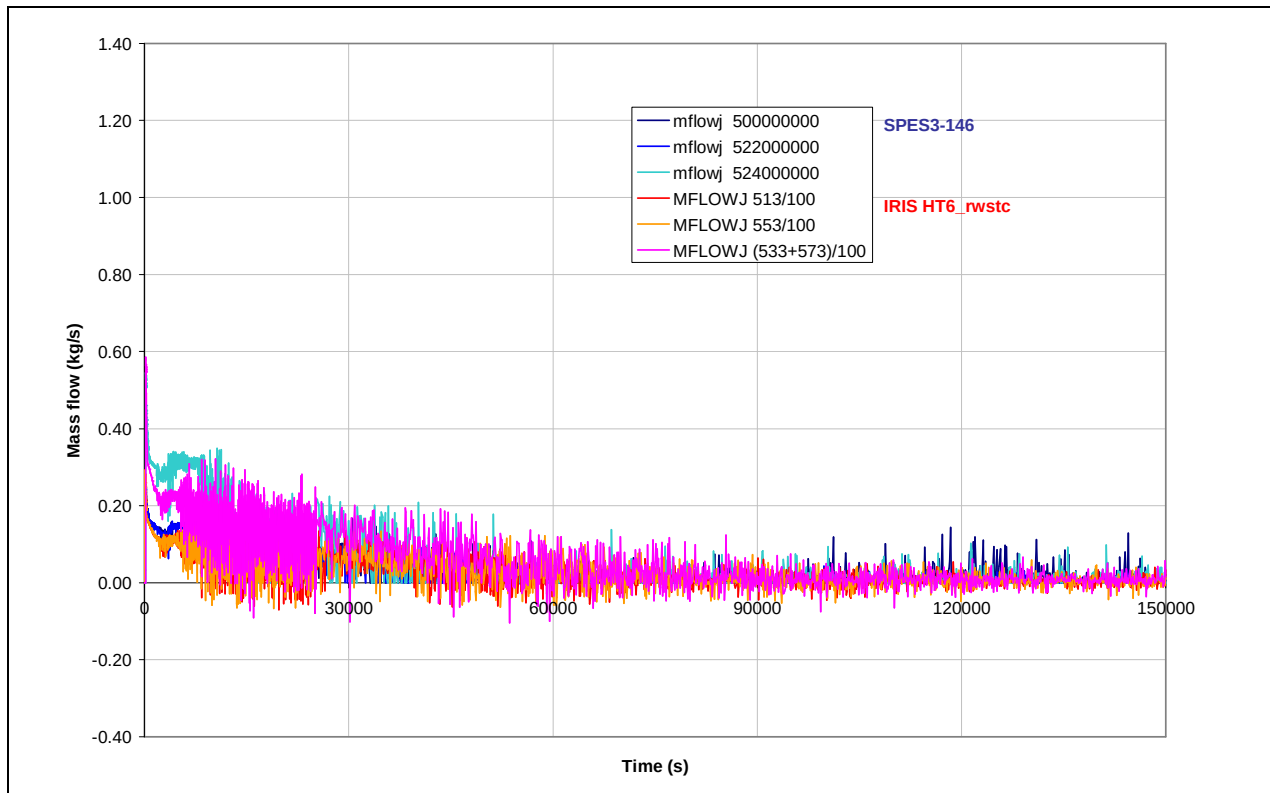


Fig.8. 39 – SPES3-146 and IRIS HT6\_rwstc EHRS power (window)

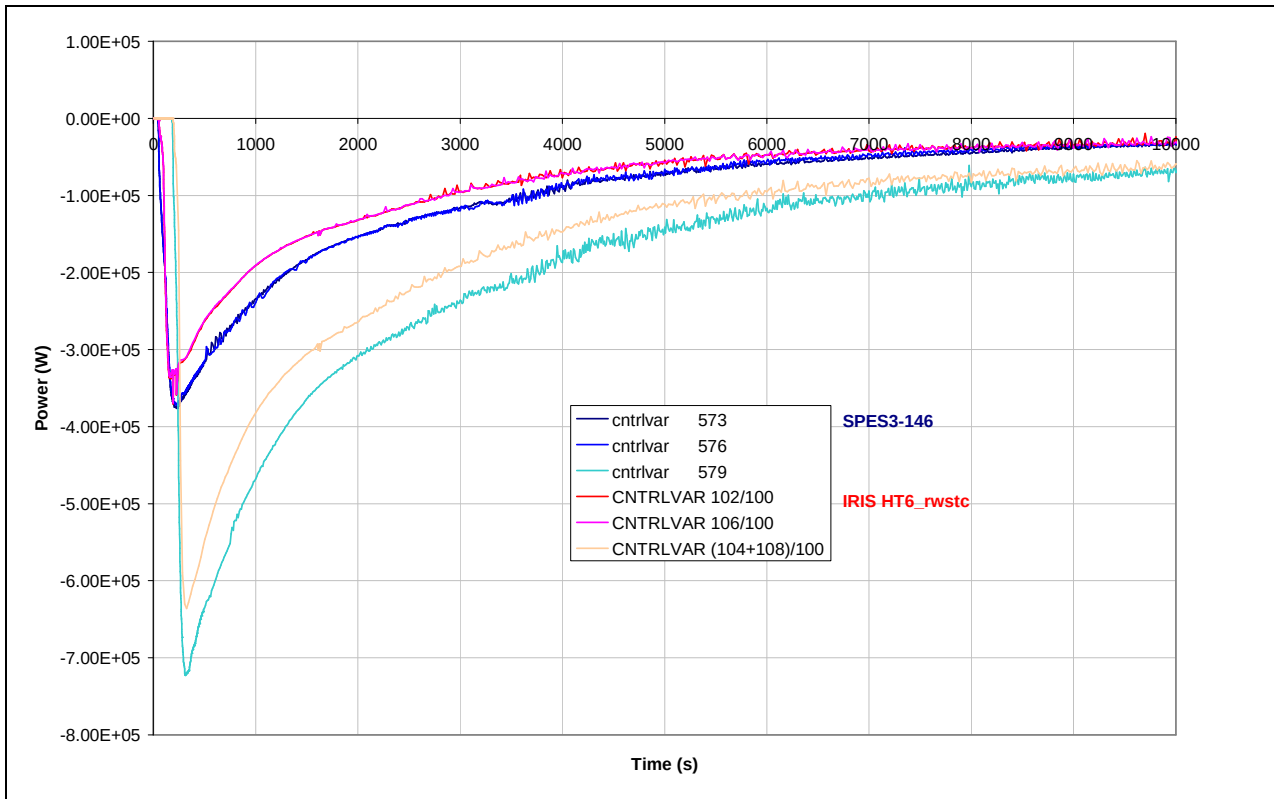
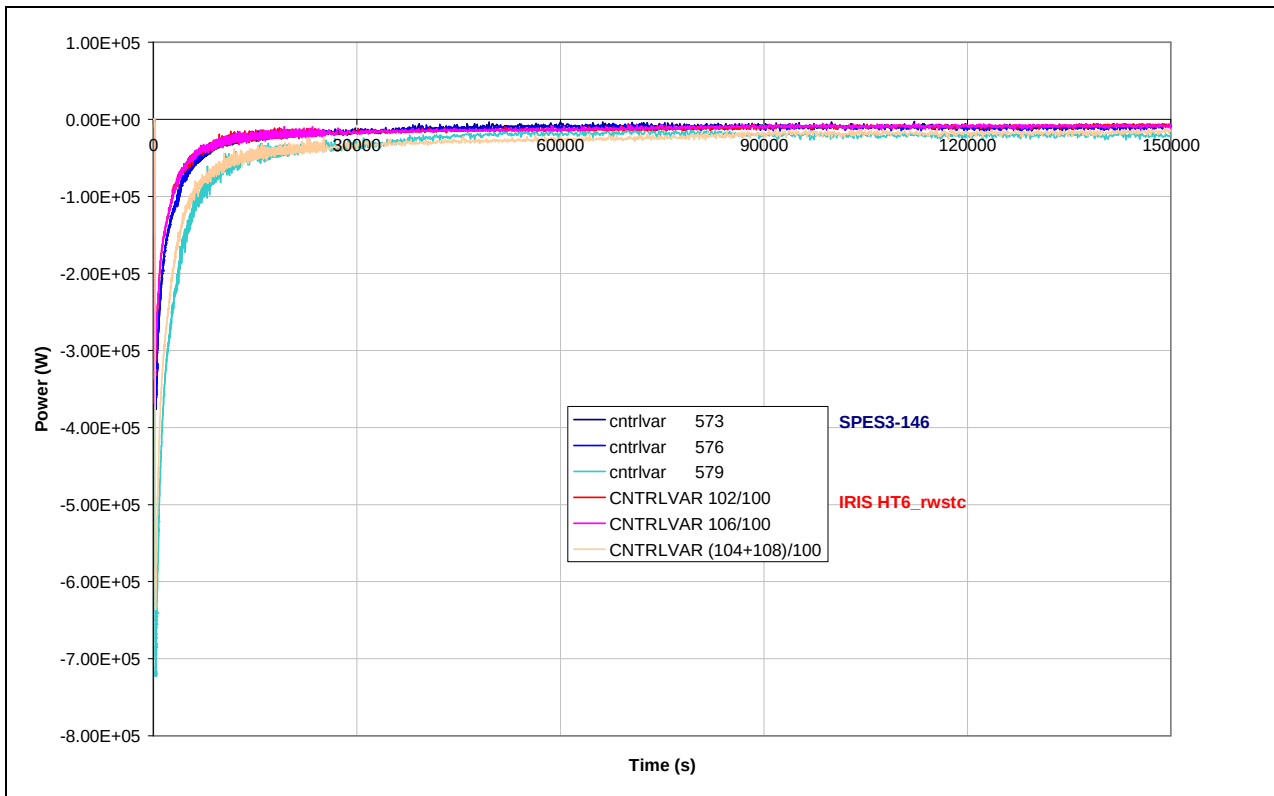
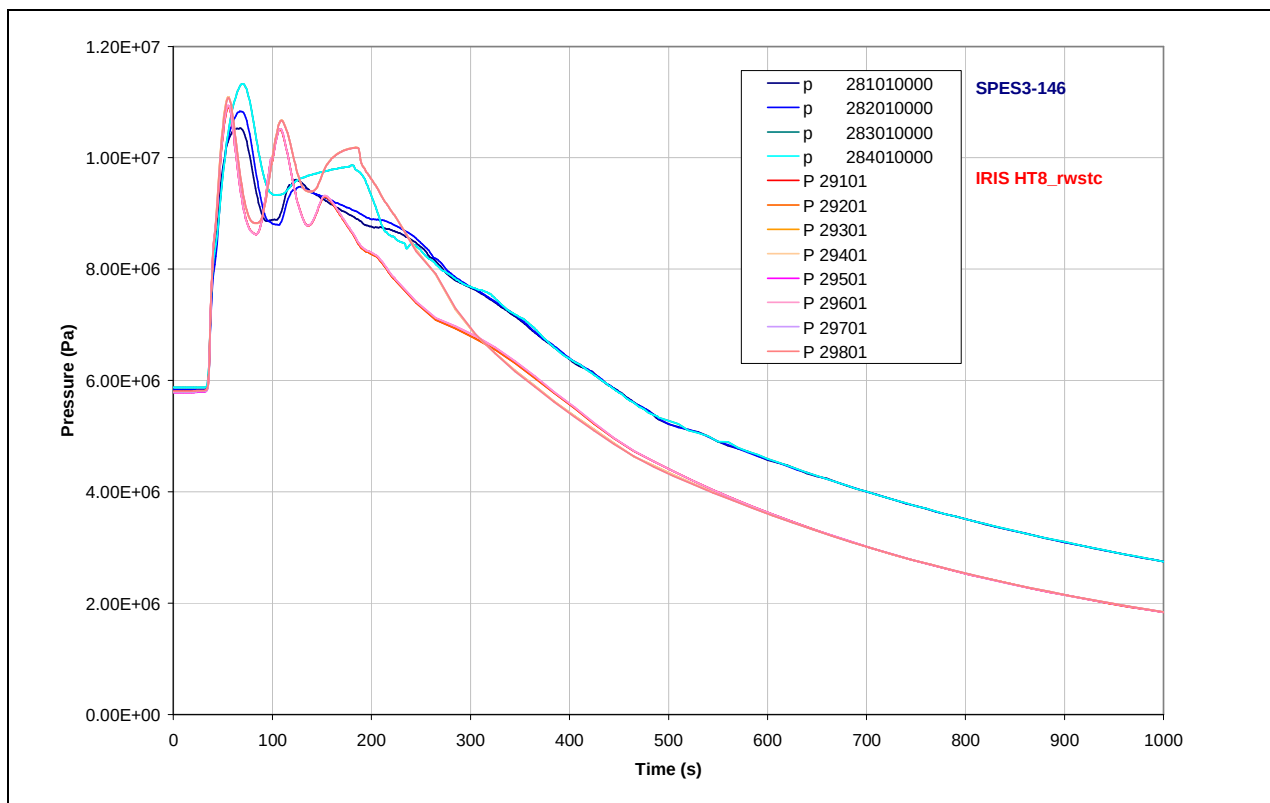


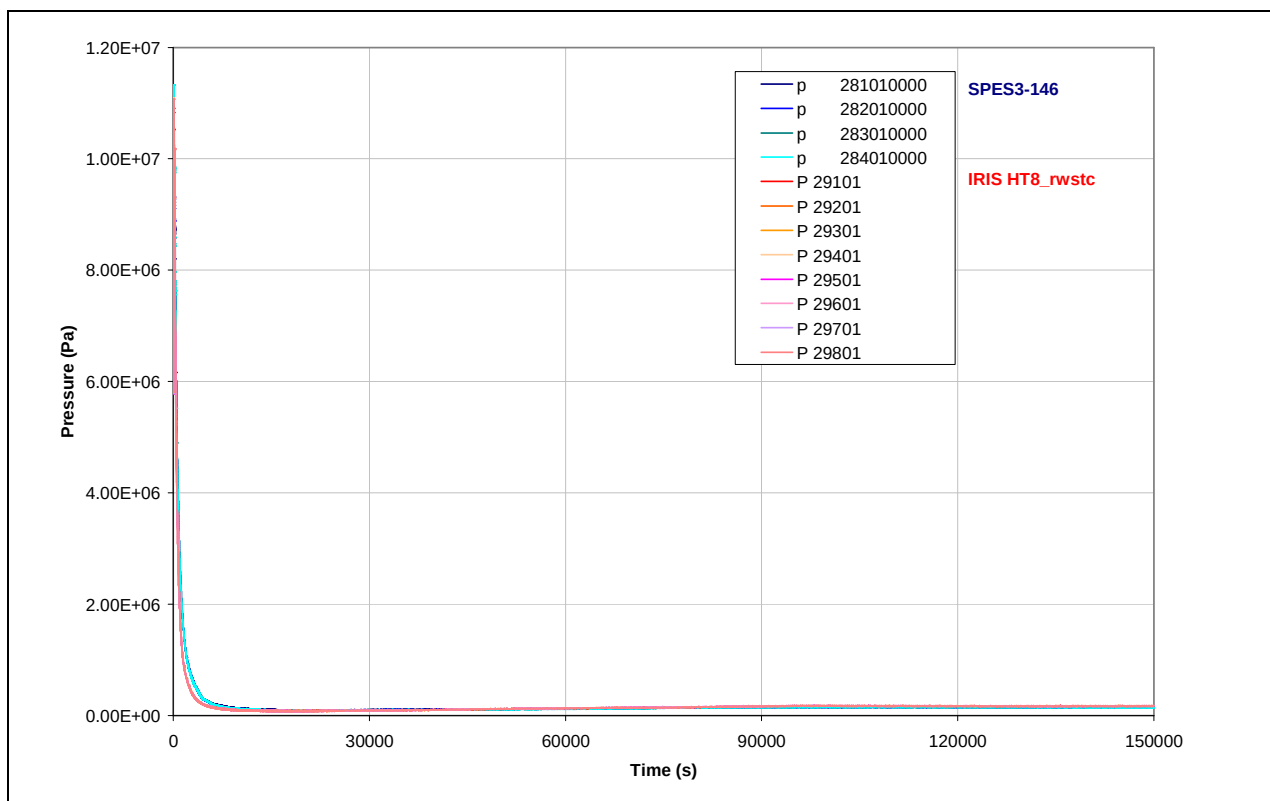
Fig.8. 40 – SPES3-146 and IRIS HT6\_rwstc EHRS power



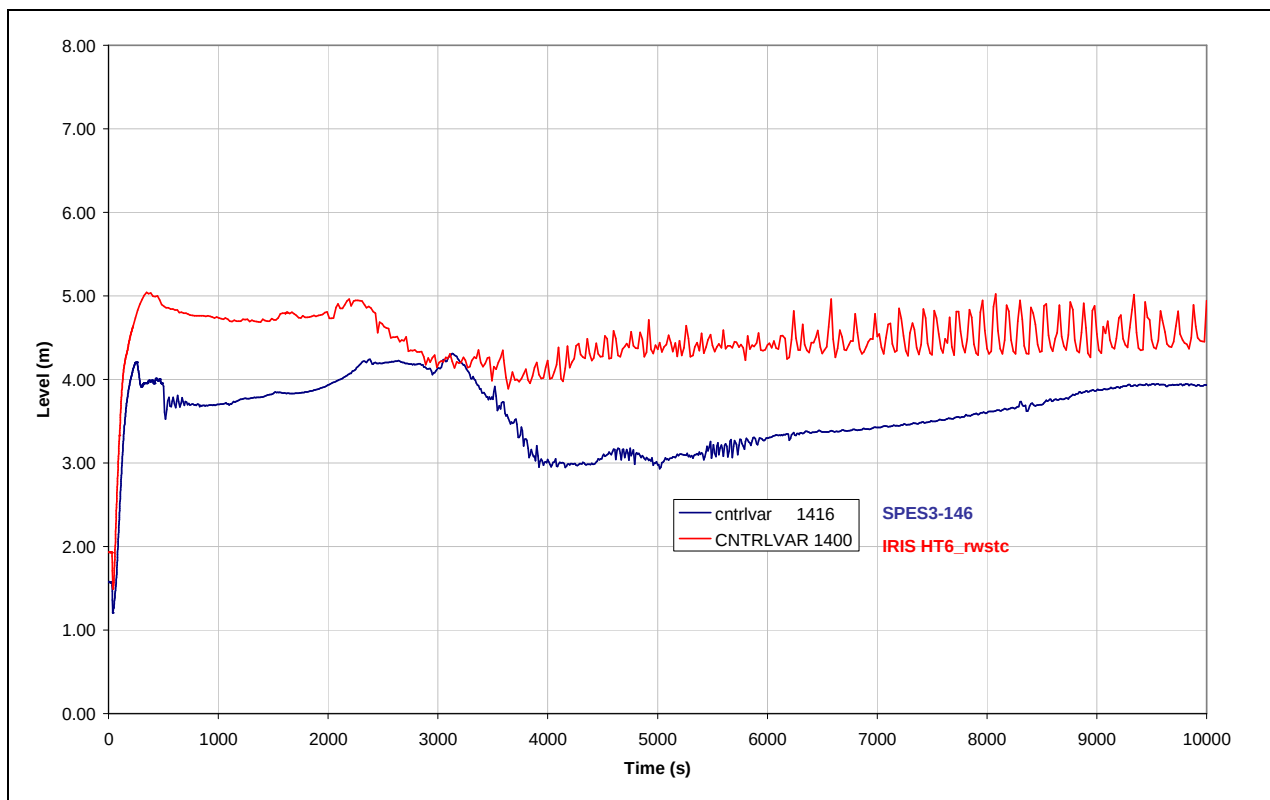
**Fig.8. 41 – SPES3-146 and IRIS HT6\_rwstc SG ss outlet pressure (window)**



**Fig.8. 42 – SPES3-146 and IRIS HT6\_rwstc SG ss outlet pressure**



**Fig.8. 43 – SPES3-146 and IRIS HT6\_rwstc SG-1ss collapsed level (window)**



**Fig.8. 44 – SPES3-146 and IRIS HT6\_rwstc SG-1ss collapsed level**

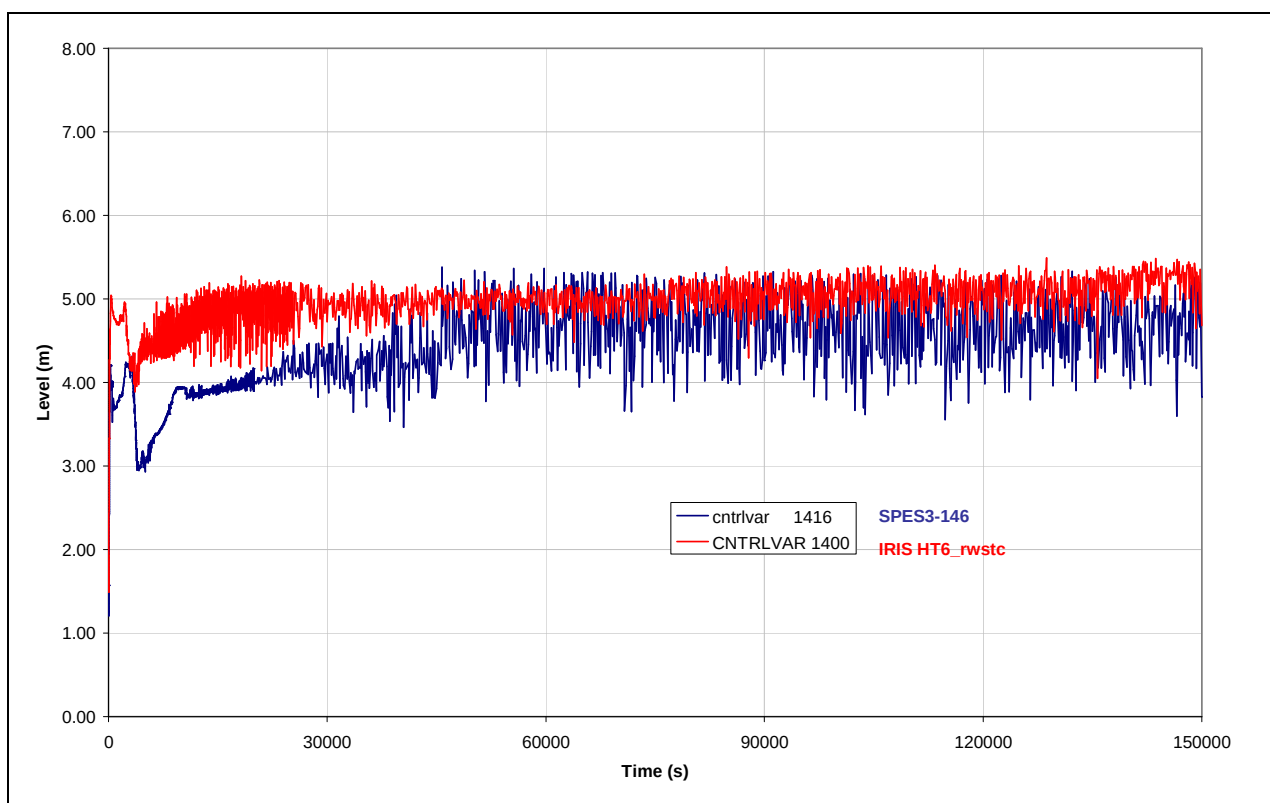


Fig.8. 45 – SPES3-146 and IRIS HT6\_rwstc PRZ level

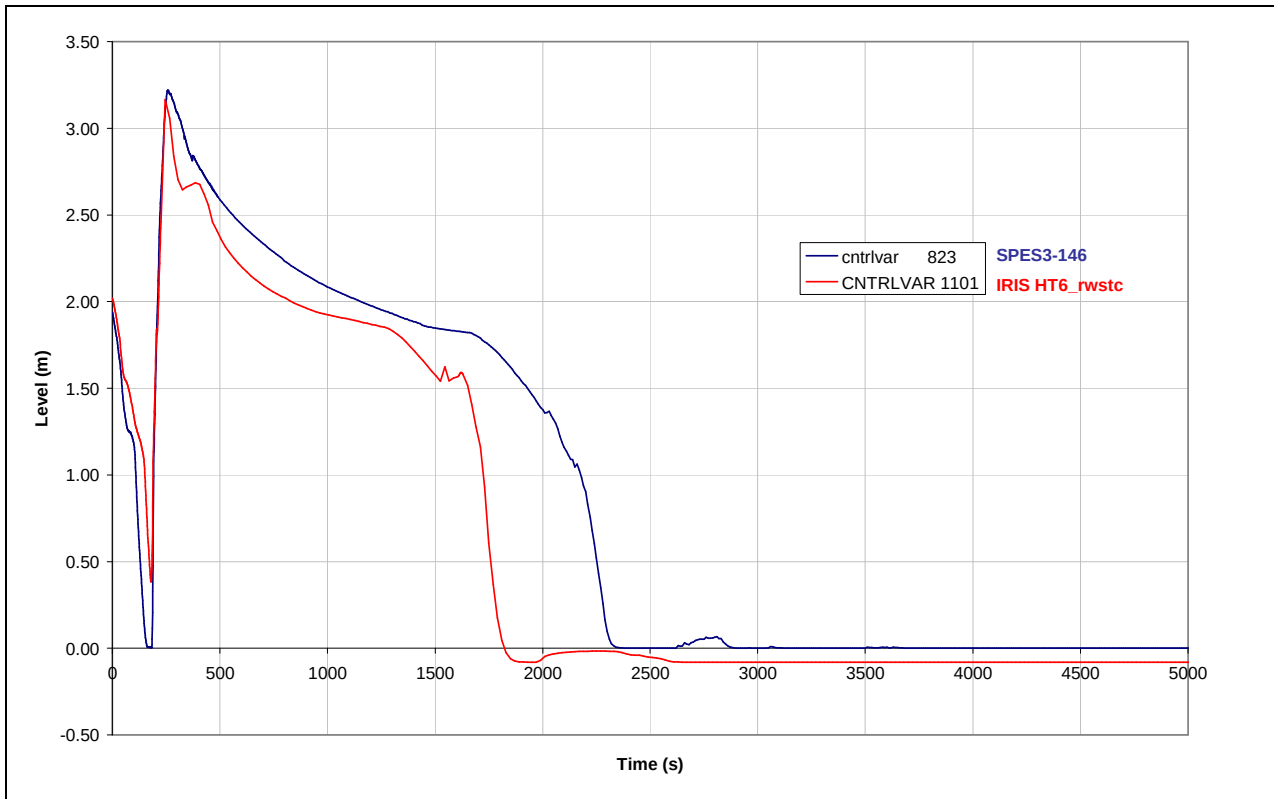
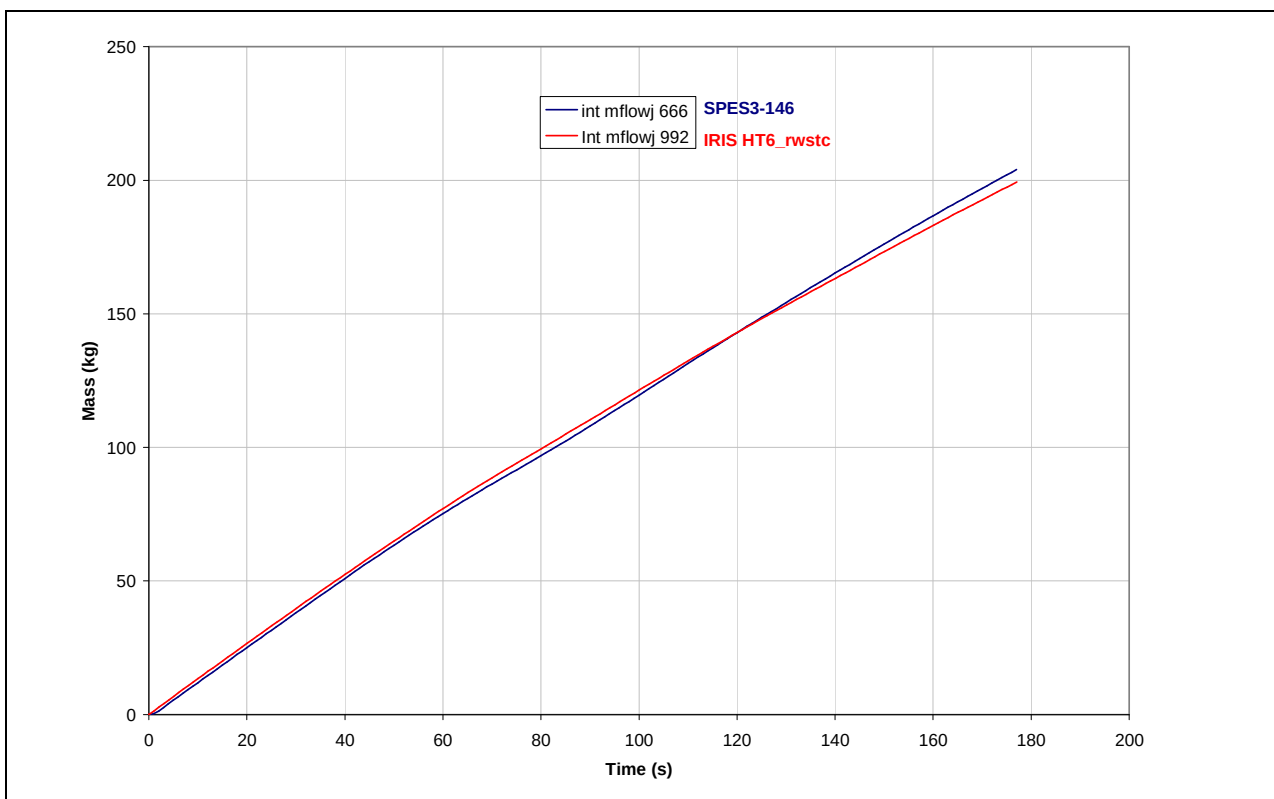
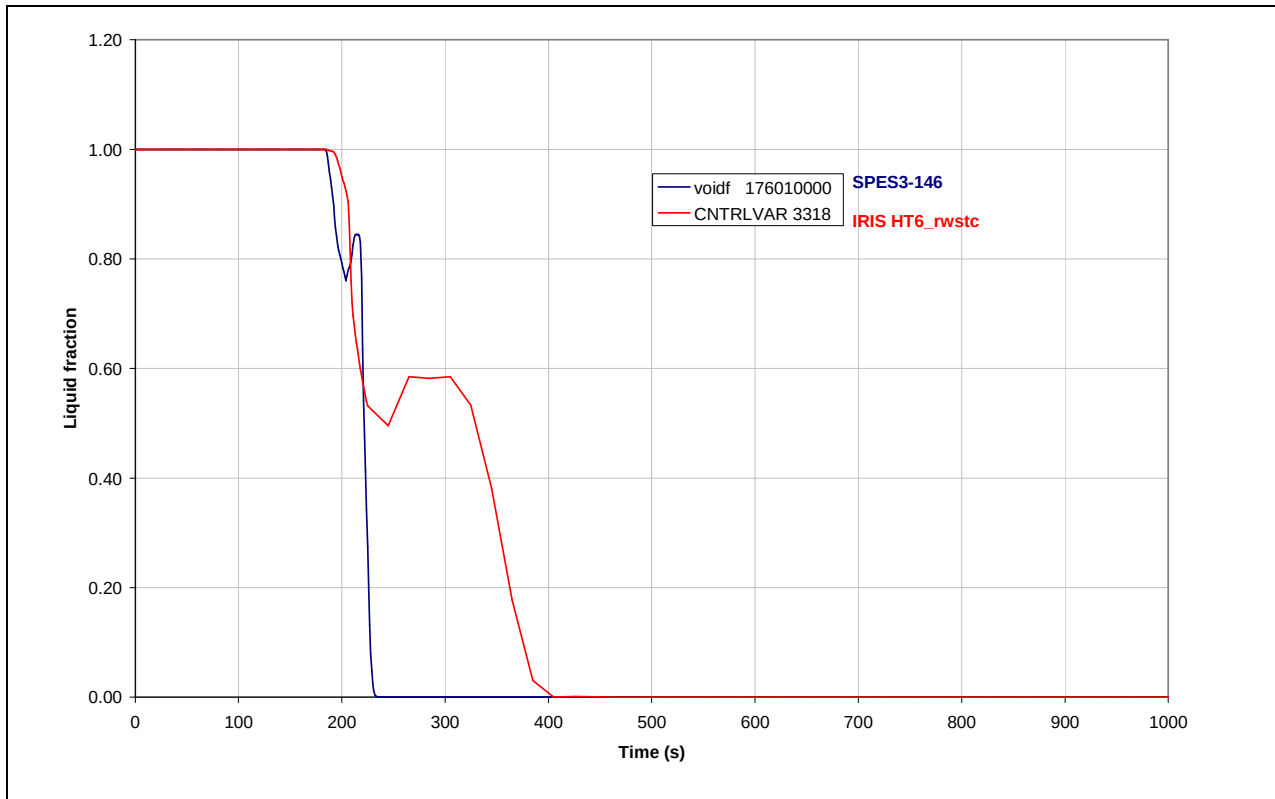


Fig.8. 46 – SPES3-146 and IRIS HT6\_rwstc DVI break SPLIT integral flow

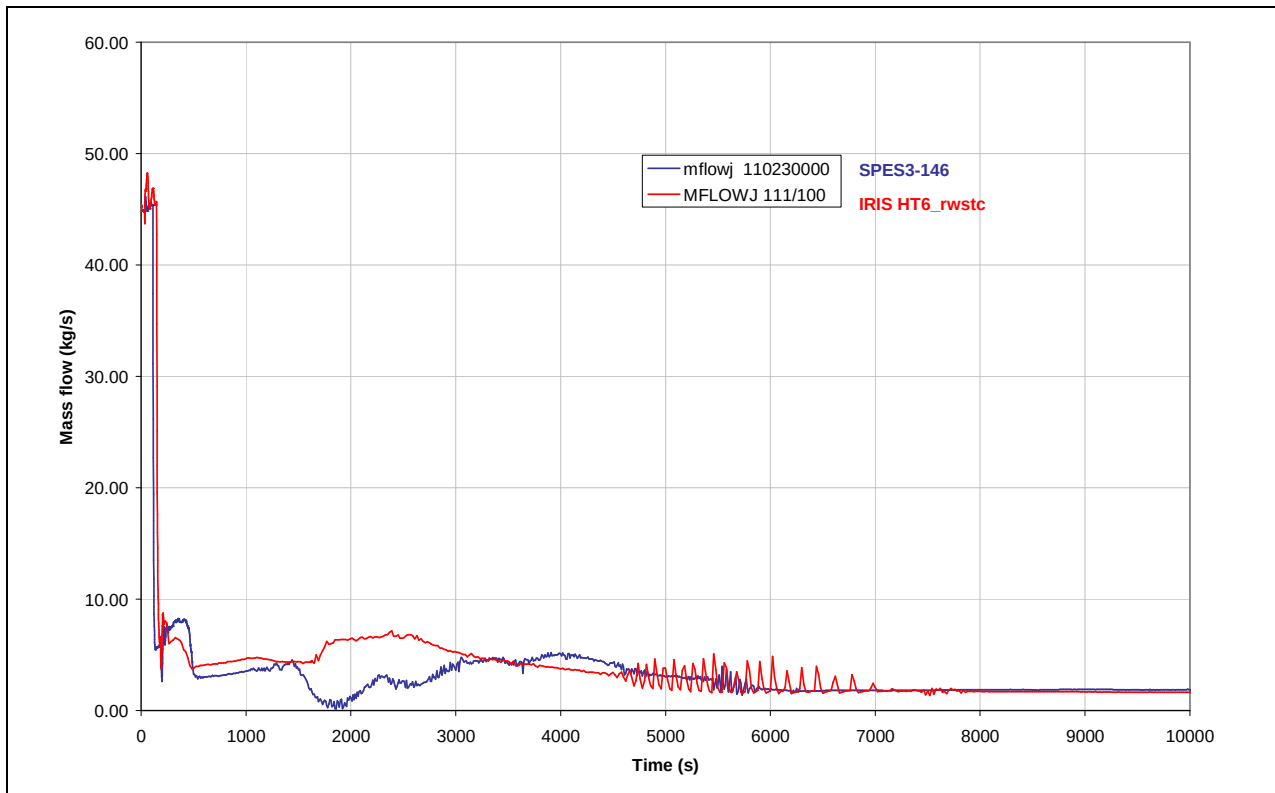




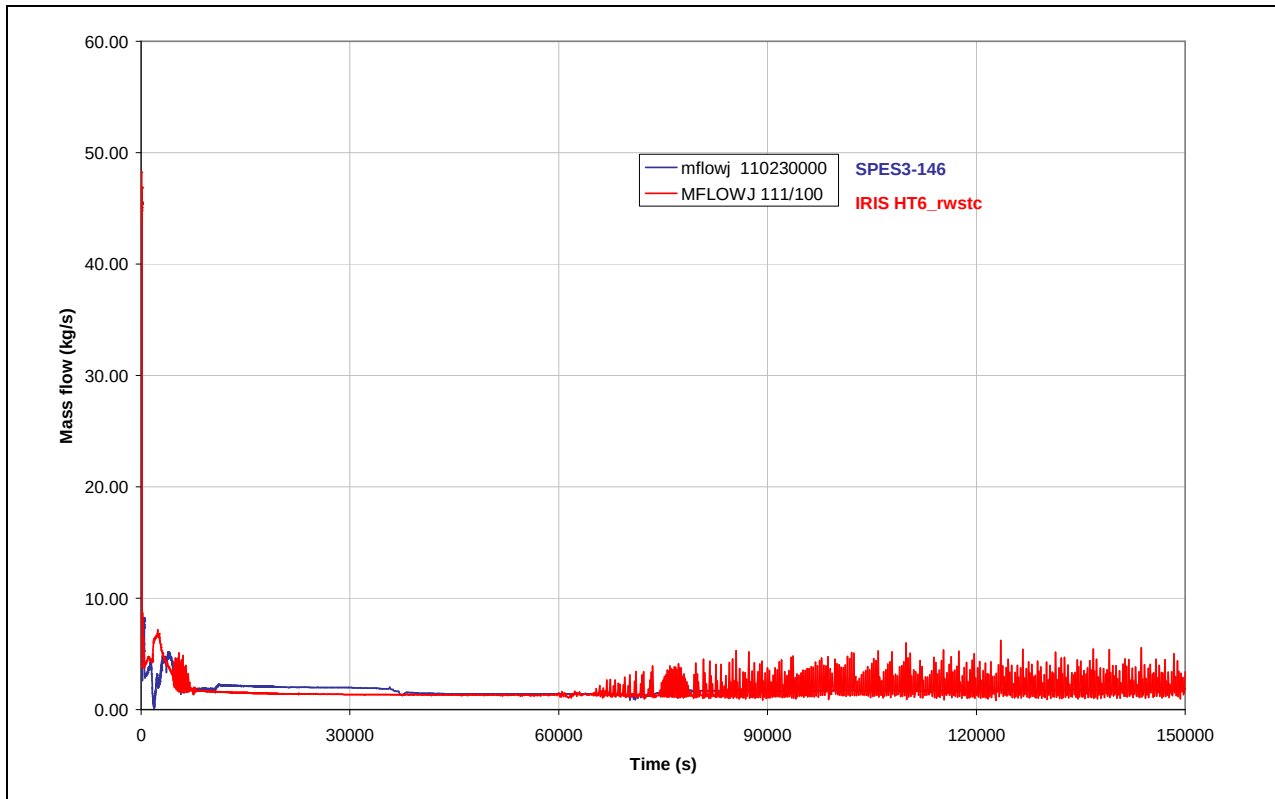
**Fig.8. 47 – SPES3-146 and IRIS HT6\_rwstc pump inlet liquid fraction**



**Fig.8. 48 – SPES3-146 and IRIS HT6\_rwstc core outlet flow (window)**



**Fig.8. 49 – SPES3-146 and IRIS HT6\_rwstc core outlet flow**



**Fig.8. 50 – SPES3-146 and IRIS HT6\_rwstc RI-DC check valve mass flow (window)**

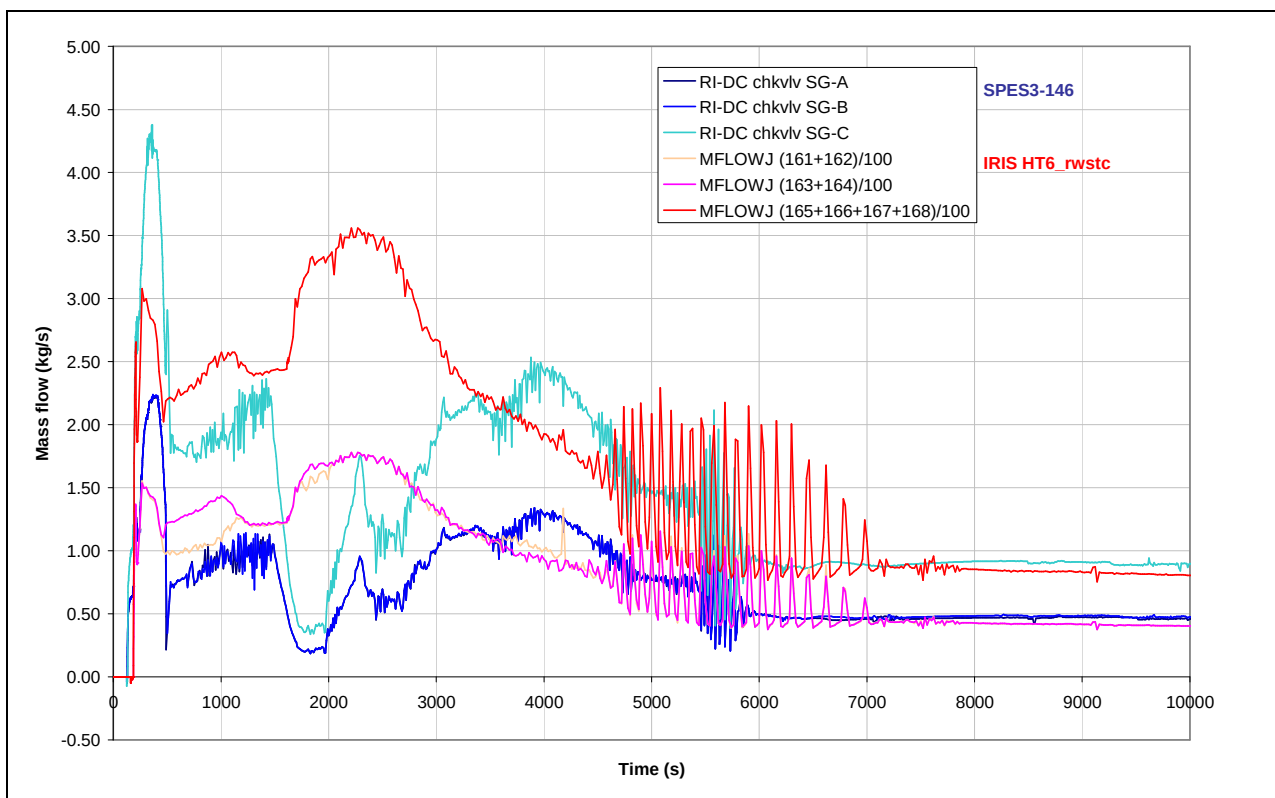


Fig.8. 51 – SPES3-146 and IRIS HT6\_rwstc RI-DC check valve mass flow

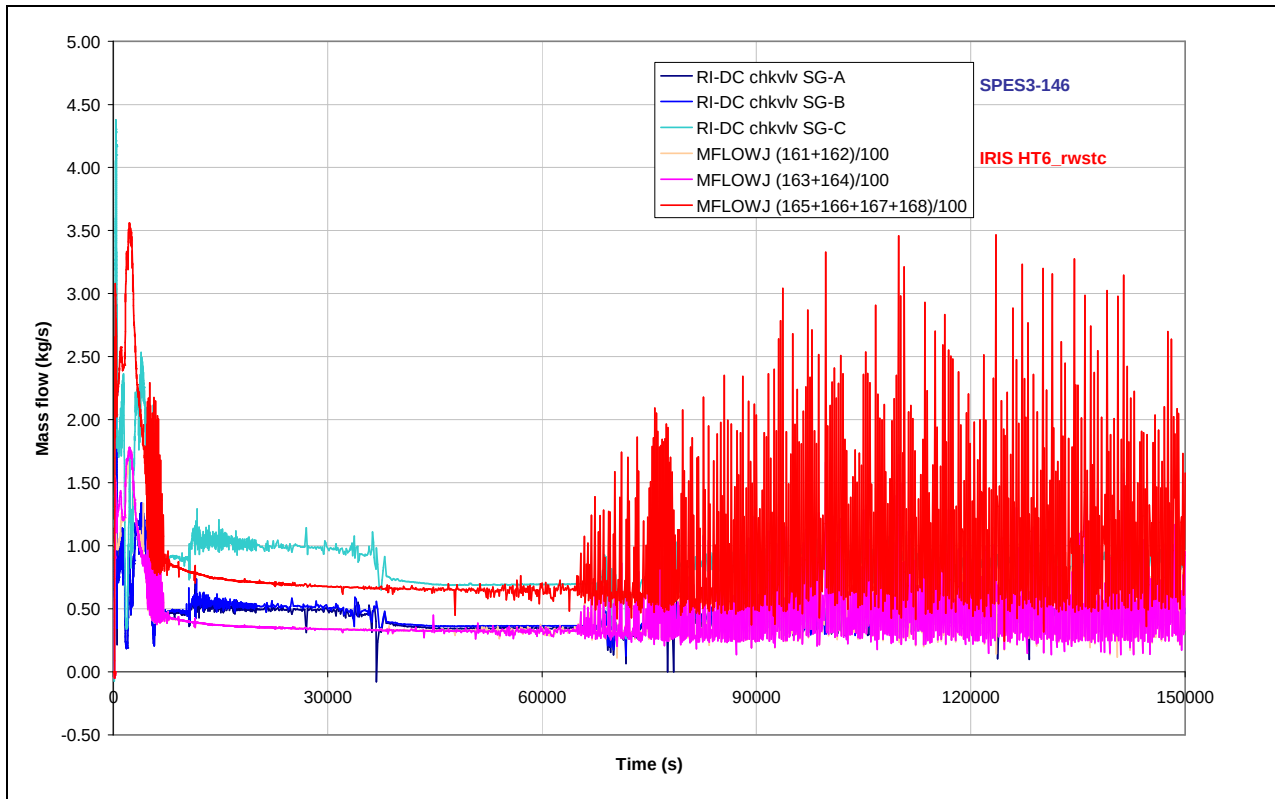
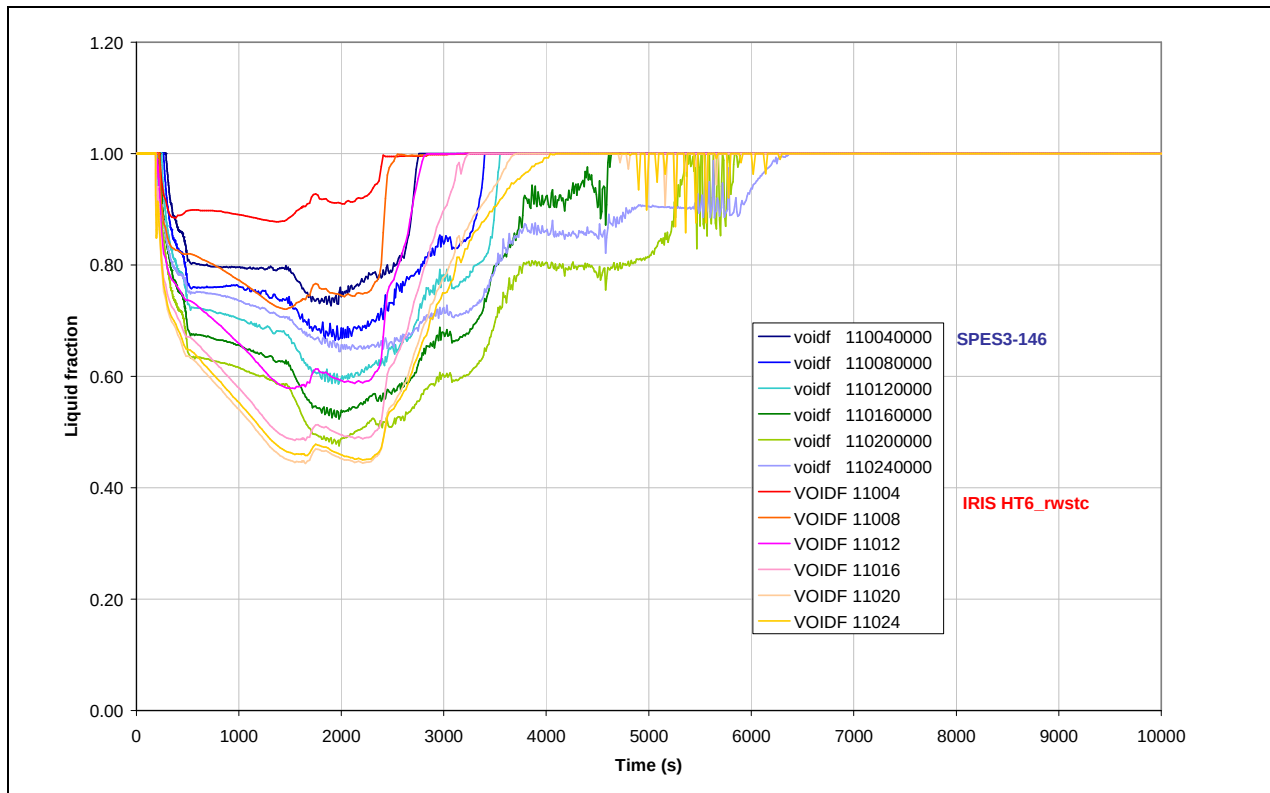
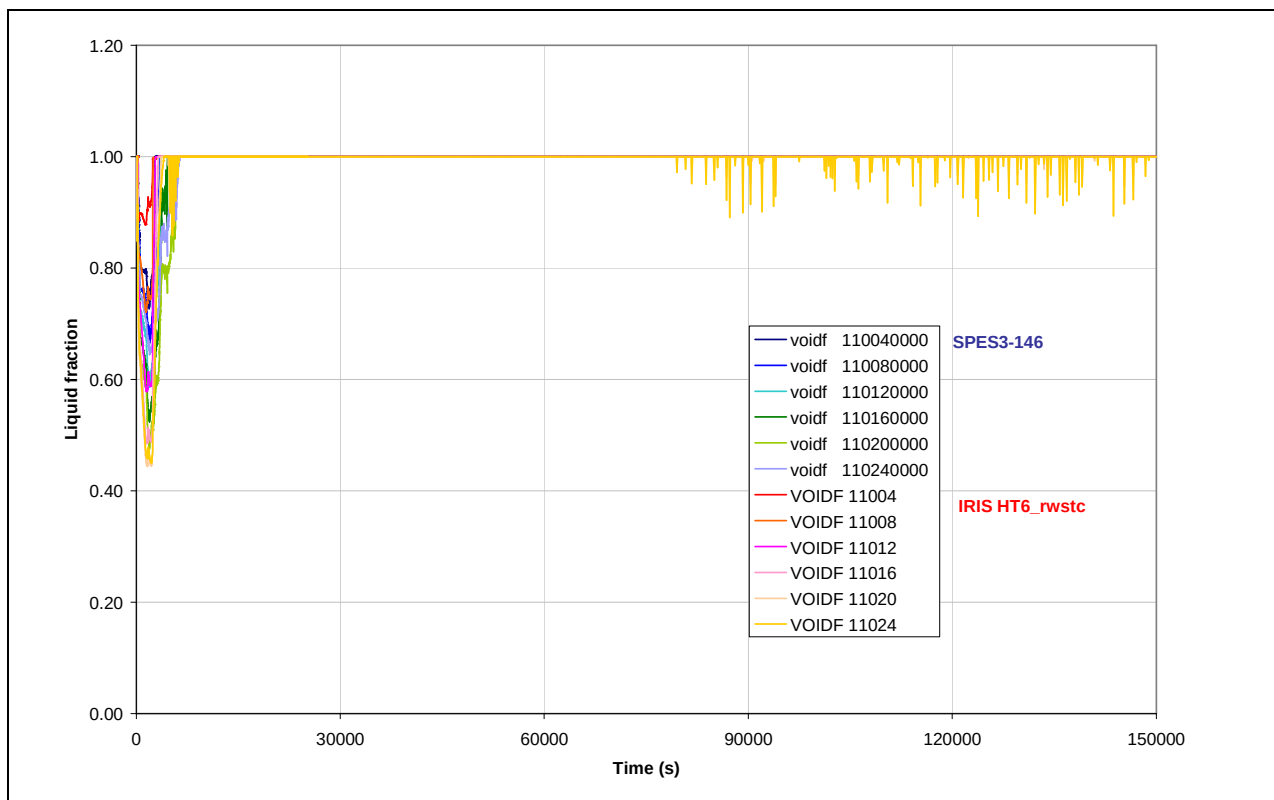


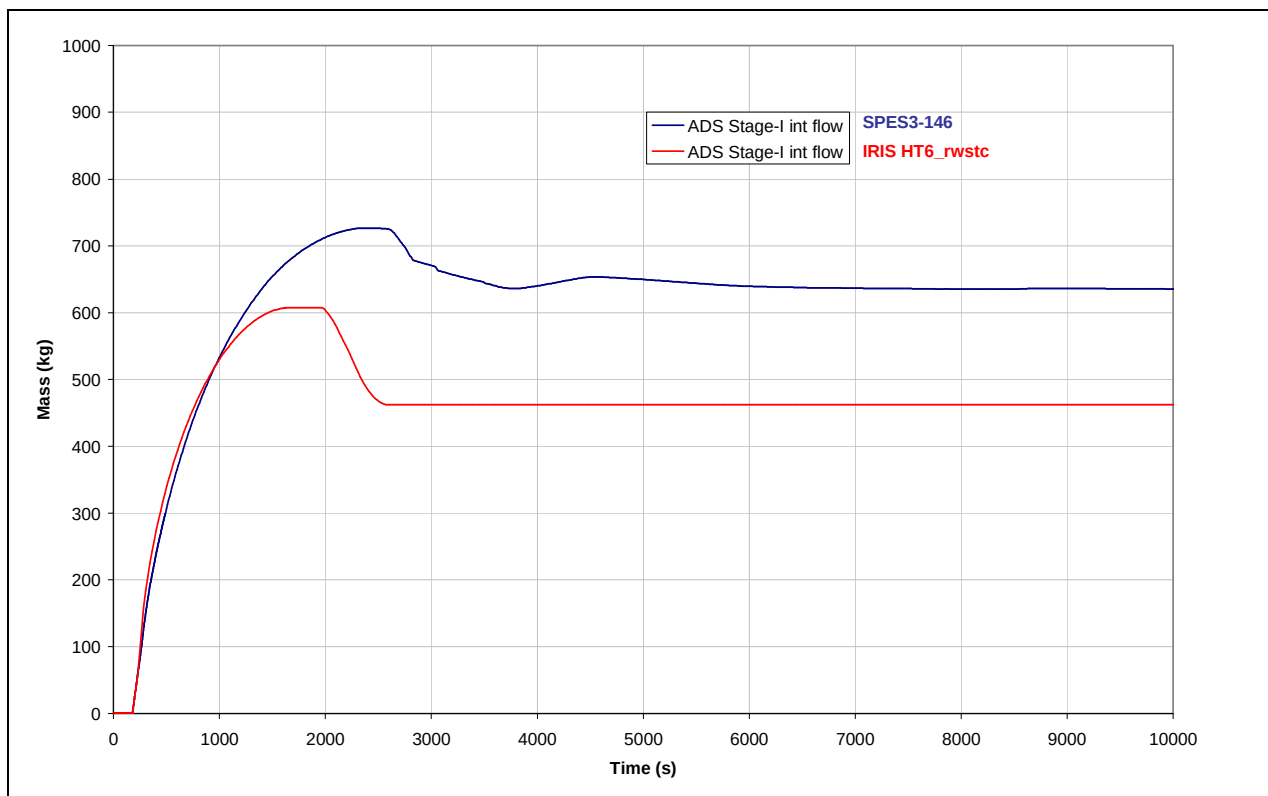
Fig.8. 52 – SPES3-146 and IRIS HT6\_rwstc core liquid void fraction (window)



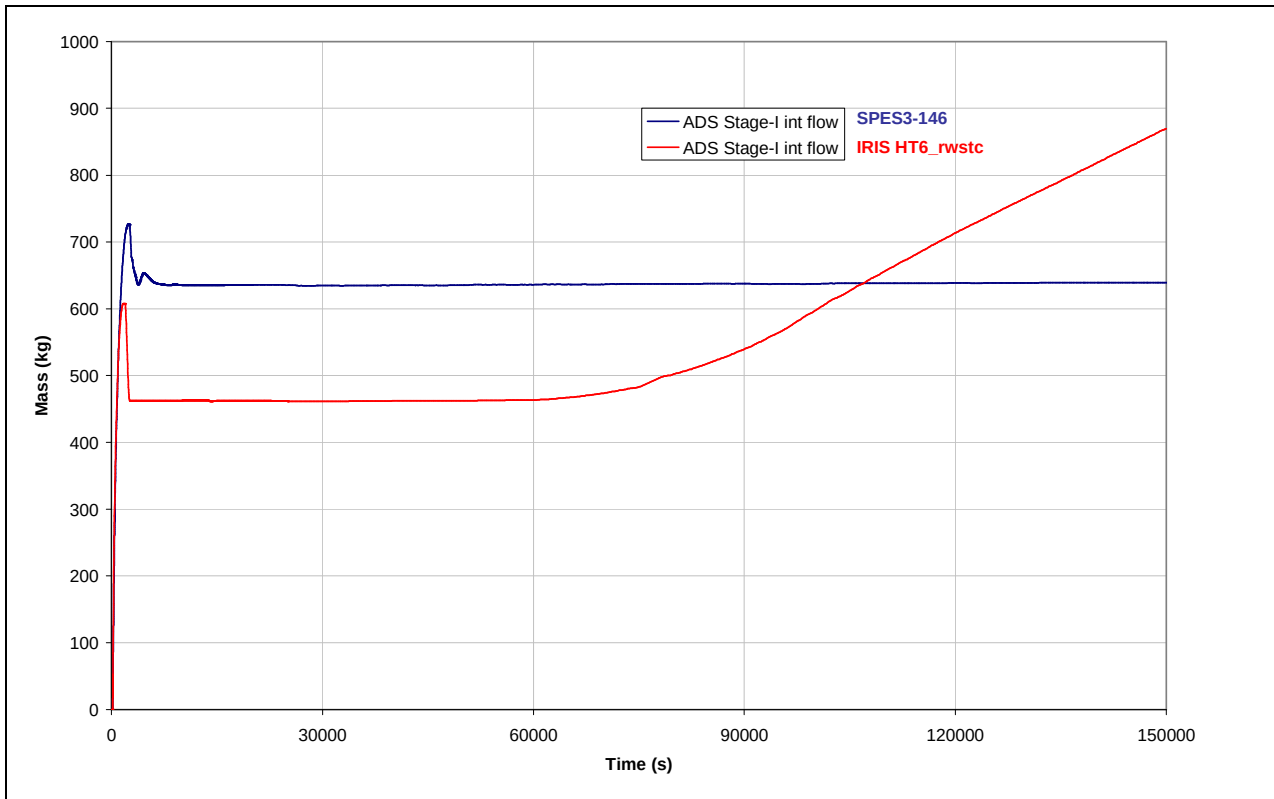
**Fig.8. 53 – SPES3-146 and IRIS HT6\_rwstc core liquid void fraction**



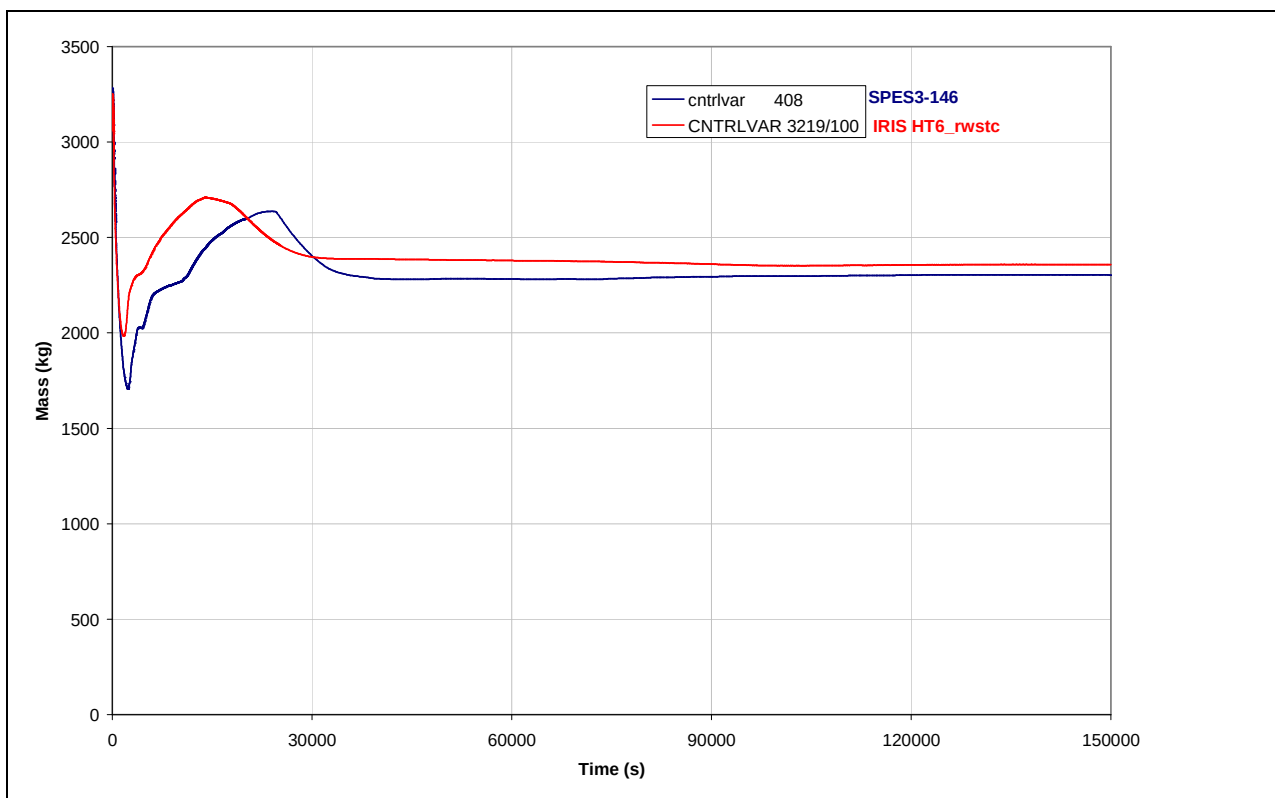
**Fig.8. 54 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-I integral flow (window)**



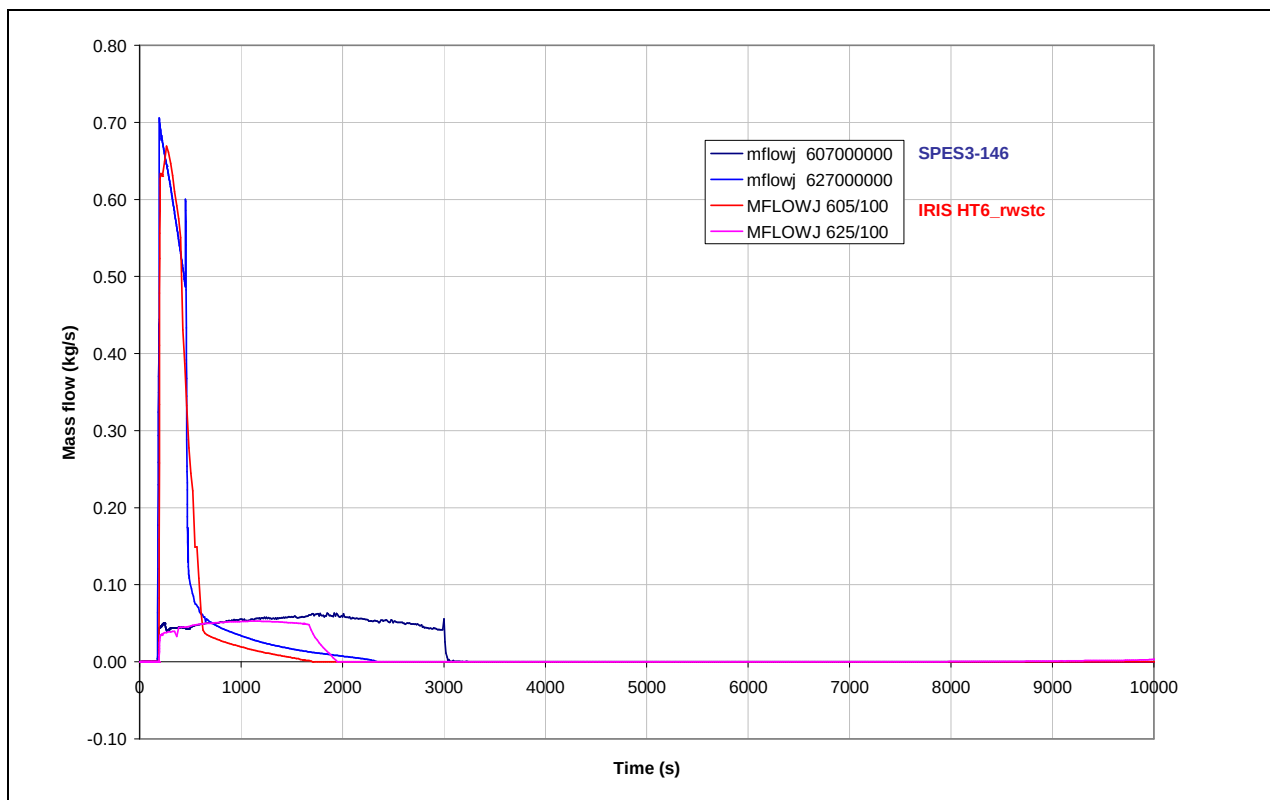
**Fig.8. 55 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-I integral flow**



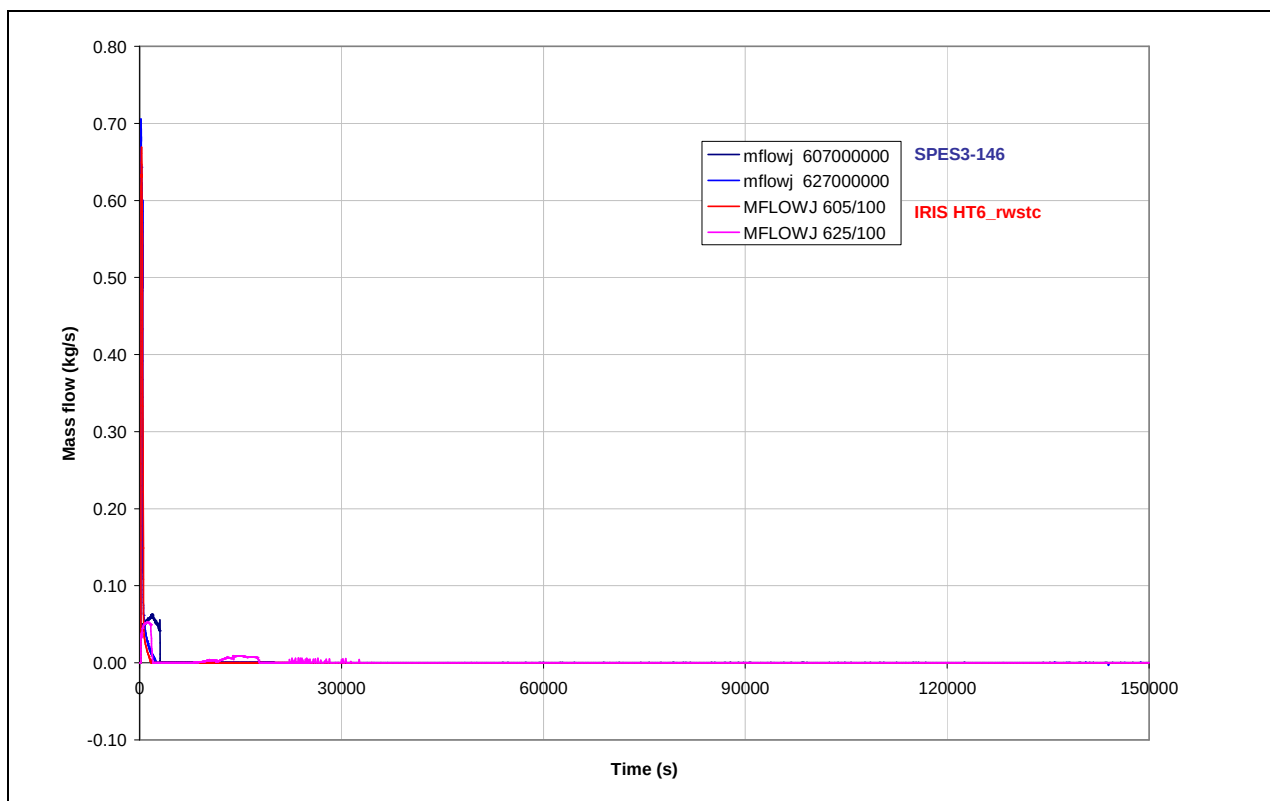
**Fig.8. 56 – SPES3-146 and IRIS HT6\_rwstc RV mass**



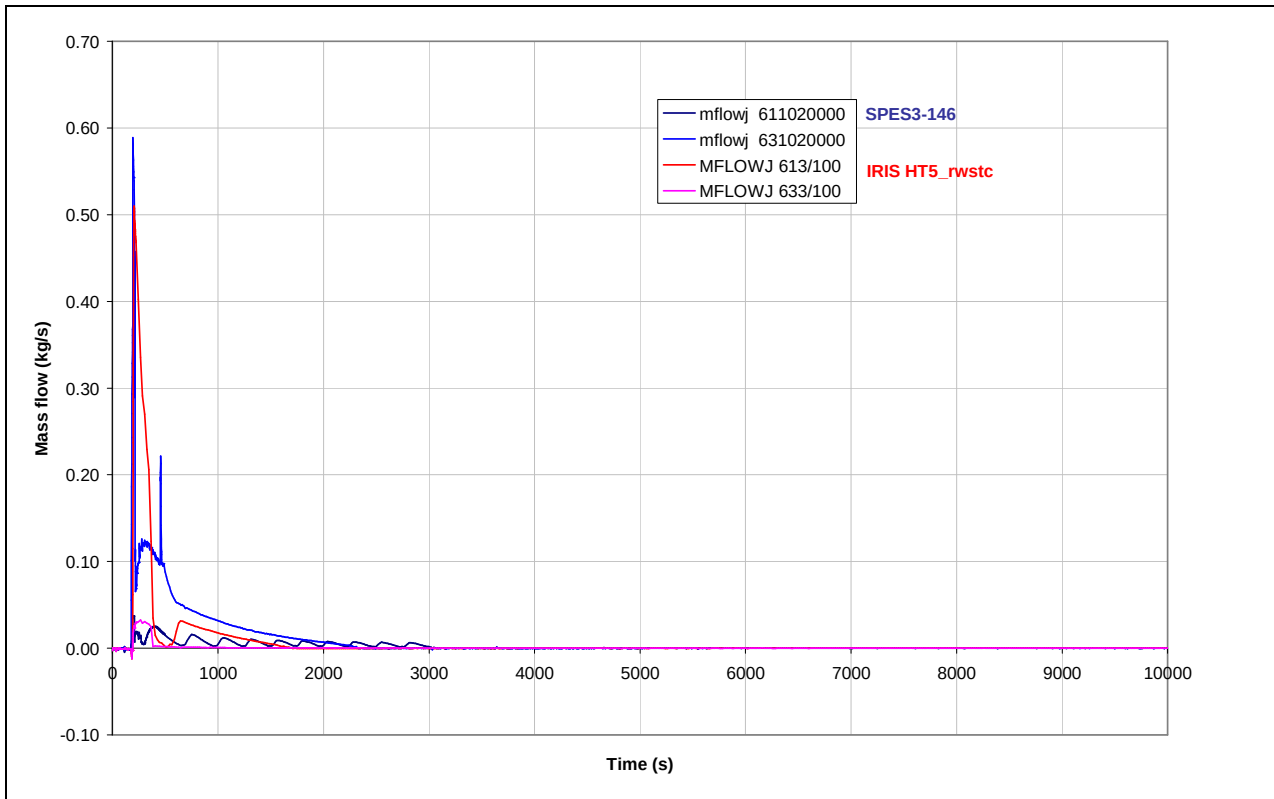
**Fig.8. 57 – SPES3-146 and IRIS HT6\_rwstc EBT injection mass flow (window)**



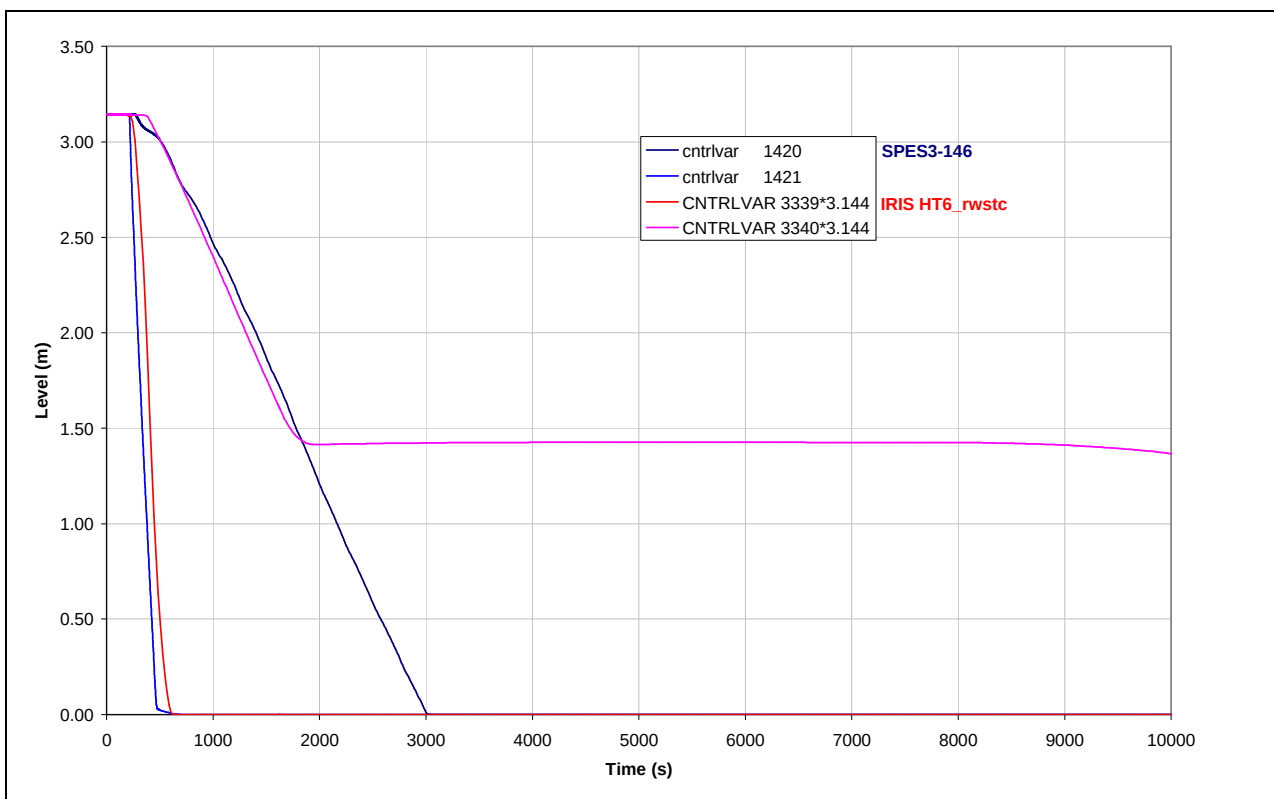
**Fig.8. 58 – SPES3-146 and IRIS HT6\_rwstc EBT injection mass flow**



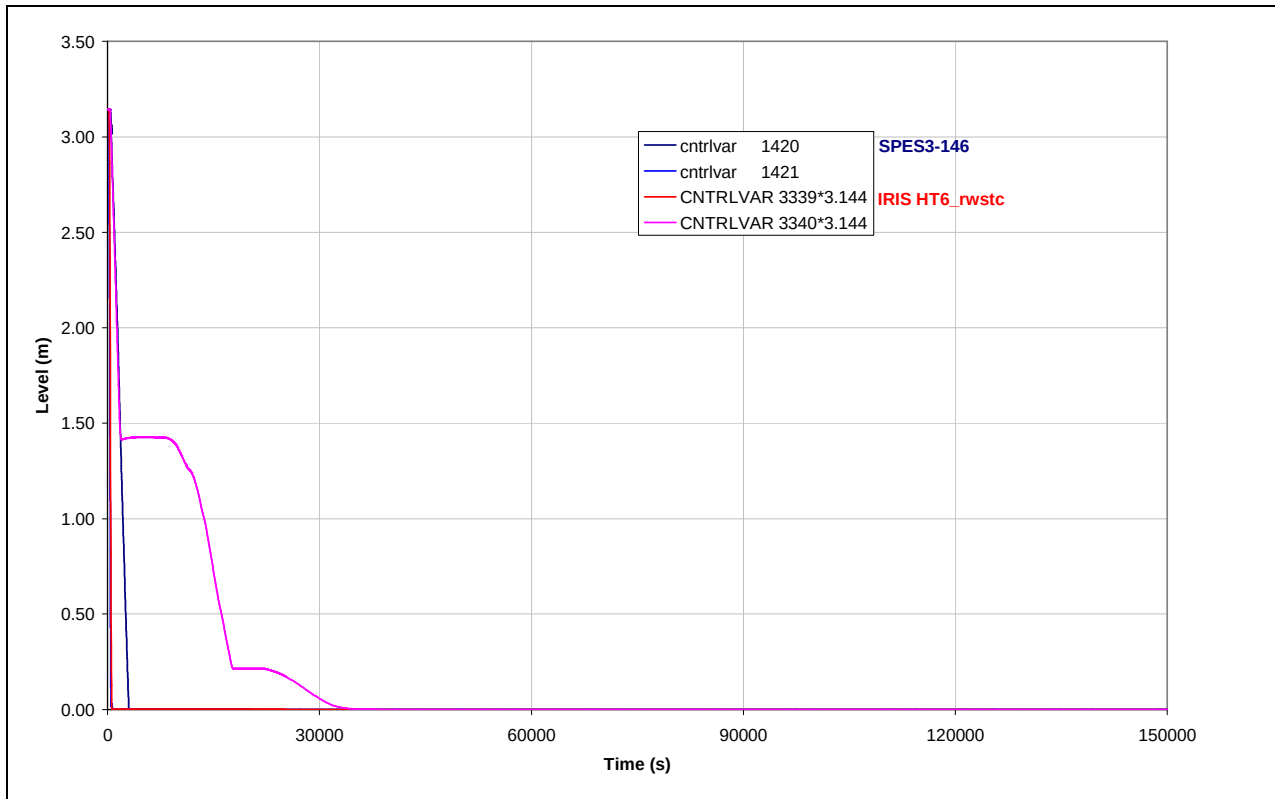
**Fig.8. 59 – SPES3-146 and IRIS HT6\_rwstc EBT balance line to RV mass flow (window)**



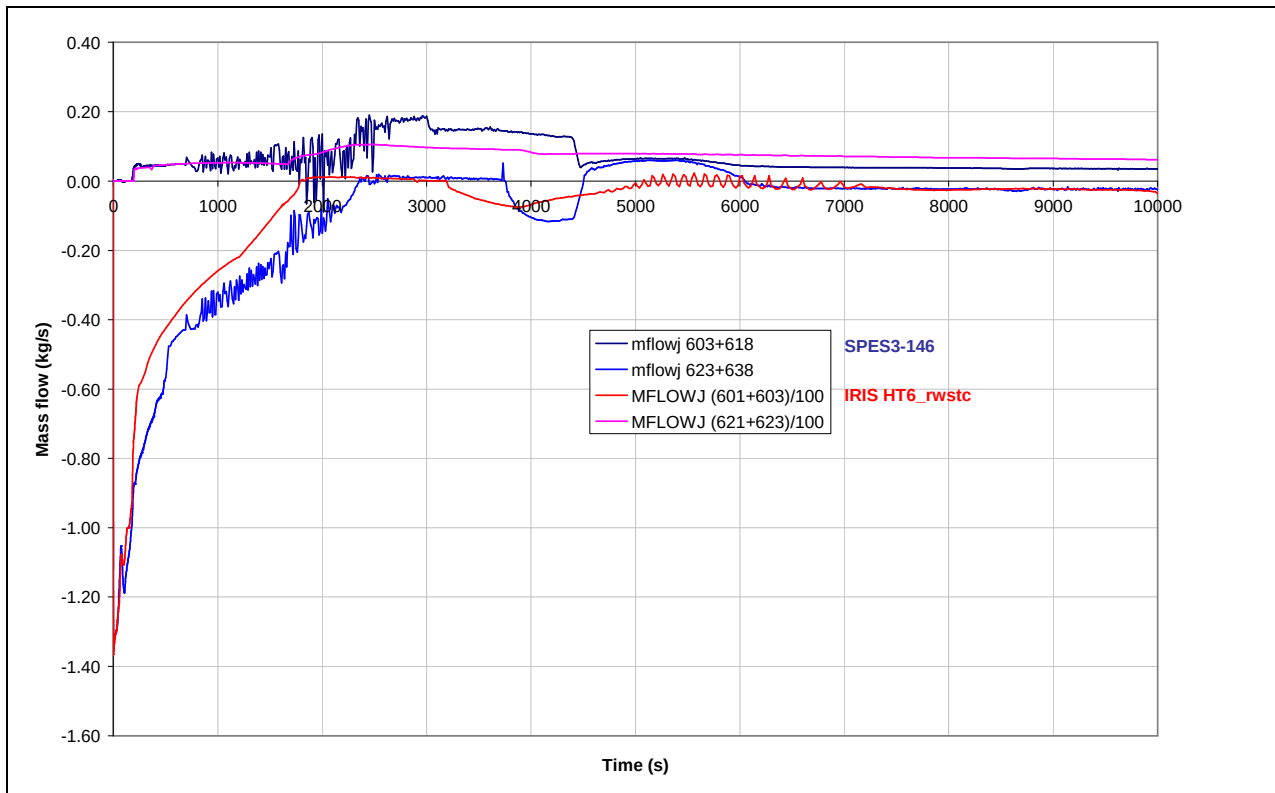
**Fig.8. 60 – SPES3-146 and IRIS HT6\_rwstc EBT level (window)**



**Fig.8. 61 – SPES3-146 and IRIS HT6\_rwstc EBT level**

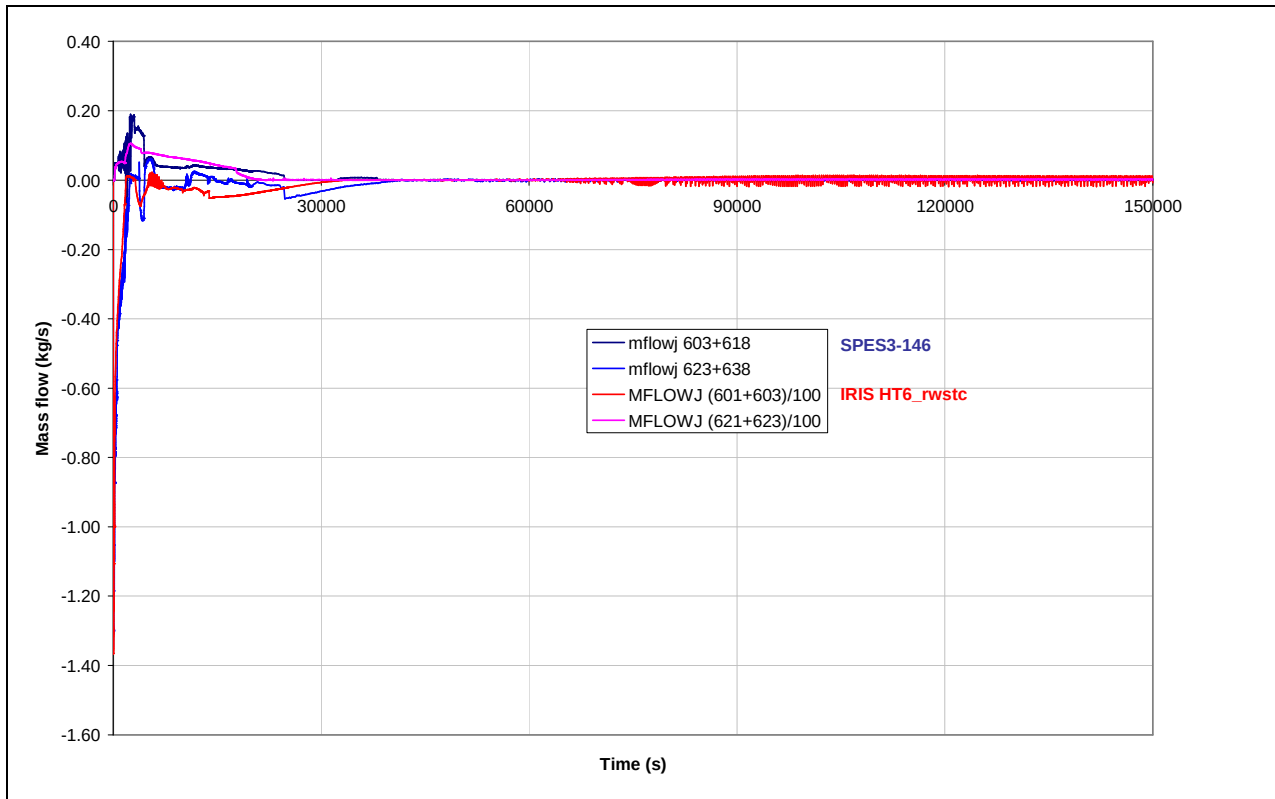


**Fig.8. 62 – SPES3-146 and IRIS HT6\_rwstc DVI mass flow (window)**

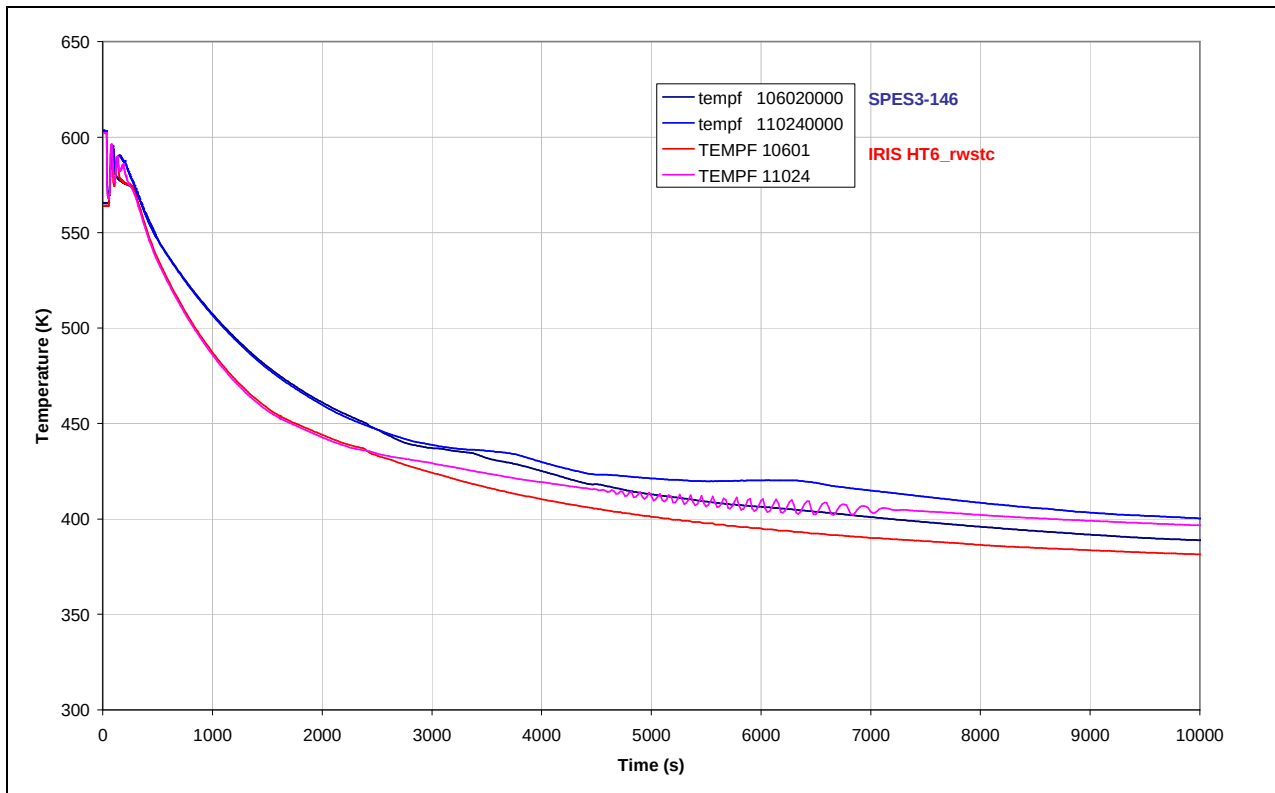




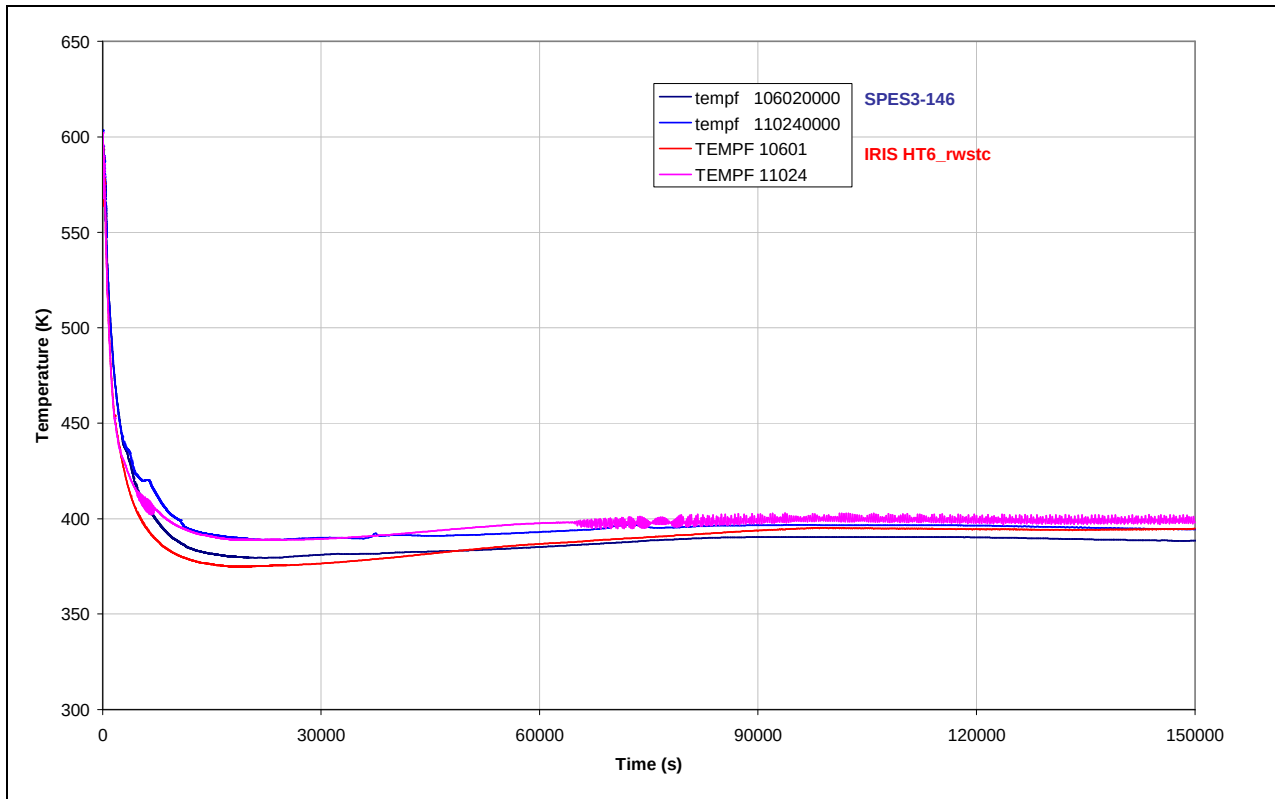
**Fig.8. 63 – SPES3-146 and IRIS HT6\_rwstc DVI mass flow**



**Fig.8. 64 – SPES3-146 and IRIS HT6\_rwstc Core inlet and outlet temperatures (window)**



**Fig.8. 65 – SPES3-146 and IRIS HT6\_rwstc Core inlet and outlet temperatures**



**Fig.8. 66 – SPES3-146 and IRIS HT6\_rwstc Core heater rod outer surface temperature (window)**

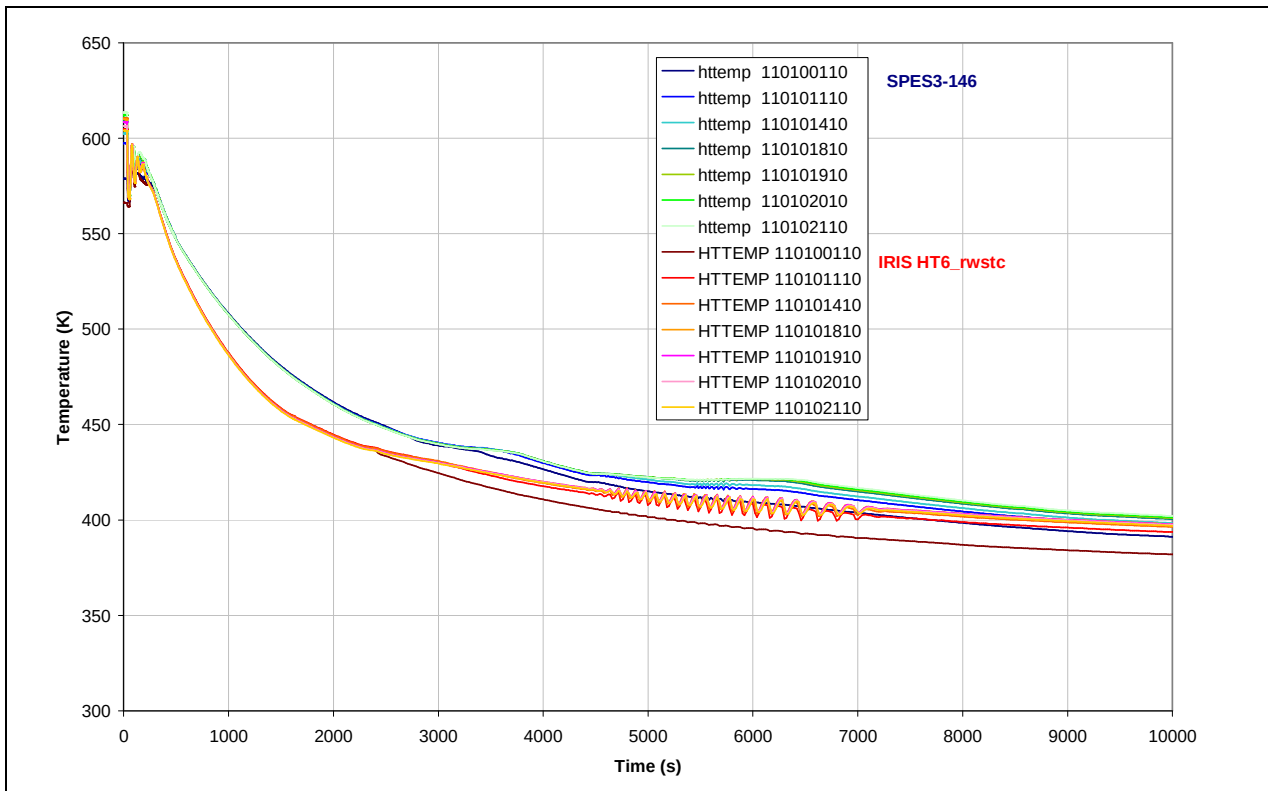


Fig.8. 67 – SPES3-146 and IRIS HT6\_rwstc Core heater rod outer surface temperature

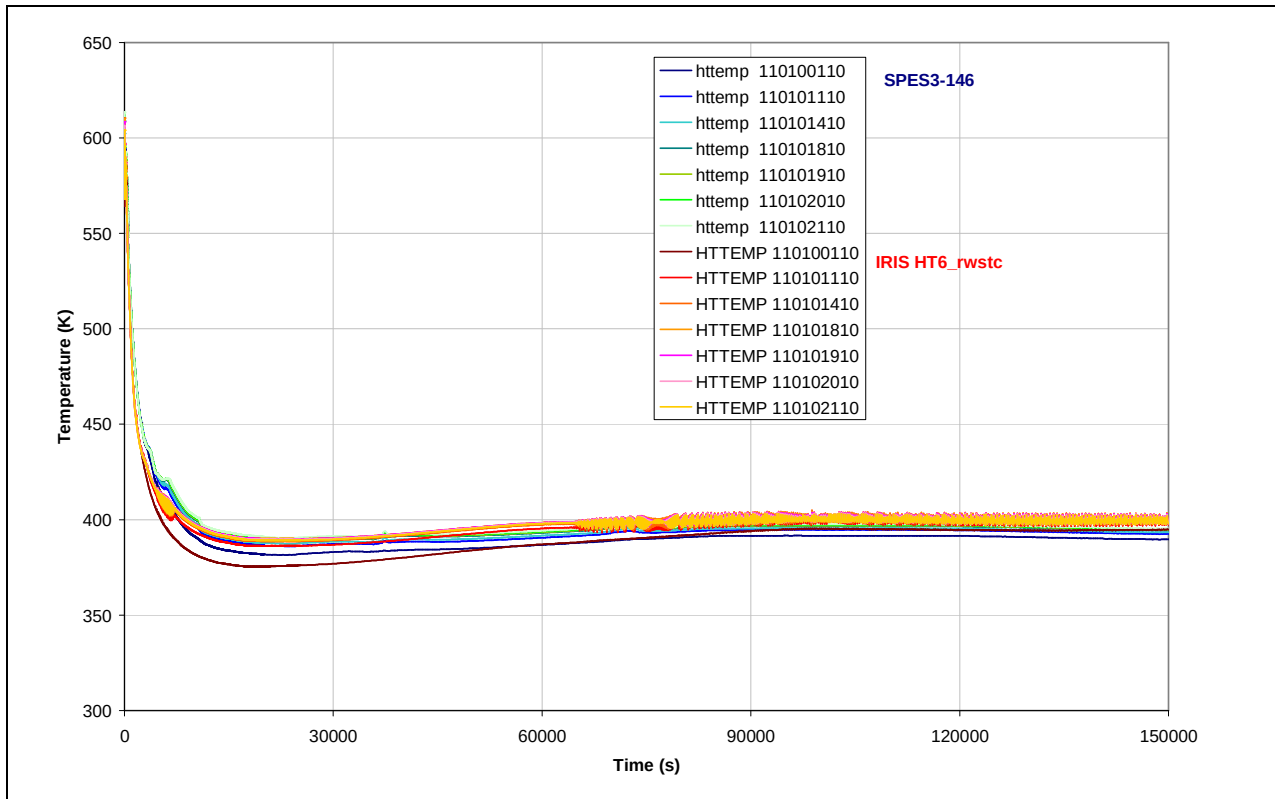


Fig.8. 68 – SPES3-146 and IRIS HT6\_rwstc LGMS injection mass flow (window)

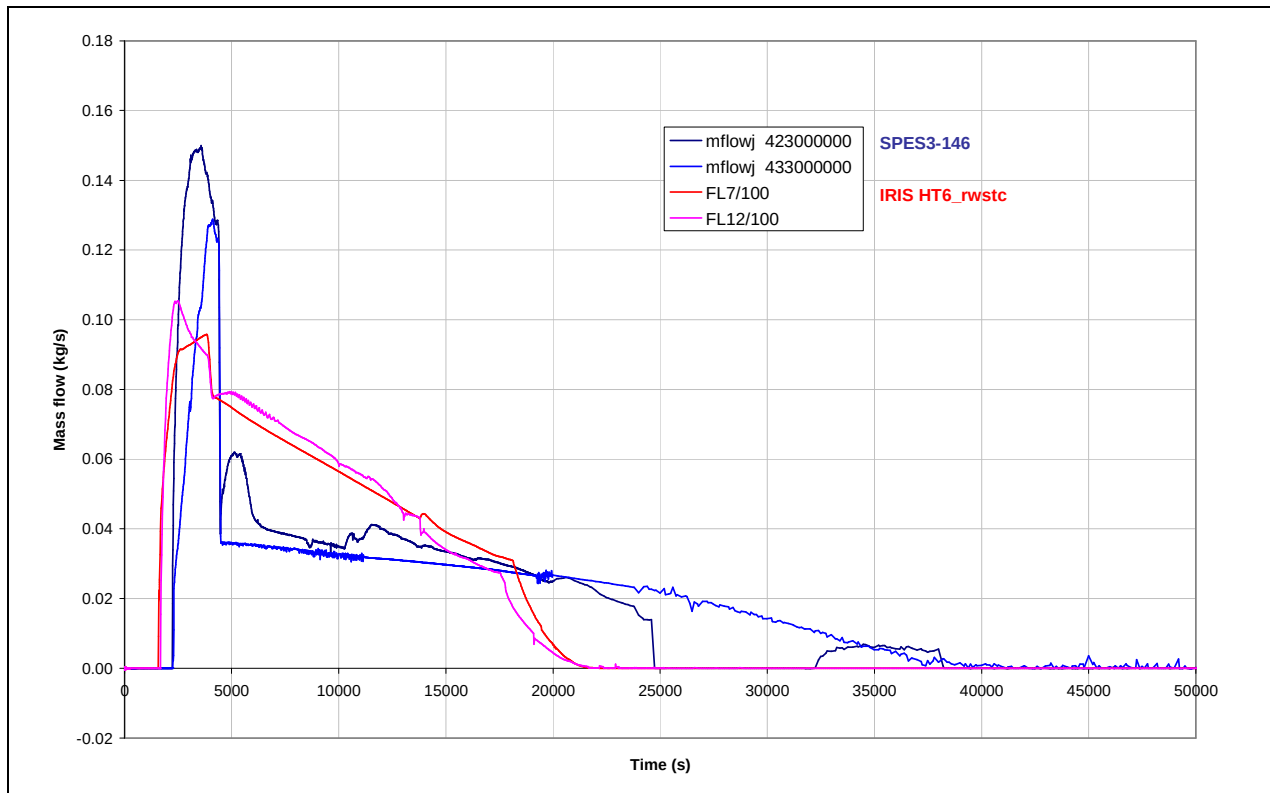


Fig.8. 69 – SPES3-146 and IRIS HT6\_rwstc LGMS mass (window)

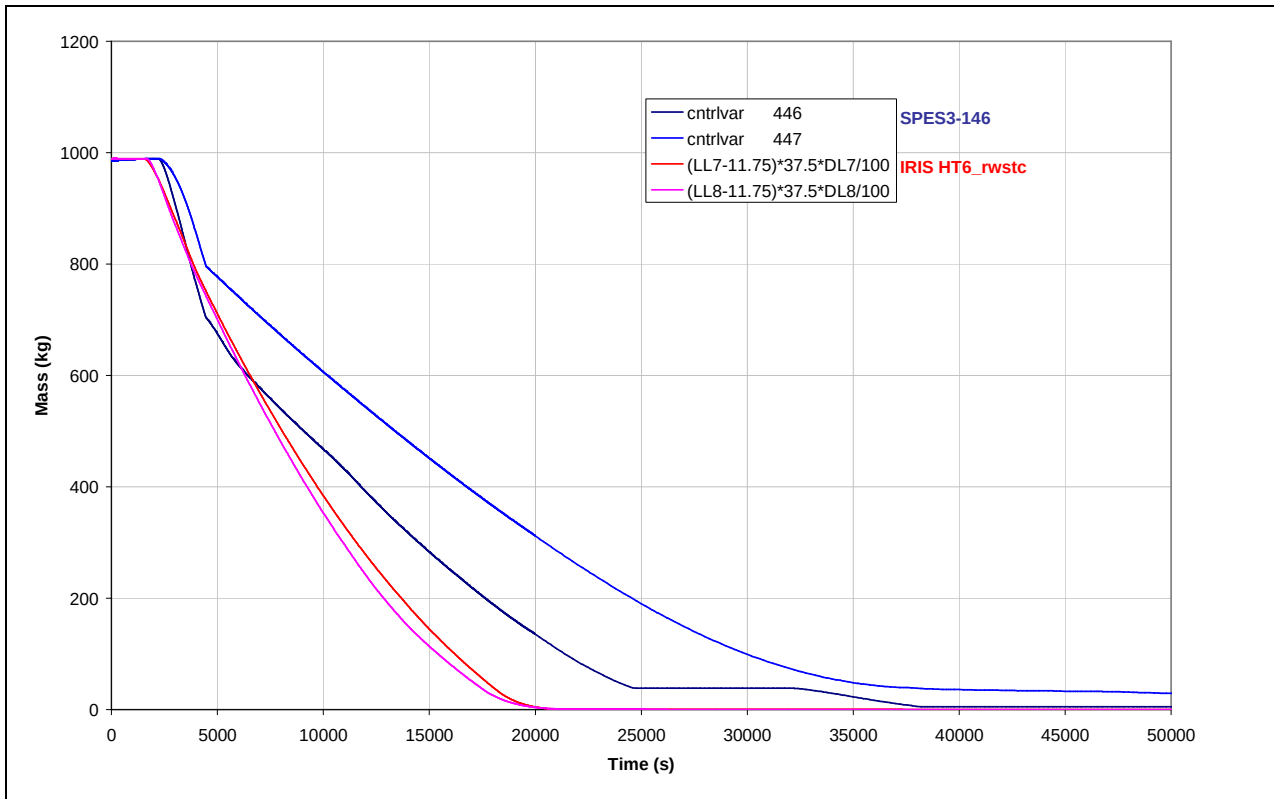


Fig.8. 70 – SPES3-146 and IRIS HT6\_rwstc LGMS and DVI pressure (window)

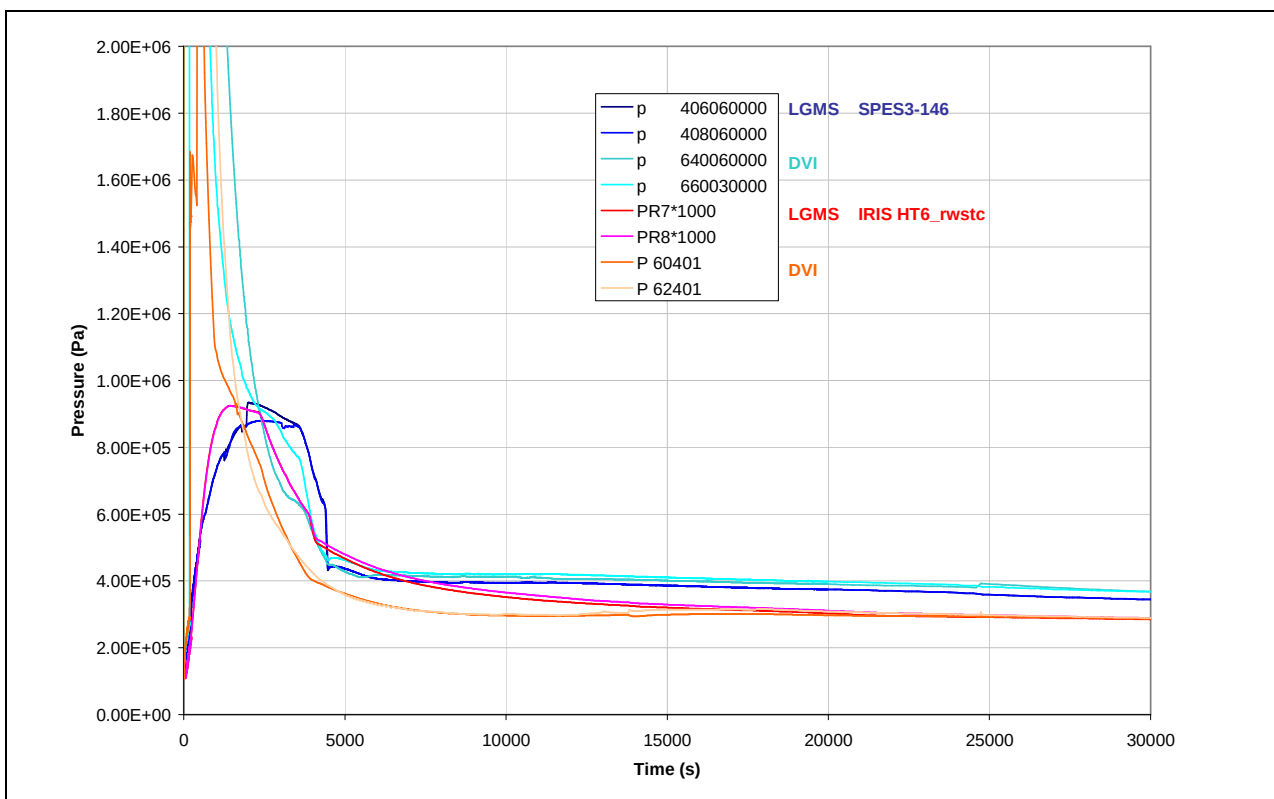


Fig.8. 71 – SPES3-146 and IRIS HT6\_rwstc LGMS and DVI pressure

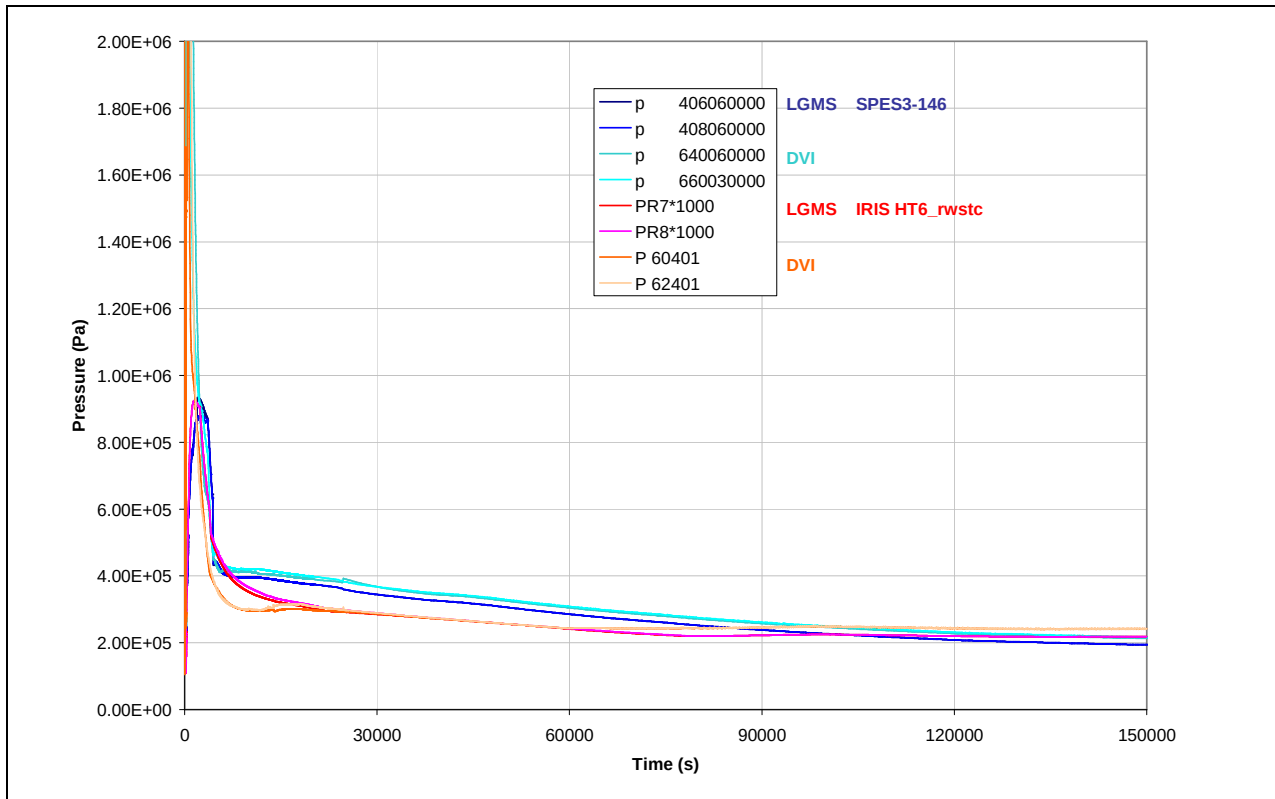
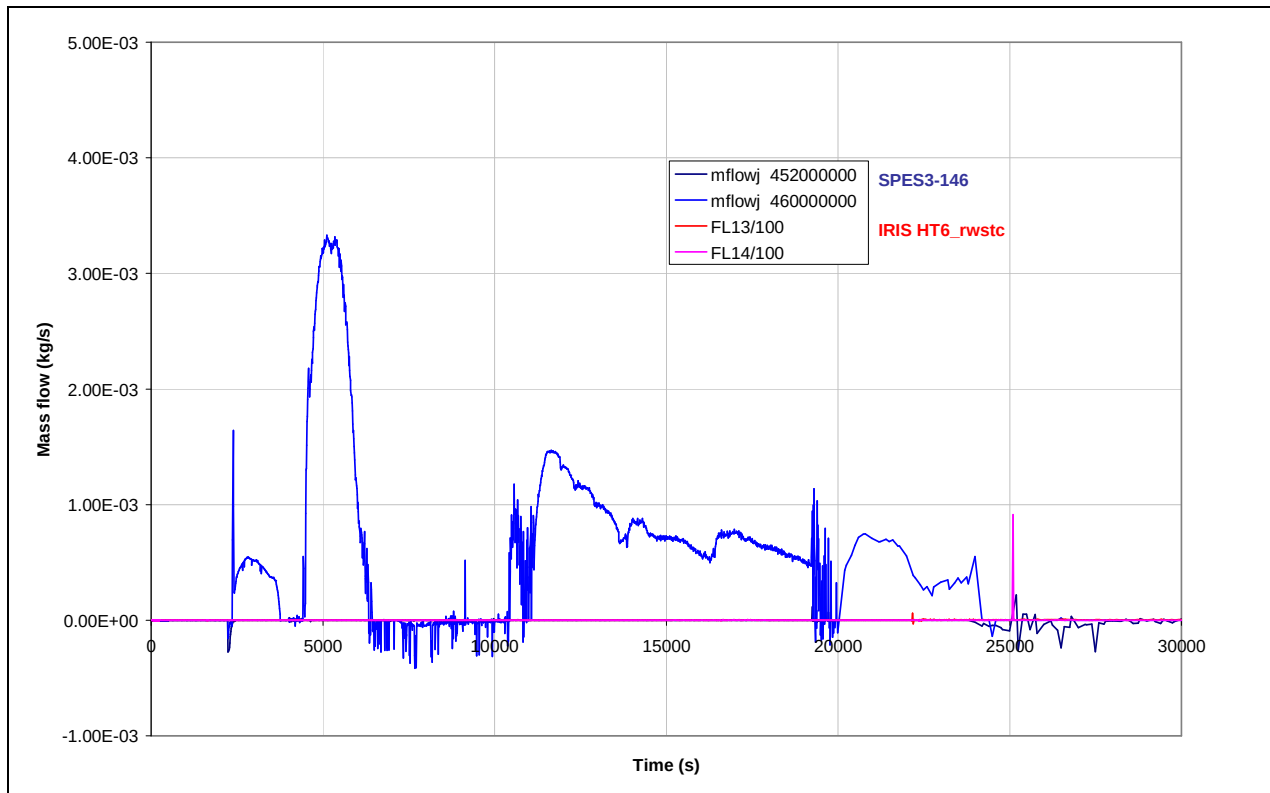
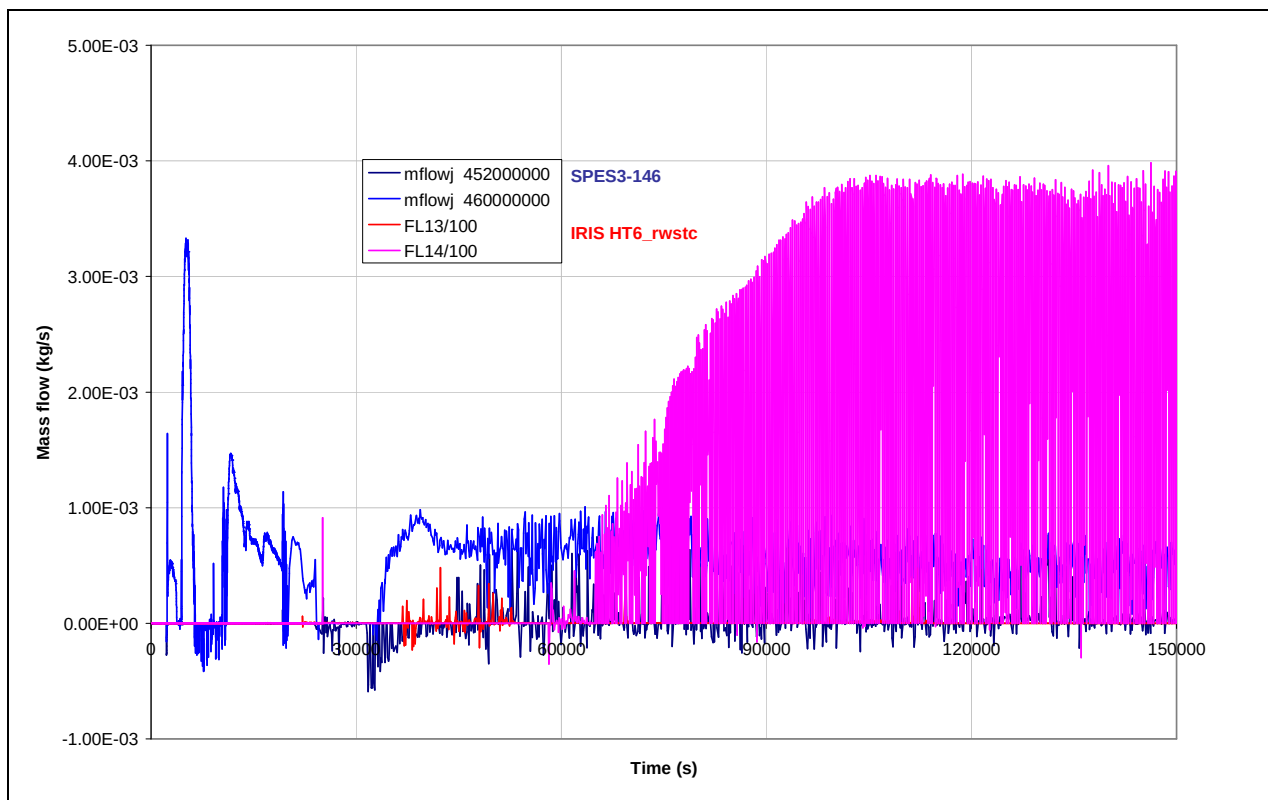


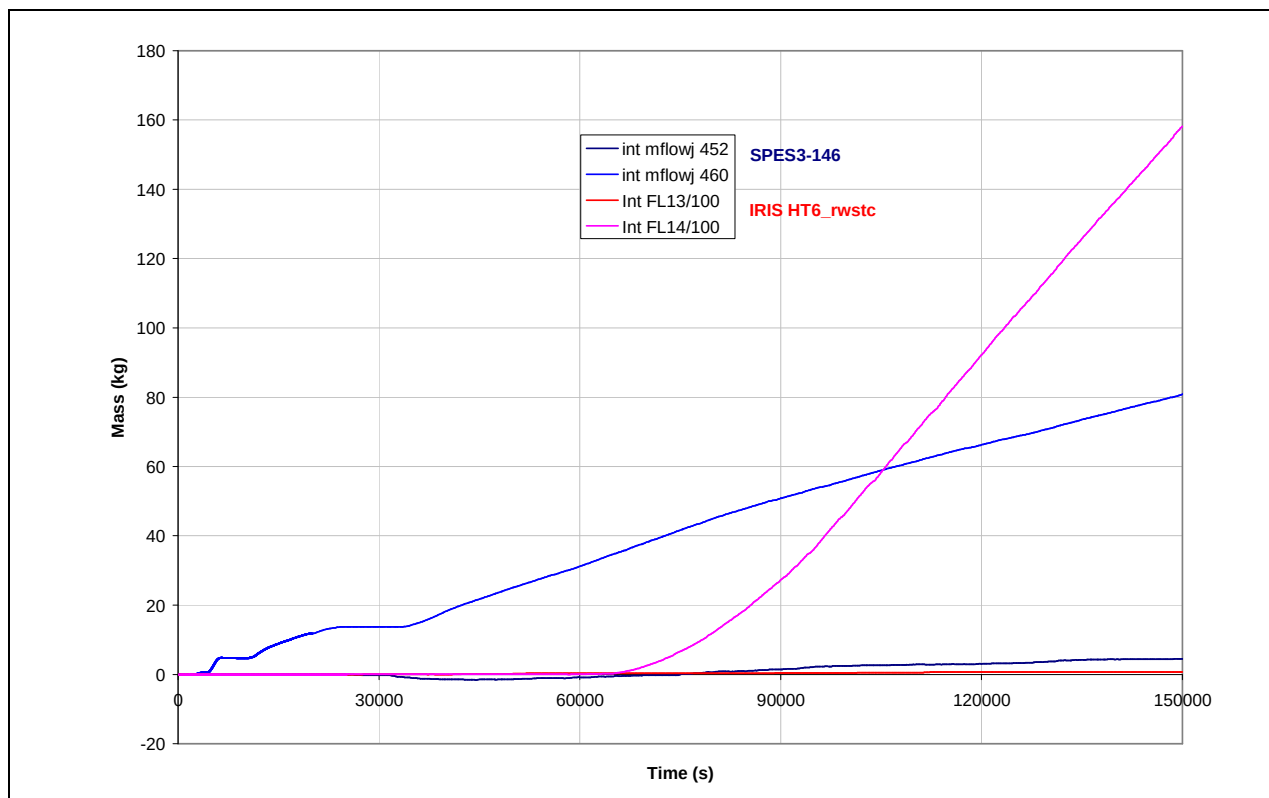
Fig.8. 72 – SPES3-146 and IRIS HT6\_rwstc RC to DVI mass flow (window)



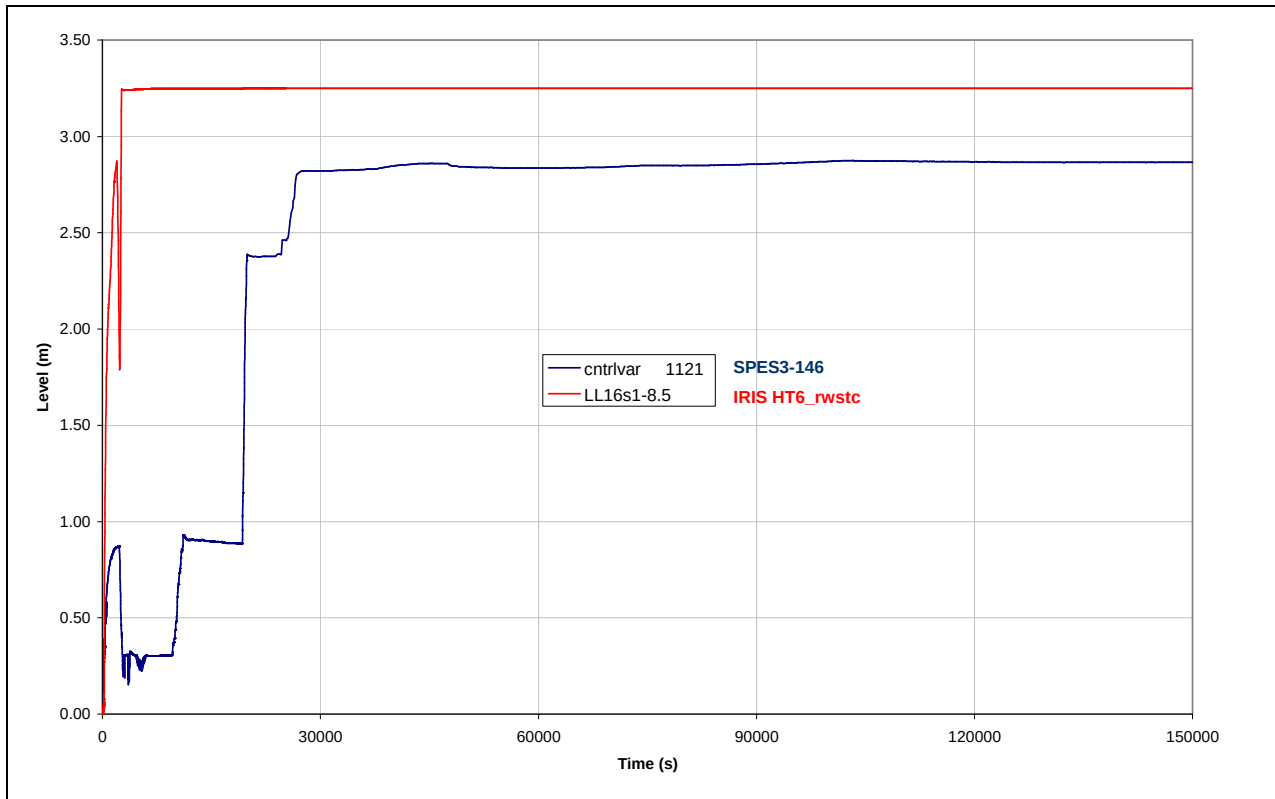
**Fig.8. 73 – SPES3-146 and IRIS HT6\_rwstc RC to DVI mass flow**



**Fig.8. 74 – SPES3-146 and IRIS HT6\_rwstc RC to DVI integral mass flow**



**Fig.8. 75 – SPES3-146 and IRIS HT6\_rwstc QT level**



**Fig.8. 76 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-II mass flow (window)**

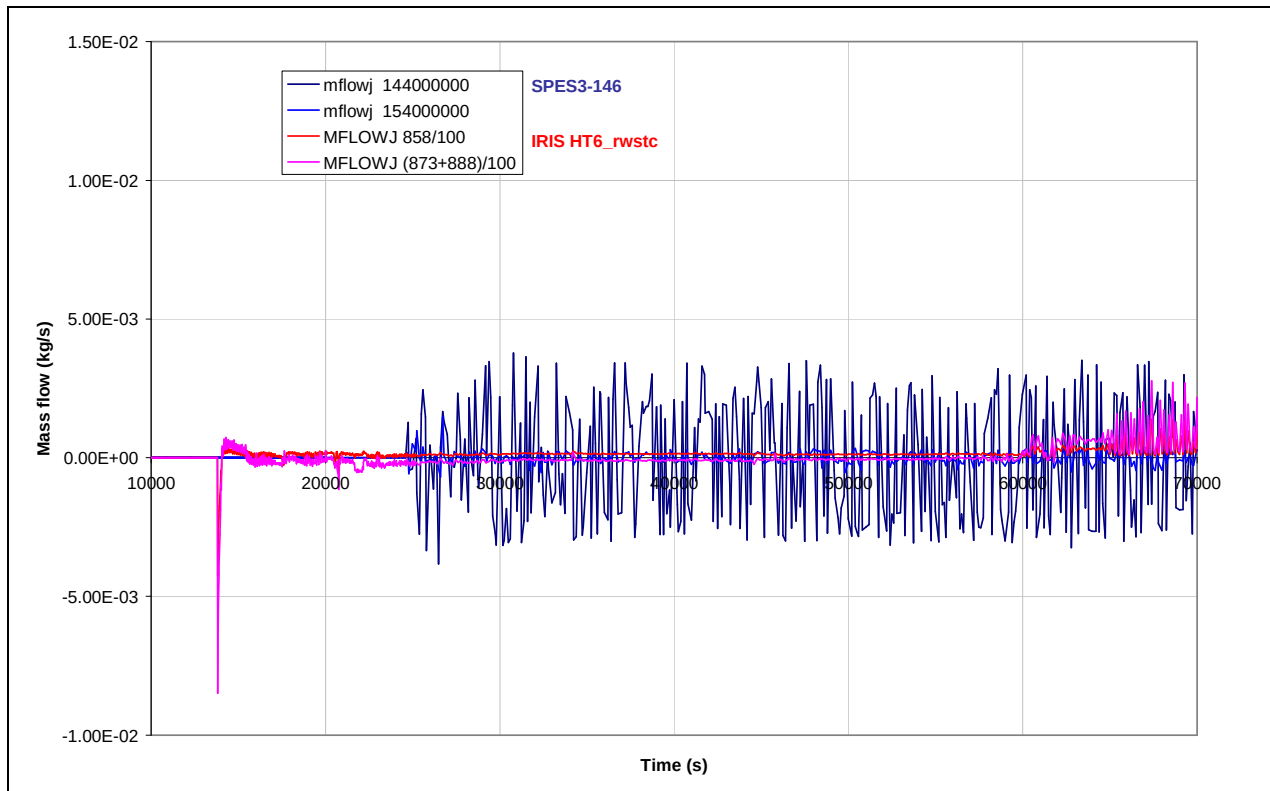


Fig.8. 77 – SPES3-146 and IRIS HT6\_rwstc ADS Stage-II mass flow

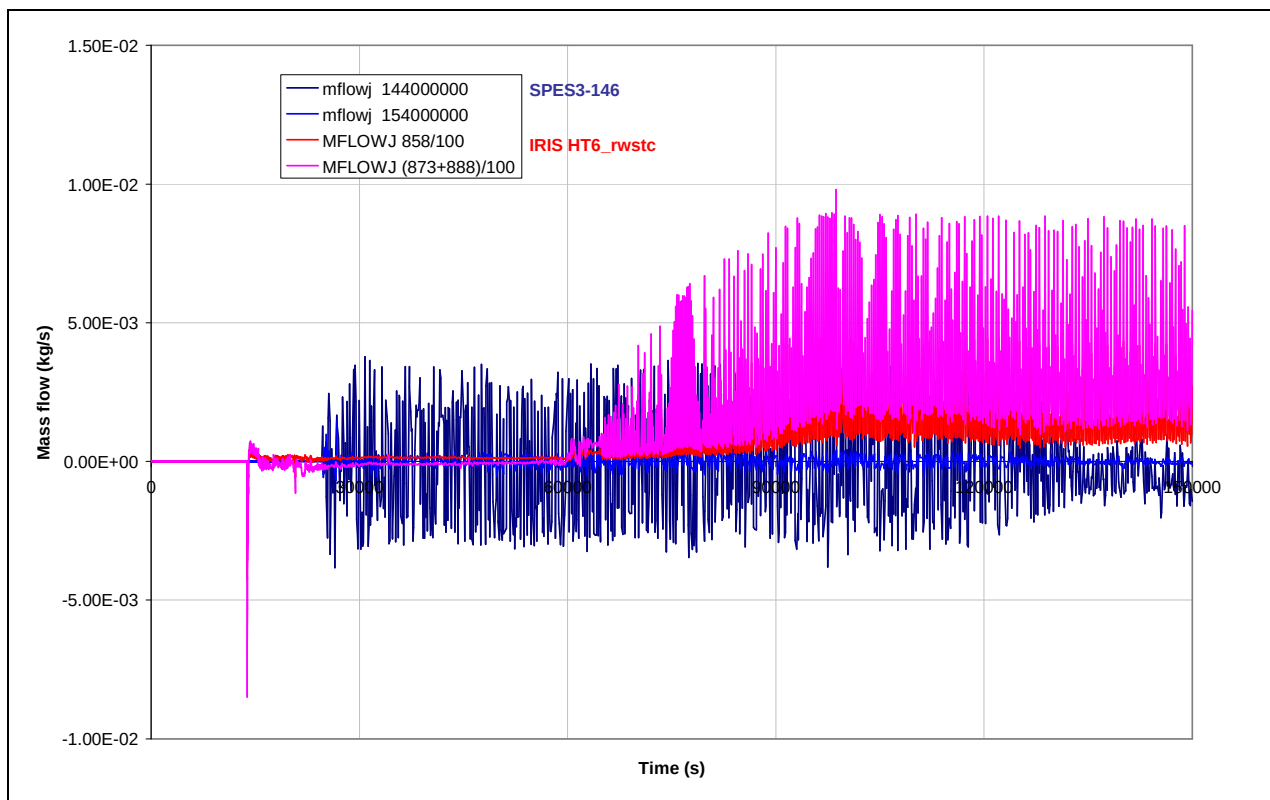
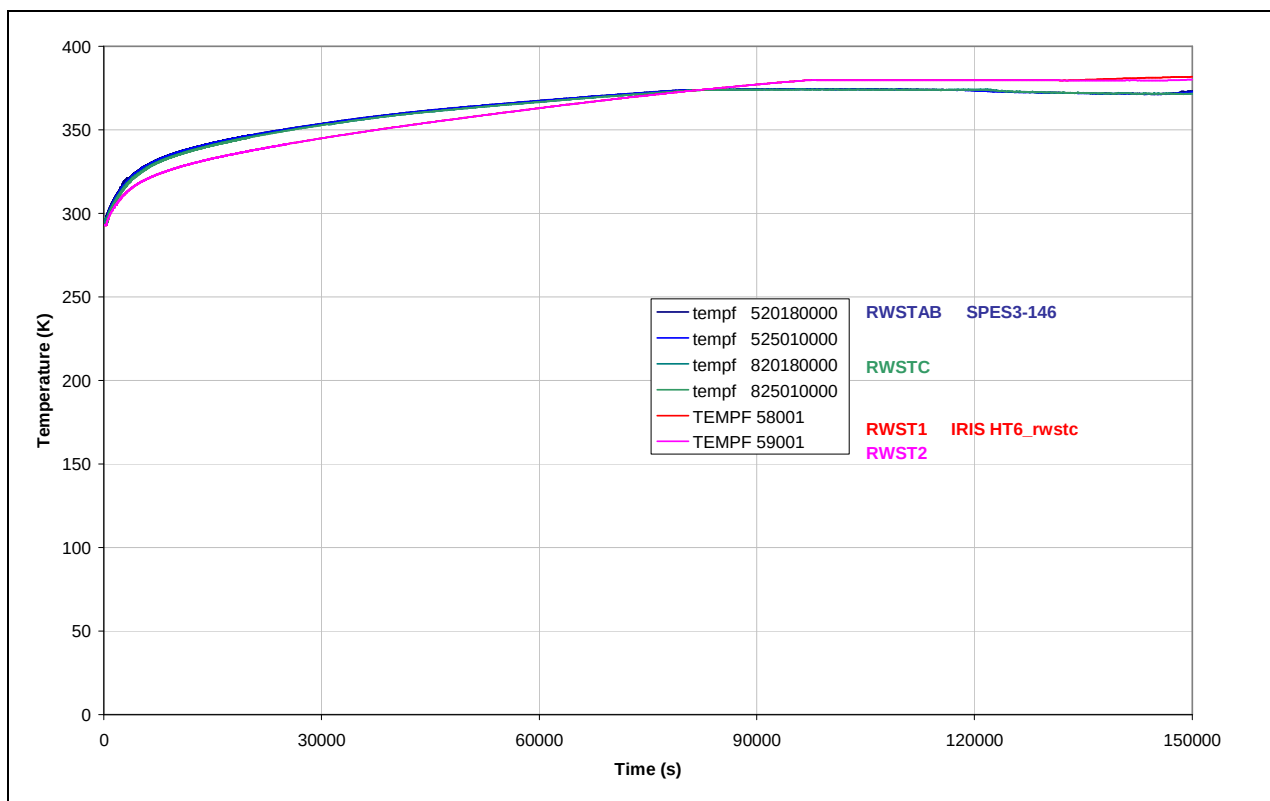
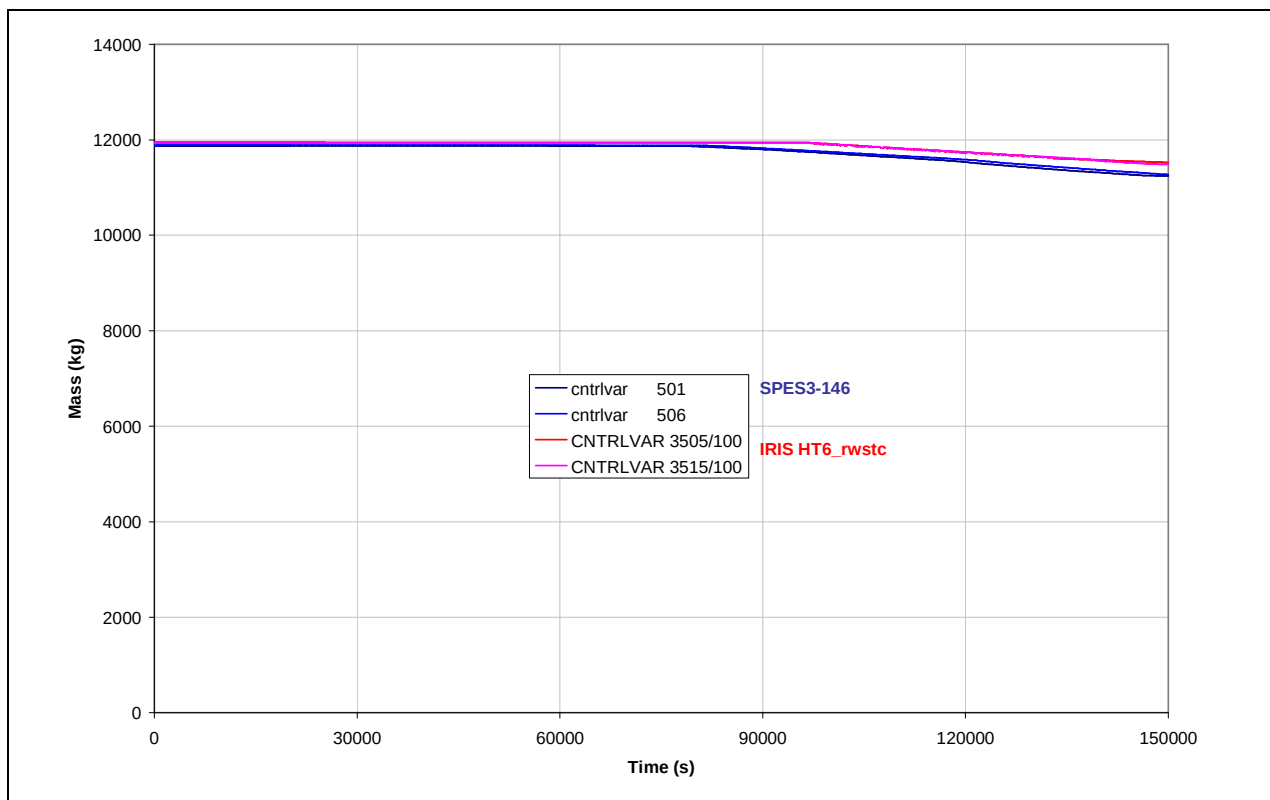


Fig.8. 78 – SPES3-146 and IRIS HT6\_rwstc RWST temperature





**Fig.8. 79 – SPES3-146 and IRIS HT6\_rwstc RWST mass**



**Fig.8. 80 – SPES3-146 and IRIS HT6\_rwstc RWST pressure**

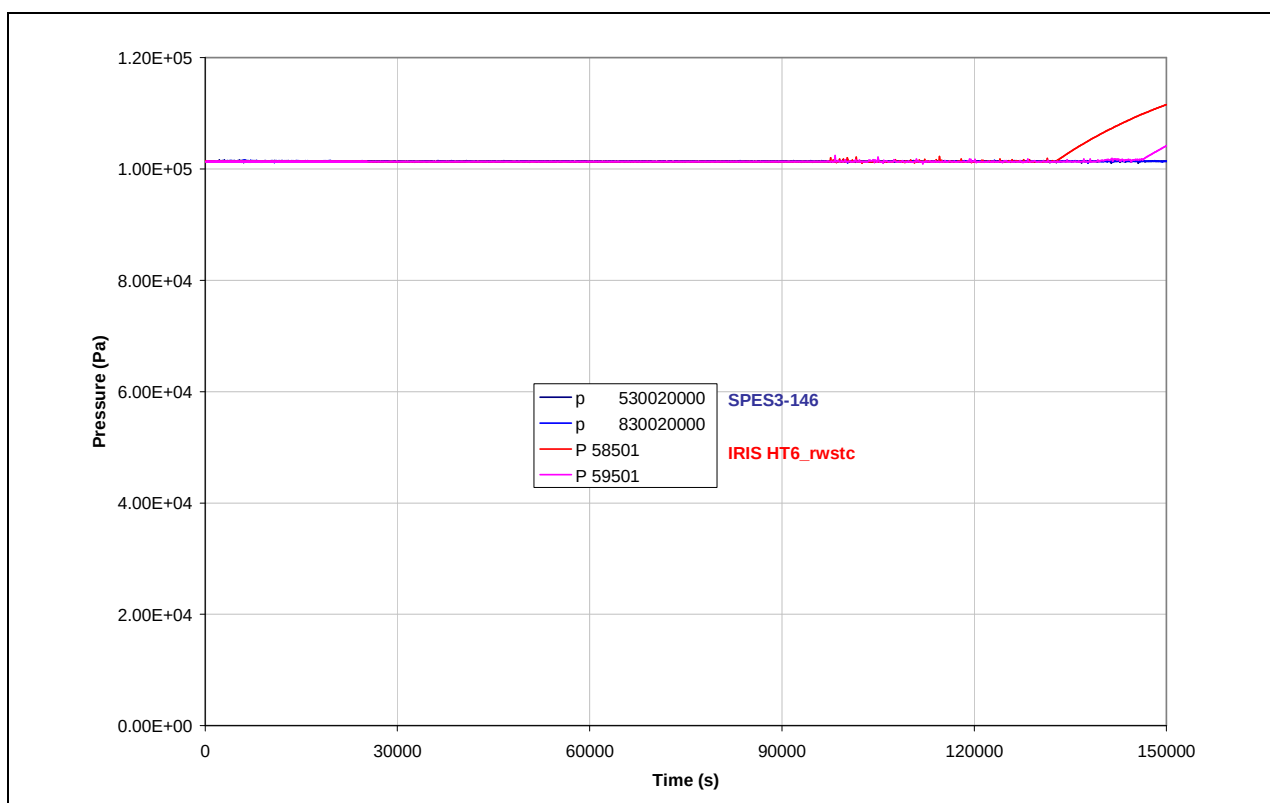


Fig.8. 81 – SPES3-146 and IRIS HT6\_rwstc RWST top mass flow

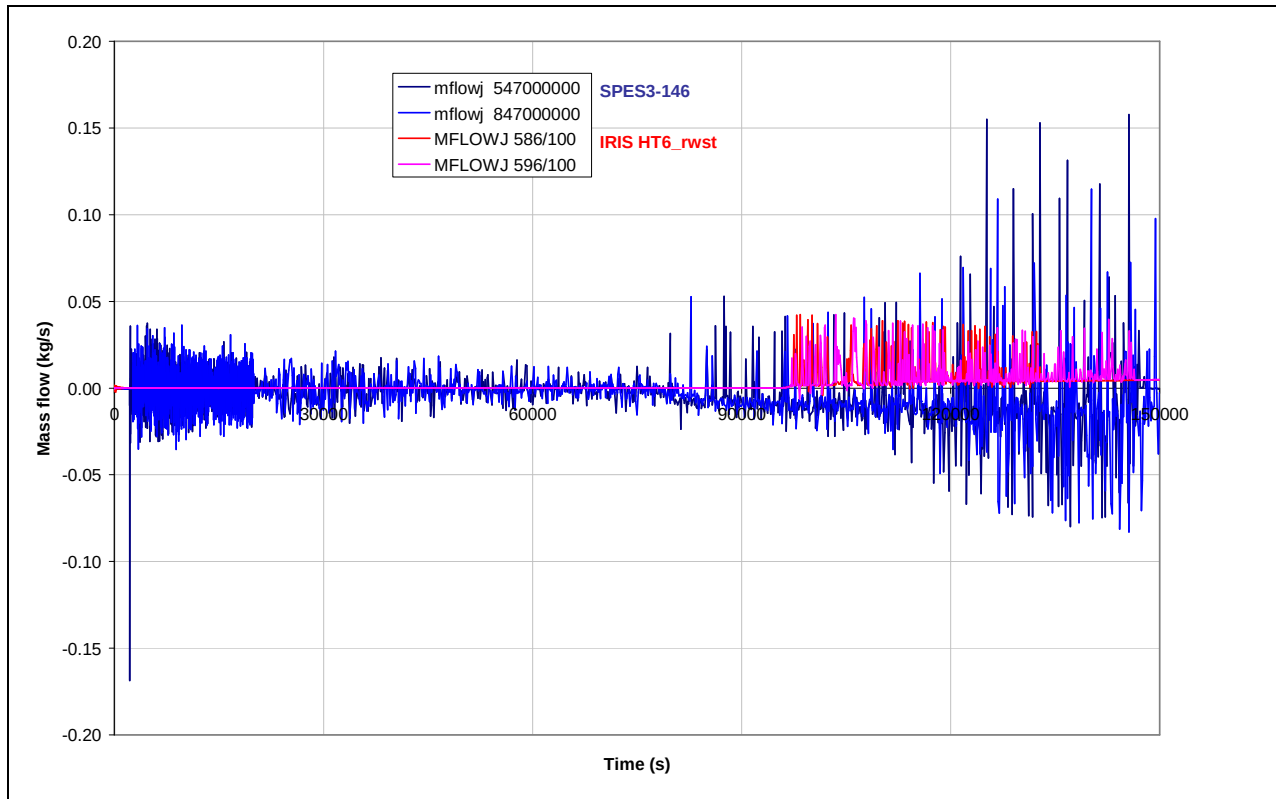
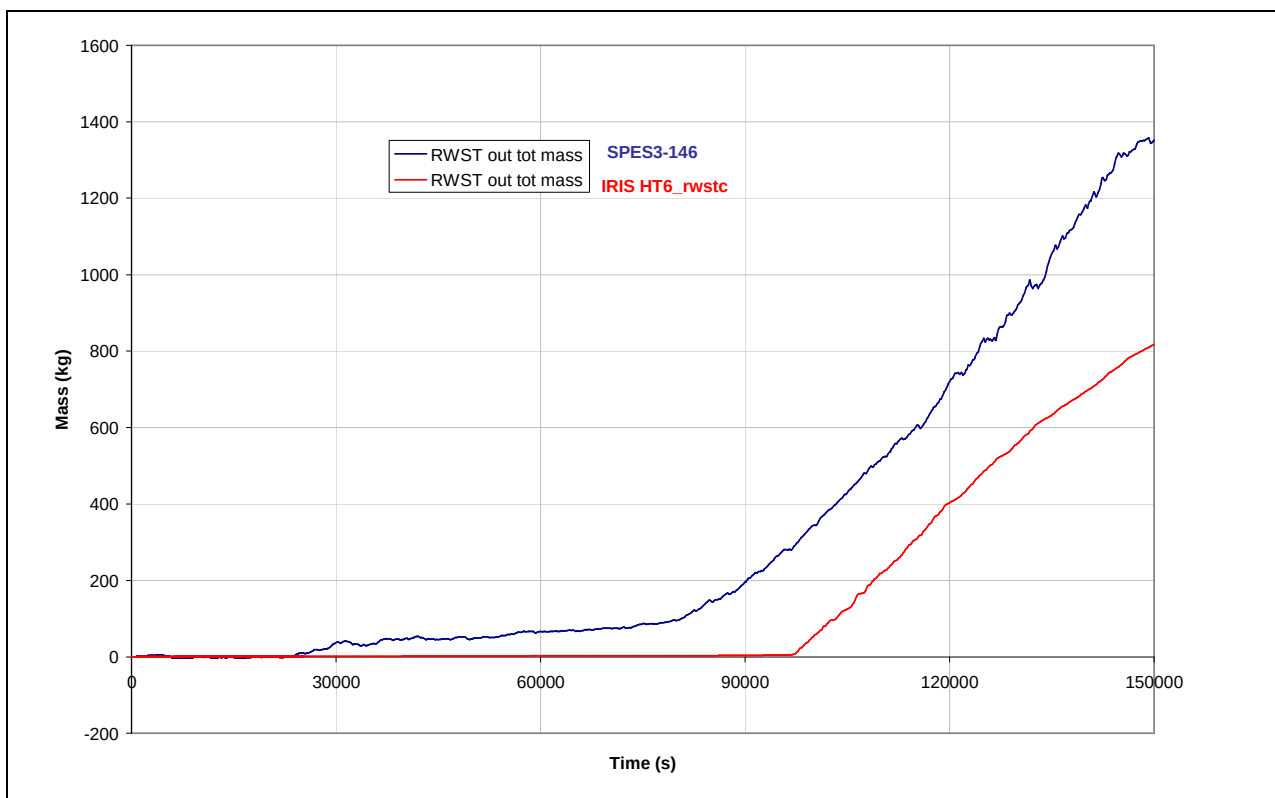
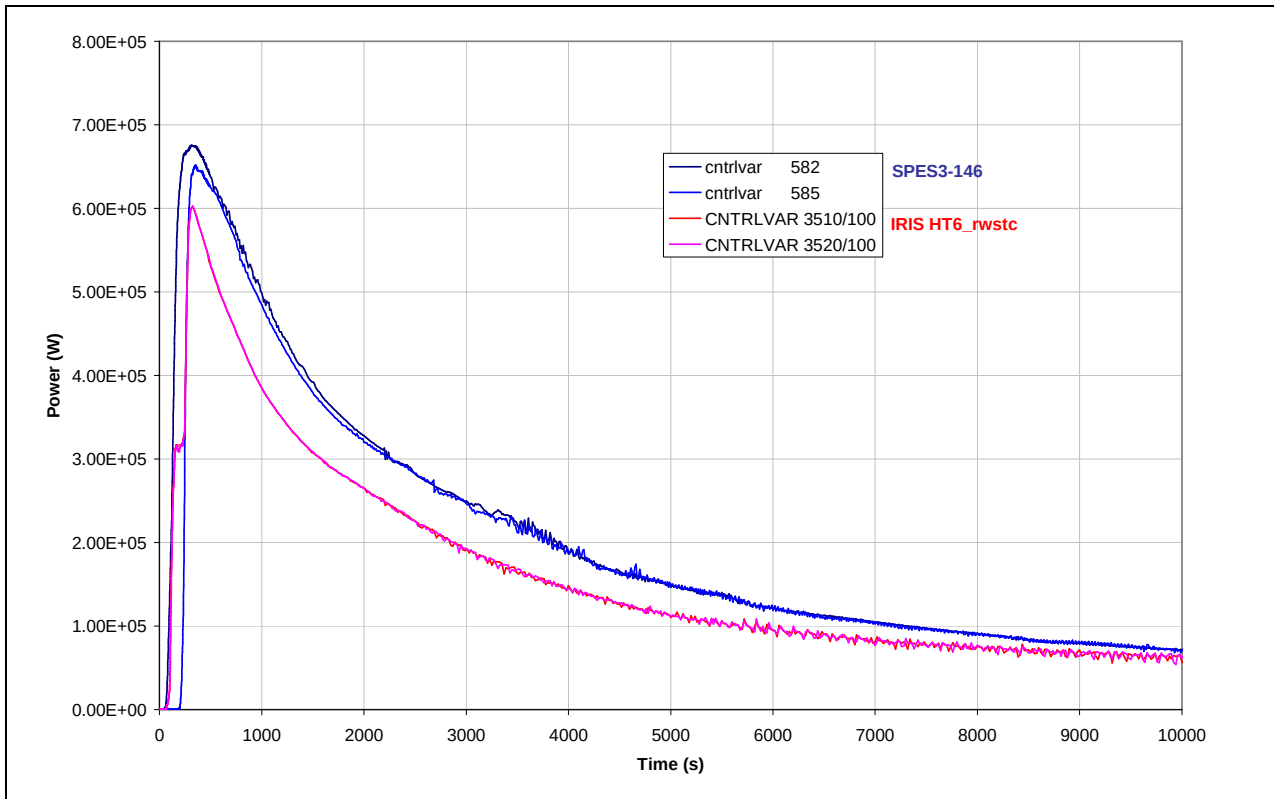


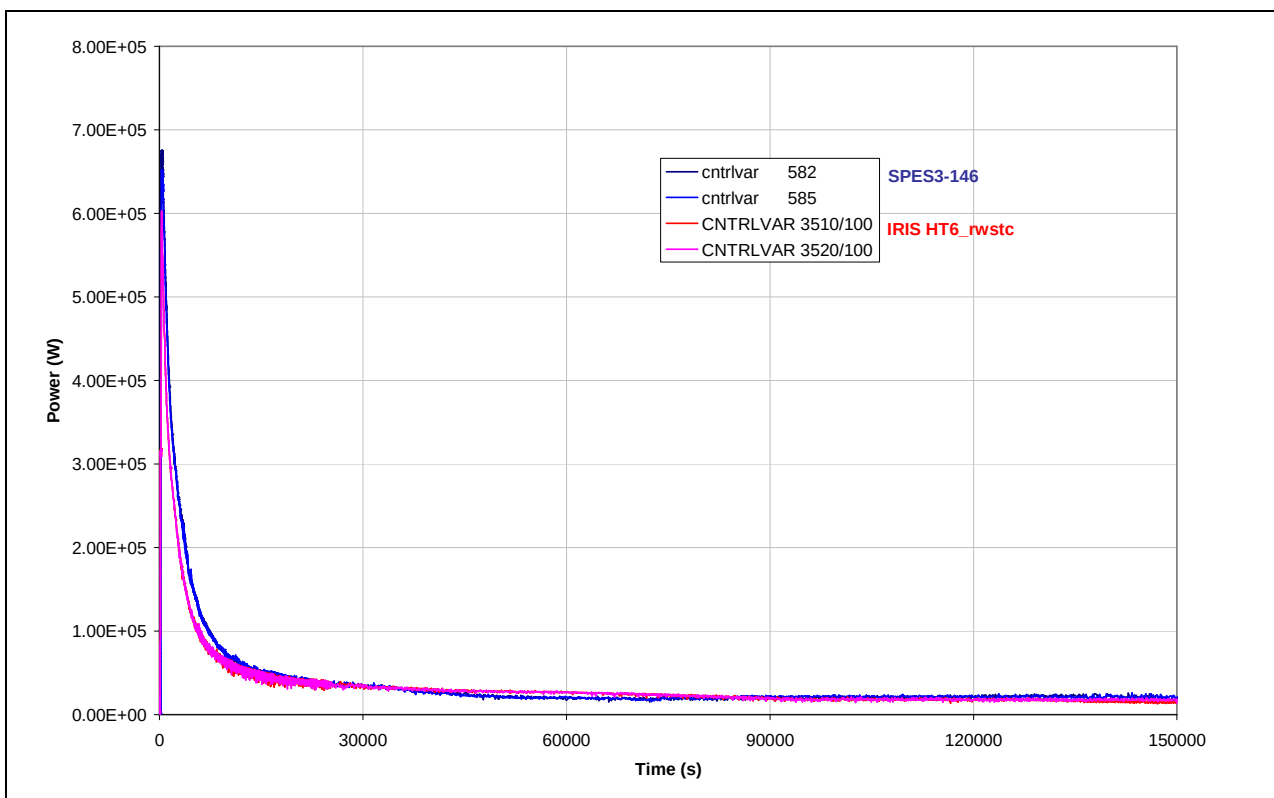
Fig.8. 82 – SPES3-146 and IRIS HT6\_rwstc RWST top integral mass flow



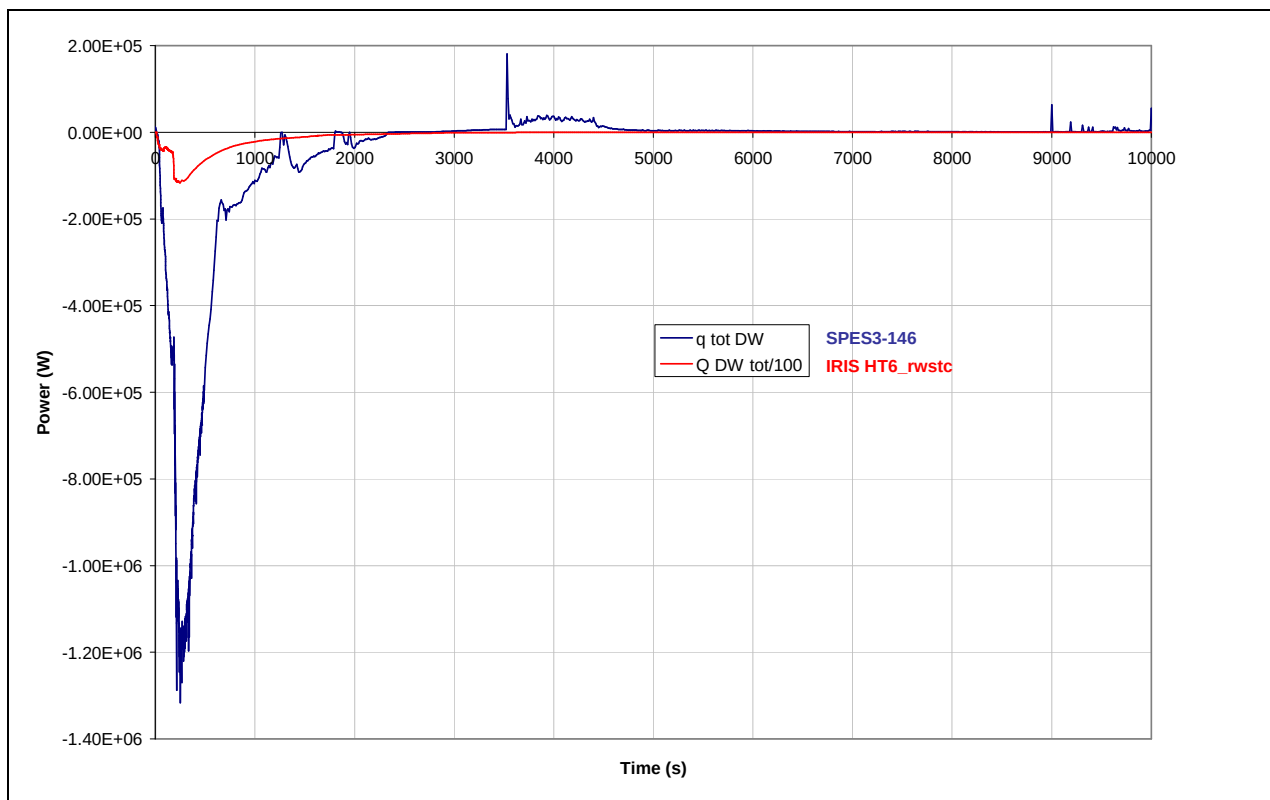
**Fig.8. 83 – SPES3-146 and IRIS HT6\_rwstc RWST power (window)**



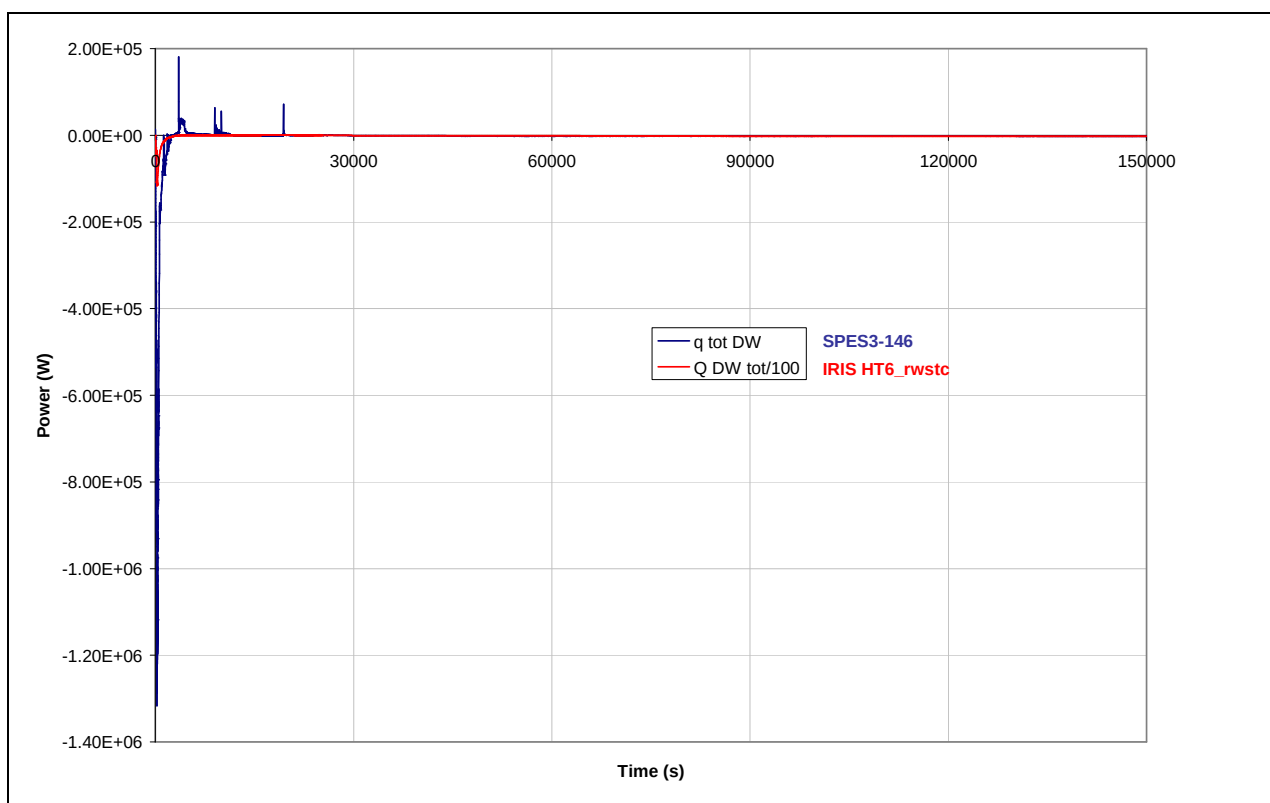
**Fig.8. 84 – SPES3-146 and IRIS HT6\_rwstc RWST power**



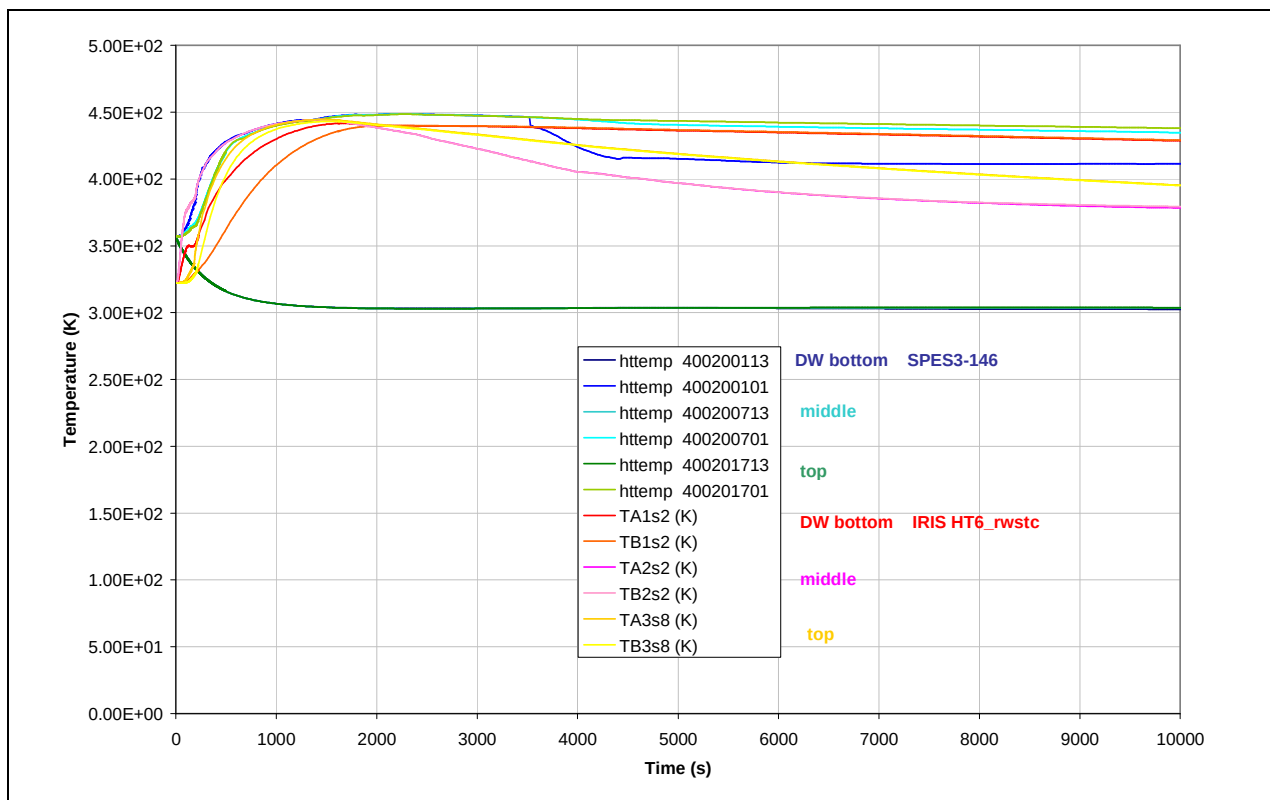
**Fig.8. 85 – SPES3-146 and IRIS HT6\_rwstc DW power (window)**



**Fig.8. 86 – SPES3-146 and IRIS HT6\_rwstc DW power**



**Fig.8. 87 – SPES3-146 and IRIS HT6\_rwstc DW inner and outer wall temperature (window)**



**Fig.8. 88 – SPES3-146 and IRIS HT6\_rwstc DW inner and outer wall temperature**

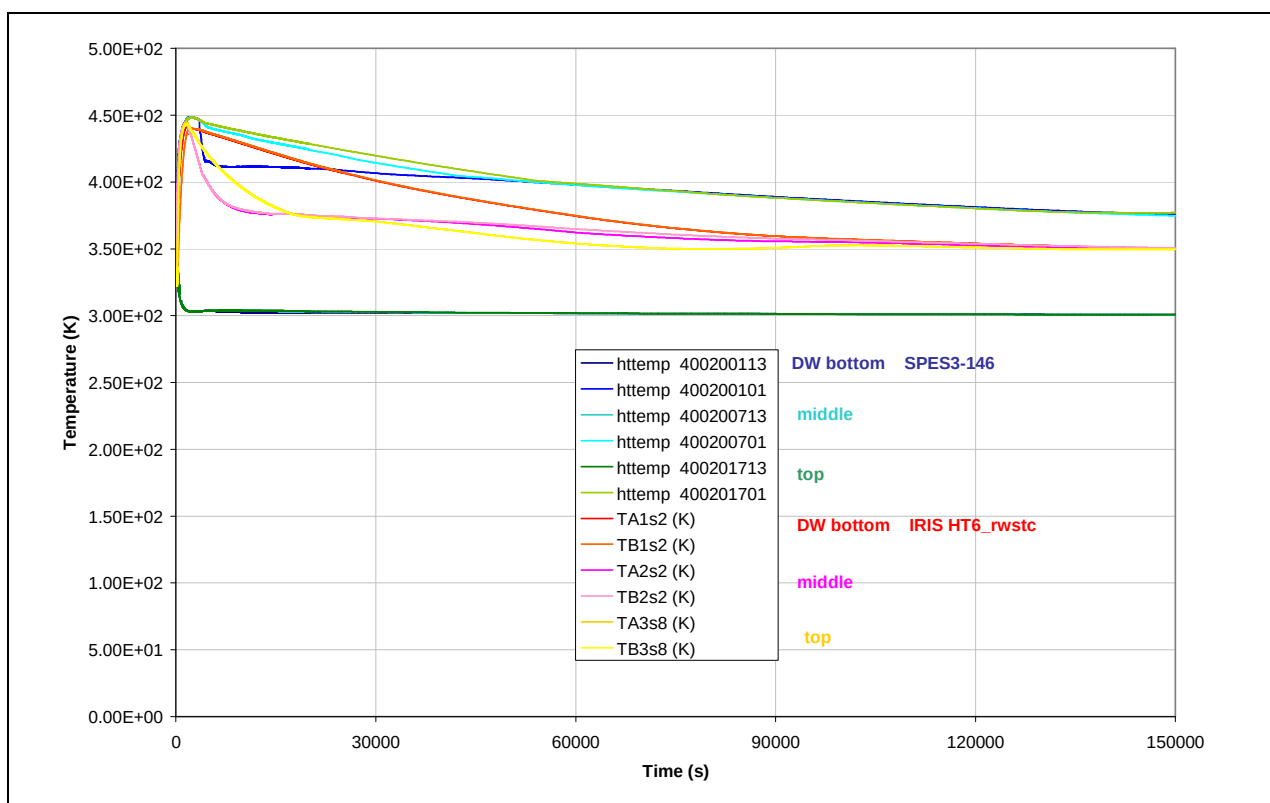


Fig.8. 89 – SPES3-146 and IRIS HT6\_rwstc T (PRZ) – T (SG)

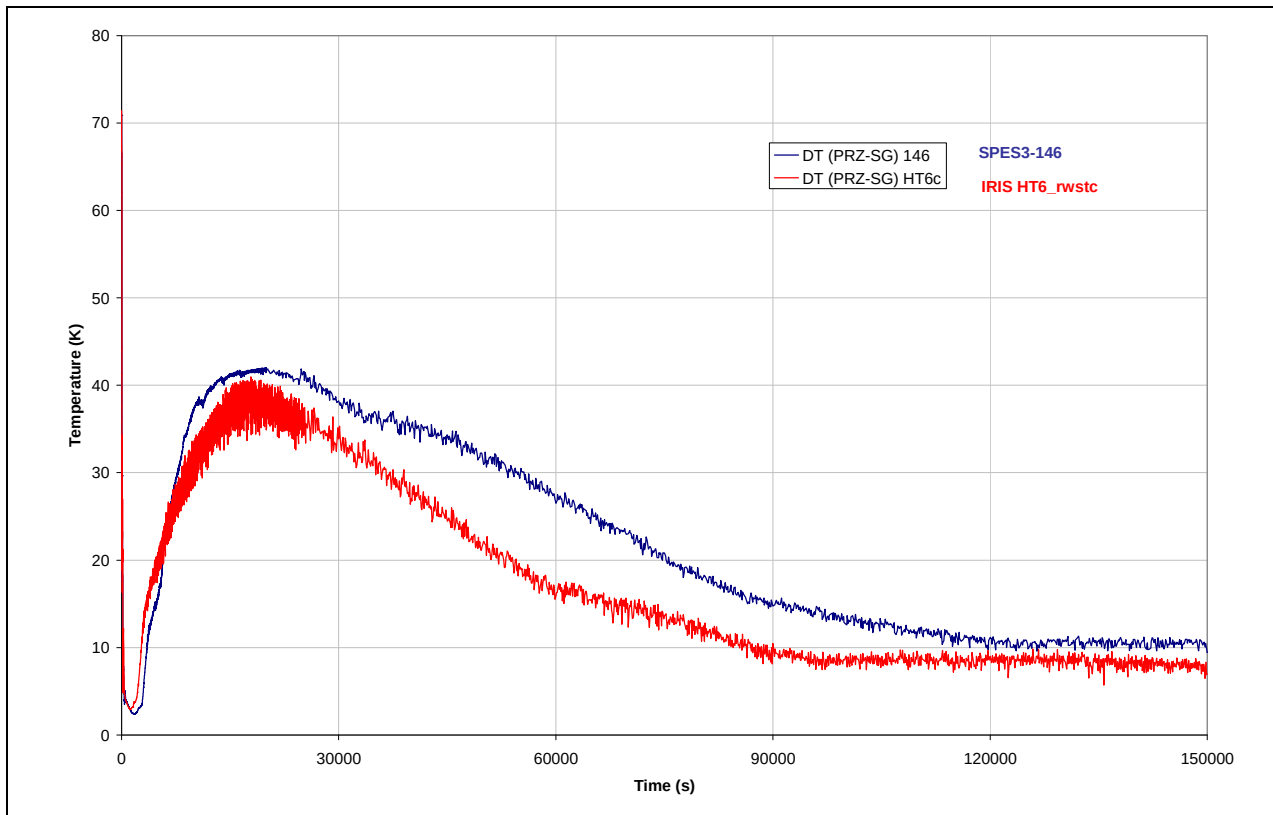
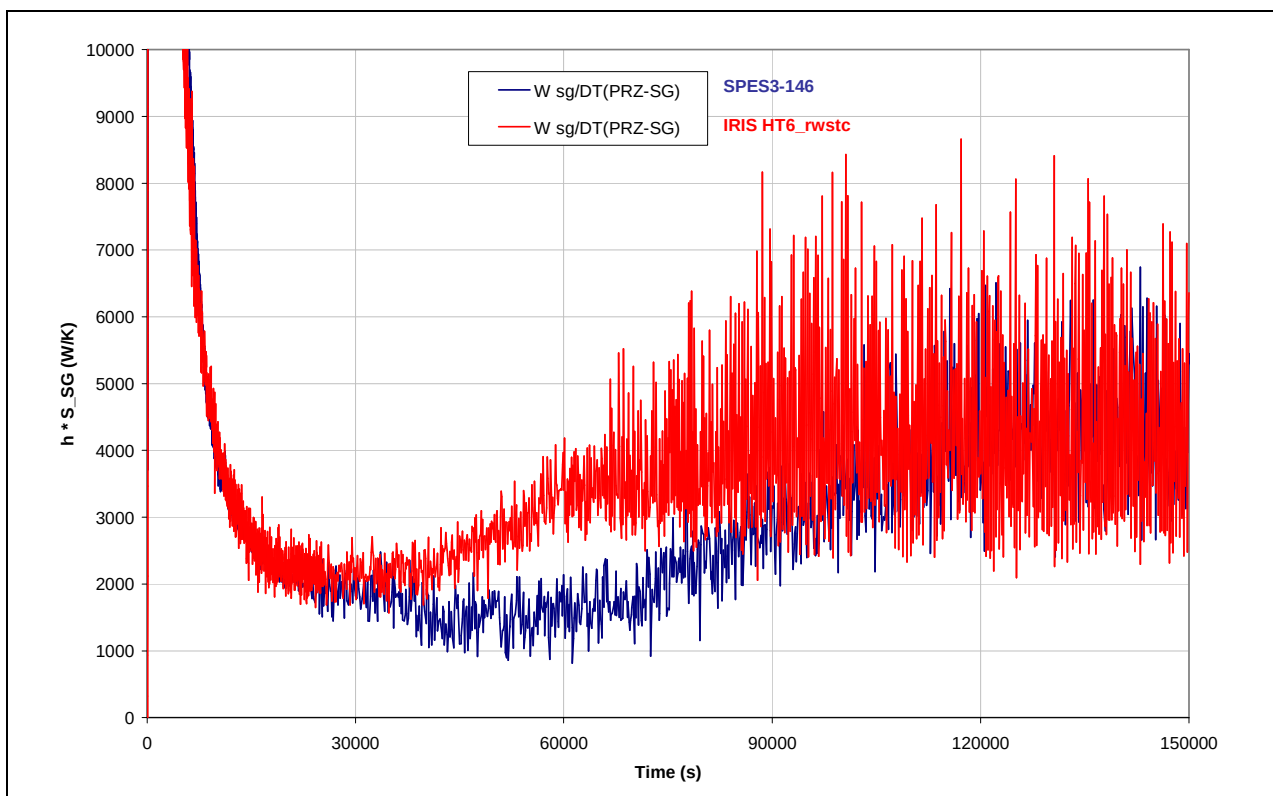
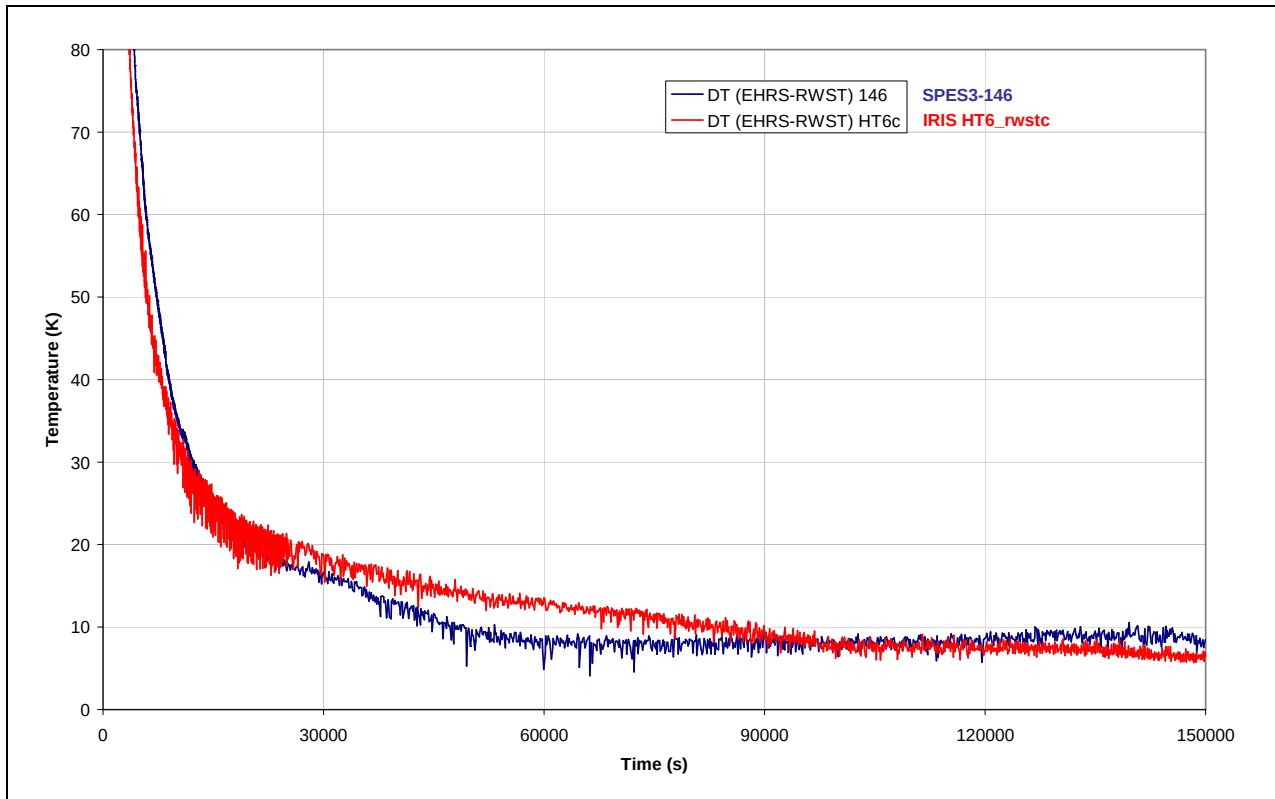


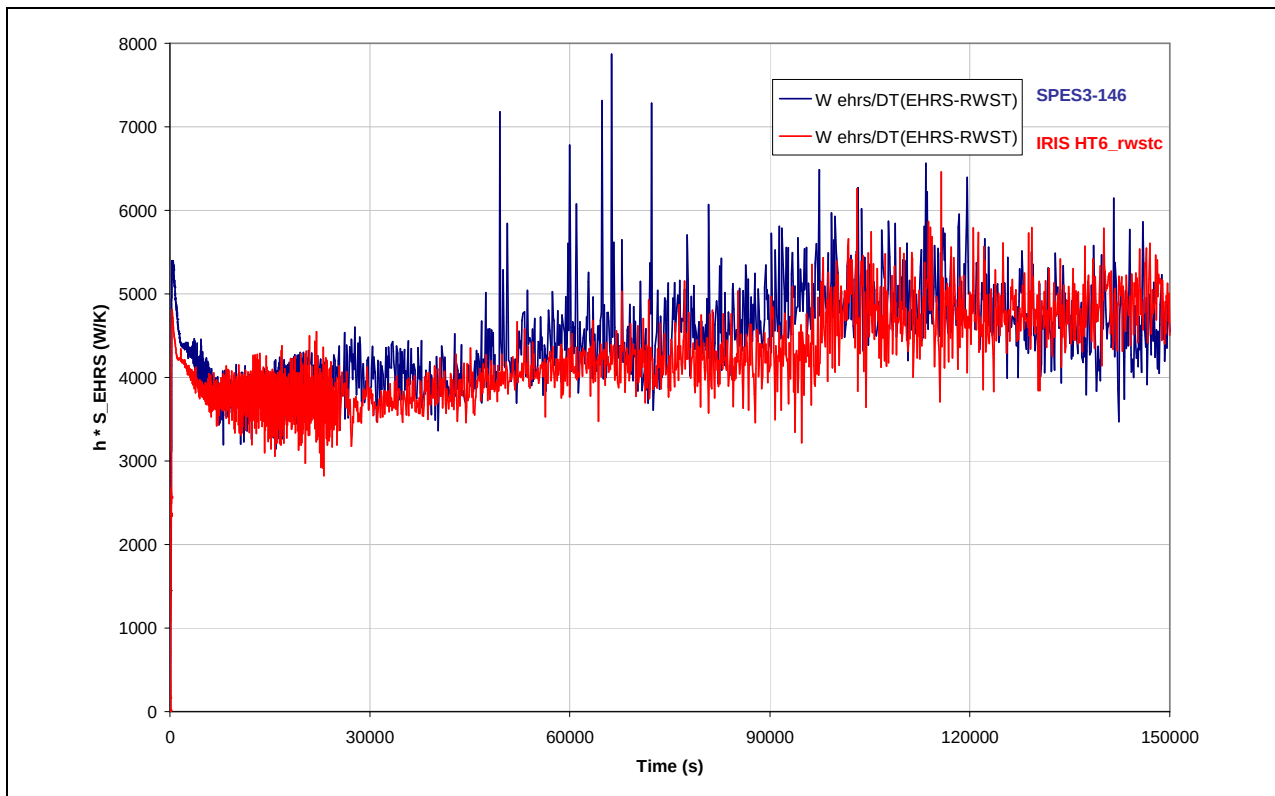
Fig.8. 90 – SPES3-146 and IRIS HT6\_rwstc SG global heat transfer coefficient



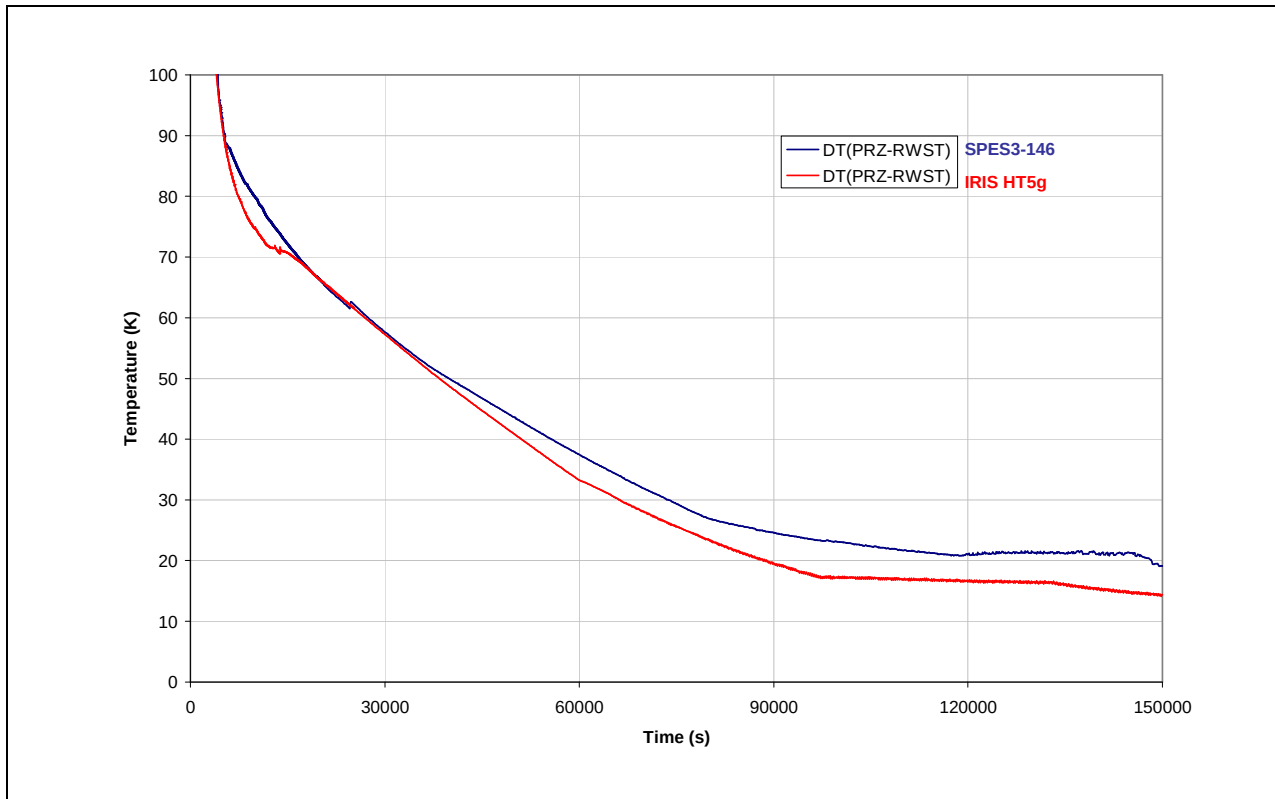
**Fig.8. 91 – SPES3-146 and IRIS HT6\_rwstc T (EHRS) – T (RWST)**



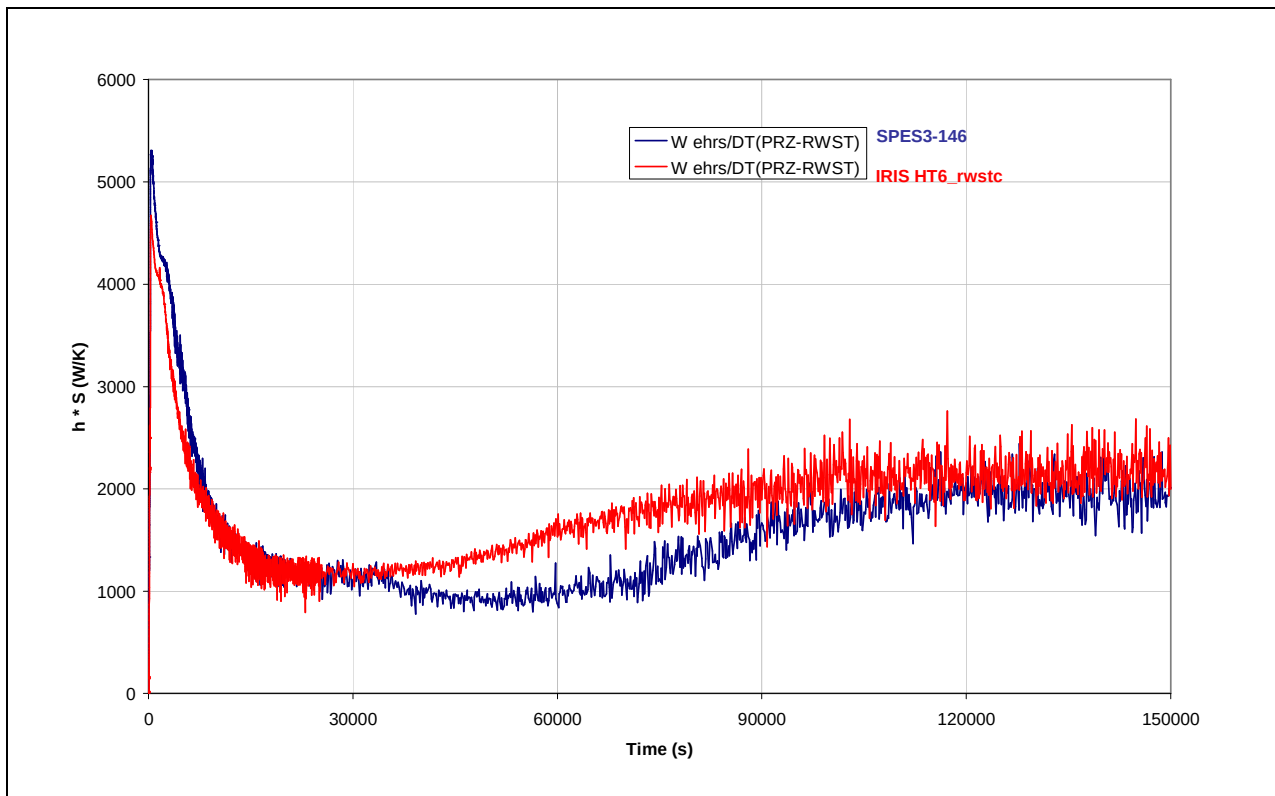
**Fig.8. 92 – SPES3-146 and IRIS HT6\_rwstc EHRS global heat transfer coefficient**



**Fig.8. 93 – SPES3-146 and IRIS HT6\_rwstc T (PRZ) – T (RWST)**



**Fig.8. 94 – SPES3-146 and IRIS HT6\_rwstc PRZ-RWST global heat transfer coefficient**





## 9. DVI DEG BREAK: DESIGN REVIEW SPES3-147 CASE AND IRIS HT6\_RWSTC

SPES3-147 and IRIS-HT6\_rwstc represent a base cases for SPES3 and IRIS, which can be utilized for the Fractional Scaling Analysis (FSA) application.

The SPES3-147 has the same characteristics as case SPES3-146, but scaling of the Steam Generator tubes is closer to 1:100 than in SPES3-146. In this case, the SPES3 SG tube number has been reduced from 14 to 13 for each row, to better represent the 656 IRIS tubes per row.

The main SPES3-147 characteristics are reported below:

*SPES3-147: DVI break base case*

- As in case SPES3-146:

Corrected input mistakes on area of volumes 509 and 513, set to  $1.4957\text{E-}4 \text{ m}^2$  (it was  $1.4957 \text{ m}^2$ );

Corrected input mistake at PSS sparger area (sngljun 474 and 484), set to  $2.0268\text{E-}3 \text{ m}^2$  (it was  $5.067\text{E-}4 \text{ m}^2$ );

DW volume  $32.27 \text{ m}^3$  ( $\text{Di} = 1.62 \text{ m}$ );

DW thickness 15 mm (corresponding to design pressure of 1.5 MPa);

RC volume  $4.5 \text{ m}^3$  ( $\text{Di top} = 0.961 \text{ m}$ ;  $\text{Di bot} = 0.553 \text{ m}$ );

RC thickness top 10 mm, bot 8 mm;

QT volume  $0.336 \text{ m}^3$  ( $\text{Di} = 0.37 \text{ m}$ );

QT thickness 6 mm;

PSS volume  $4.59 \text{ m}^3$  ( $\text{Di top} = 1.182 \text{ m}$ ;  $\text{Di bot} = 0.679 \text{ m}$ );

PSS thickness top 12 mm, bot 8 mm;

LGMS volume  $1.5 \text{ m}^3$  ( $\text{Di top and bot} = 0.554 \text{ m}$ ;  $\text{Di mid} = 0.831 \text{ m}$ );

LGMS height 4 m;

LGMS thickness top and bot 8 mm, middle 10 mm;

ADS ST Stage-I calibrated orifice diameter 5.637 mm;

ADS DT Stage-I calibrated orifice diameter 7.973 mm;

EHRSA and B CL calibrated orifice diameter 5.9 mm (resized for pressure drop adjustment, original size 5 mm);

EHRSC CL calibrated orifice diameter 8.3 mm (resized for pressure drop adjustment, original size 7 mm);

RC to DVI line calibrated orifice diameter 1 mm;

Main PSS vent pipe diameter 2 ½" Sch. 40 ( $\text{Di} = 62.7 \text{ mm}$ ) (from 2" Sch. 40);

Extension PSS vent pipe diameter 1" Sch. 40 ( $\text{Di} = 26.6 \text{ mm}$ ) (from ½" Sch. 40);

LGMS to DVI line calibrated orifice diameter 3.6 mm;

Extension PSS orifice resized ( $\text{D} = 17.5 \text{ mm}$ ) to compensate for pressure drops variation for PSS sparger area correction (original size 19 mm);

Extension PSS vent pipe length decreased to match IRIS length. Connection to DW 20.664 m from RV bottom (original elevation 22.098 m);

PSS sparger set at 0.75 m from PSS bottom to match IRIS (original position 1 m from bottom);

PSS bottom modeled with two branches, Fig.3. 9;

RWST top pipe connection to atmosphere control volume, Fig.3. 10;  
 LGMS initial level set to have 1 m<sup>3</sup> water;  
 EHRS-A and B: 0.6 tubes out of 3 thermally insulated with Teflon to simulate 240 IRIS EHRS tubes; 4% total surface covered to compensate for AISI-304 instead of Inconel-600;  
 EHRS-C: 0.2 tubes out of 5 thermally insulated with Teflon to simulate 480 IRIS EHRS tubes; 4% total surface covered to compensate for AISI-304 instead of Inconel-600;  
 EHRS Hot Leg-A and B resized to 1 ¼" Sch. 80 (original size 2" Sch. 80); EHRS loops in Fig.3. 11.  
 EHRS Cold Leg-A and B resized to ½" Sch. 80 (original size 1 ¼" Sch. 80);  
 EHRS Hot Leg-C resized to 2" Sch. 80 (original size 2 ½" Sch. 80);  
 EHRS Cold Leg-C resized to ¾" Sch. 80 (original size 1 ½" Sch. 80);  
 EHRS HL-A and B added an orifice (D = 17 mm ) for pressure drop adjustment;  
 EHRS HL-C added an orifice (D = 24 mm ) for pressure drop adjustment;  
 EHRS tube Fouling Factor: Left 2.9 (original value 2.725); Right 2.77 (original value 3.54284);  
 RWST-AB slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.490494 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);  
 RWST-C slice: Hot column area 0.119167 m<sup>2</sup> (original area 0.492521 m<sup>2</sup>); Cold column area 1.601169 m<sup>2</sup> (original area 1.217681 m<sup>2</sup>);  
 RWST-AB and C side junction area 0.134618 m<sup>2</sup> (original value 0.105772 m<sup>2</sup>).  
 Resized orifice at SG inlet (D = 11.7 mm) for SG parallel tube row oscillation reduction (original size 12.5 mm)  
 DW, RC, PSS, LGMS, QT heat structure initial temperature 84 °C;

- New for this case

SG tube number reduced to 13 for each SG pair (original tube number 14).

## 9.1 SPES3-147 and IRIS HT6\_rwstc

The full power steady conditions, starting point for the transient, are summarized in Tab.9. 1 for SPES3 and IRIS.

The list of the main events occurring during the transient with timing and quantities is reported in Tab.9. 2.

### 9.1.1 Transient phases and description

The first 10 s of SPES3 data (-10 s to 0 s) are steady state conditions. The IRIS data start from the break occurrence.

All times of the events are given with respect to the break time assumed as time 0 s.

#### Break

The break mass flow peaks and trends, RV side (identified as SPLIT), are very similar in SPES3 and IRIS until the ADS intervention (190.99 s in SPES3 and 174 s in IRIS), Fig.9. 1. Later, during the phase of critical flow, until the containment and primary pressure equalization (2340 s in SPES3 and 1730 s in IRIS), the SPES3 mass flow is greater than IRIS one, driven by the higher SPES3 primary side pressure (higher pressure probably due to the larger thermal inertia of RV metal structures), Fig.9. 1, Fig.9. 2, Fig.9. 3. When

the break flow is no more critical, some differences are observed, mostly related to the containment-RV differential pressure that drives water in a sense or the opposite, Fig.9. 4, Fig.9. 5, Fig.9. 9, Fig.9. 10.

The break mass flow containment side (identified as DEG) is related to the safety injection of EBT (190.99 s in SPES3 and 174 s in IRIS) and later of LGMS (2225.69 s in SPES3 and 1585 s in IRIS), Fig.9. 2, Fig.9. 57, Fig.9. 68.

A reverse flow from containment to RV is observed through the SPLIT line, after the RC level has reached the DVI elevation up to reach the DW, accordingly to phases when the containment pressure is higher than the RV pressure, Fig.9. 2, Fig.9. 3, Fig.9. 26, Fig.9. 27.

### *Blowdown, RV depressurization, containment pressurization*

The blowdown phase depressurises the RV with mass and energy transfer to the containment.

The SPES3 and IRIS PRZ pressures are shown in Fig.9. 6, Fig.9. 7, Fig.9. 8. The depressurization rate is very similar until the ADS intervention (190.99 s in SPES3 and 174 s in IRIS), then SPES3 pressure is higher than IRIS, probably due to the heat release from RV metal structures (oversized in SPES3) and for the lower mass discharged through the ADS in SPES3, until about 1500 s, Fig.9. 54. After the containment and RV pressures are coupled (2340 s in SPES3 and 1730 s in IRIS) the SPES3 PRZ pressure stays above, correspondingly to the SPES3 containment one, Fig.9. 9, Fig.9. 10. In the long term, SPES3 shows a larger depressurization rate than IRIS, and they seem to stabilize around 0.2 MPa around 150000 s, Fig.9. 10.

While the PRZ depressurizes, the containment pressure increases as shown in Fig.9. 6, Fig.9. 7, Fig.9. 4, Fig.9. 5, Fig.9. 9. The SPES3 and IRIS DW pressurization trend is similar even if delayed in SPES3 due to the greater containment heat structures, Fig.9. 4, Fig.9. 5. The pressure increase around 190 s is due to the ADS Stage-I intervention that discharge mass and energy into the DW, Fig.9. 12. After that, pressure increases up to reach a peak of 0.935 MPa in SPES3 at 2230 s and 0.936 MPa in IRIS at 1405 s. When the RV and DW pressures equalize, the ADS Stage-I mass flow stops and the DW pressure decreases thanks to the LGMS injection into the RV (intact loop) and into the RC (broken loop), Fig.9. 9, Fig.9. 68.

A faster DW depressurization occurs when a reverse flow from the PSS to the RV occurs through the vent lines, Fig.9. 14, starting at 3230 s (PSS-A) – 3370 s (PSS-B) s in SPES3 and 2310 s in IRIS.

### *Steam dumping into PSS*

The containment space (DW and RC) pressurization causes the transfer of a steam-gas mixture from the DW to the PSS through the vent lines (starting at 15 s in SPES3 and 22 s in IRIS) lasting until mass flow exits the ADS-Stage-I, Fig.9. 14, Fig.9. 12. The mass transferred from PSS to the DW is shown in Fig.9. 15. Due to the different shape of the PSS in SPES3 and IRIS, starting with the same initial mass and ending the injection at the same final level (sparger elevation), the total mass injected from PSS to DW results about 155 kg greater in SPES3 than IRIS, Fig.9. 15, Fig.9. 16.

The non-condensable gas quality in the DW is shown in Fig.9. 17 and Fig.9. 18. The way steam sweeps away gas from the DW seems similar in SPES3 and IRIS, even if the air quality remains higher in IRIS containment than SPES3 one. Moreover, the DW air quality increases more in IRIS than SPES3 in the last phase of PSS to the DW injection as if a larger quantity of air were transferred back from the PSS, Fig.9. 18, Fig.9. 14.

Steam is dumped underwater through the PSS sparger and gas (air in SPES3 and N<sub>2</sub> in IRIS) pressurizes the PSS and LGMS gas space, Fig.9. 19, Fig.9. 20, Fig.9. 21, Fig.9. 22. The PSS and LGMS pressure follows the DW pressure trend and, after the containment depressurization for LGMS and PSS injection, it is lower in IRIS than SPES3 until about 120000 s when the situation reverts due to the larger SPES3 depressurization rate, Fig.9. 23, Fig.9. 24. Anyway, an important difference between SPES3 and IRIS occurs when the PSS injection into the DW stops. In SPES3, all containment volumes reach the same pressure

while in IRIS, the LGMS and PSS remain more pressurized than the DW, Fig.9. 23, Fig.9. 24. In IRIS, the PSS and DW volumes remain separated, from the pressure point of view, as the PSS to DW vent pipes remain partially full of water after the PSS injection to the DW is over, preventing non-condensable gas flowing from PSS to DW and pressure equalization, Fig.9. 25. In SPES3, the PSS to DW vent pipes empty after the injection is over and pressure equalizes. Fig.9. 16 shows the PSS levels. The initial value is different in SPES3 and IRIS due to the different tank shape with the same liquid mass contained. The final value of level, with respect to the PSS bottom, is the same and it corresponds to the PSS sparger elevation.

The PSS water temperature increases, Fig.9. 28, Fig.9. 29, thanks to the mass transfer from the DW, Fig.9. 14. Temperature increases more in SPES3 than IRIS notwithstanding the lower mass transferred from the DW to the PSS, in SPES3, during the first phase of injection, Fig.9. 30. This can be explained considering the higher SPES3 PRZ pressure and the consequently higher energy fluid exiting the RV and entering the DW and PSS, Fig.9. 6.

Both the liquid and gas temperatures are reported in Fig.9. 28, Fig.9. 29. In IRIS, the top gas temperature is generally higher than the liquid one (Gothic code results not clearly explainable here), while in the PSS lower part, the gas temperature is closer to liquid one than in SPES3. This can be explained by the initial heat structure preheating in the gas zone of SPES3 PSS that limits the gas temperature decrease.

Temperatures always remain below saturation at the maximum PSS pressure and also when pressure decreases (maximum liquid temperature reached in SPES3 is 120 °C at 0.91 MPa and in IRIS 94 °C at 0.25 MPa). In the long term, the SPES3 PSS temperature decreases more than IRIS one, being related to the containment pressure and probably due to the higher heat losses to the environment.

#### *S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation*

The high containment pressure set-point (1.7e5 Pa) is reached at 32.09 s in SPES3 and 30 s in IRIS and it triggers the S-signal.

The S-signal (Safeguard) starts the reactor SCRAM, isolates the three secondary loops and actuates the EHRS-A and B.

Power released to the fluid in the core is shown in Fig.9. 31 and Fig.9. 32 and very similar trends are observed between SPES3 and IRIS.

Power transferred to the steam generators is shown in Fig.9. 33 and Fig.9. 34. The peak of removed power occurs following the EHRS-C intervention with similar values in SPES3 and IRIS (1.68 MW at 306 s in SPES3 and 1.69 MW at 320 s in IRIS), after that, removed power in SPES3 is higher than in IRIS until about 7500 s to become very similar for the rest of the transient.

The MFIV and MSIV of the secondary loops are contemporarily closed in 5 s both in SPES3 and IRIS. The secondary loop mass flows are shown in Fig.9. 35 and Fig.9. 36. They stop at the secondary loop isolation and re-start at the EHRS actuation. The EHRS-A and B in SPES3 are actuated at the secondary side isolation and a natural circulation flow establishes. The corresponding EHRS-1 and 3 in IRIS are actuated with 10 s delay with respect to the secondary loop isolation, and a short pause in secondary loop flow is observed, Fig.9. 35. The EHRS-C in SPES3 is actuated at LM-signal, starting the secondary loop natural circulation after about 150 s from the loop isolation. EHRS-2 and 4 in IRIS are actuated on LM-signal, Fig.9. 35. For a direct comparison of the eight SG mass flow in IRIS and three SGs in SPES3 (loop C consists of two tube rows), the SG mass flow curves have been summed in IRIS. It appears that, at the EHRS actuation, the SPES3 and IRIS mass flow peaks are similar.

The SPES3 EHRS-A and B and the EHRS-1 and 3 in IRIS are actuated by opening in 2 s the related isolation valves. The peak flowrate of 0.265 kg/s is reached at 38 s in SPES3 while a peak of 0.287 kg/s is reached in IRIS at 45 s. Between 1000 s and 10000 s, a quite steady condition is reached with the SPES3 natural circulation about 18% higher and less oscillating than IRIS, Fig.9. 37. After 10000 s, larger

oscillations appear in SPES3 and mass flows decrease getting closer to IRIS ones. After about 70000 s, mass flows are very similar in the two plants, Fig.9. 38.

Power removed by the EHRs is shown in Fig.9. 39, Fig.8. 39 and Fig.9. 40. The SPES3 EHRs-A and B peaks of removed power occur at 205 s with a value of 369 kW each, while the IRIS EHRs-1 and 3 power peaks of 335 kW occur at 158 s. The average power removed by the SPES3 EHRs-A and B in the long term is around 10.1 kW each, while the IRIS EHRs-1 and 3 is about 9 kW each.

The secondary side pressures are shown in Fig.9. 41 and Fig.9. 42. After isolation, pressure increases due to the heat transfer from the primary side that makes water contained in the SG tubes evaporate. The SG tube levels decrease until water stored in EHRs heat exchangers is poured into the loops and power begins to be removed, Fig.9. 43 and Fig.9. 44, Fig.9. 33. Similar trends are observed for SPES3 and IRIS, even if SPES3 level is about 1 m below, until 20000 s. After that, the SPES3 SG level slowly increases getting closer to IRIS. When SPES3 SG tube level is below the IRIS one, a larger surface is available for the heat transfer with the primary side and consequently a larger exchanged power results, Fig.9. 43 and Fig.9. 44.

The SG pressure peaks are reached around 69 s in SPES3 and 57 s in IRIS, then pressure decreases after some oscillations lasting until about 200 s, Fig.9. 41. The pressure decreasing rate is similar in SPES3 and IRIS as power transferred through the SGs is similar, Fig.9. 34,

#### *Pump coastdown and primary circulation through RI-DC check valves*

The PRZ levels of SPES3 and IRIS are shown in Fig.9. 45. The early phase of level decrease, until the ADS Stage-I intervention (190.99 s in SPES3 and 174 s in IRIS), is due to the loss of mass from the break. In this phase, mass lost from the break, RV side (DVI split) is very similar in IRIS and SPES3, Fig.9. 46. The observed difference in PRZ level can be explained hypothesizing flow instabilities due to steam bubbles at the PRZ surge holes in IRIS, not occurring in SPES3. The level increase after the ADS Stage-I actuation is similar in the two cases until the ADS stop when the containment and RV pressure equalize (2340 s in SPES3 and 1730 in IRIS). The liquid fraction at the pump inlet is reported in Fig.9. 47. Due to the loss of mass from the break, the pump uncovers soon. Water sucked at the ADS Stage-I maintains a certain liquid fraction at the pump suction until about 400 s in IRIS, while the SPES3 pump is uncovered soon after the PRZ early emptying. This can be explained considering the different position of the pump in the two plants, inside the RV in IRIS and outer and connected by piping in SPES3, less interested by the water path to the ADS through the PRZ surge holes.

The pump coastdown is triggered by a Low PRZ level signal delayed of 15 s (129.83 s in SPES3 and 145 s in IRIS). Soon after the pump suction is uncovered, the RV natural circulation through the pump interrupts.

The core outlet flow is shown in Fig.9. 48 and Fig.9. 49 and it is similar for IRIS and SPES3 except between 1500 s and 3000 s, probably related to the void fraction of fluid at the check valves. Later the values are very similar, even if IRIS shows stronger oscillations.

The pump stop and pressure decreasing in the DC, let the RI-DC check valves open at 139÷142 s in SPES3 and 185 s in IRIS and allow the natural circulation from riser to SG annuli at a lower level in the RV. The RI-DC check valve mass flows are shown in Fig.9. 50 and Fig.9. 51 for each SG (for SG-A in SPES3 it is the sum of mass flows through the check valves 161 and 164, for SG-B of mass flow through the check valves 162 and 165 and for SG-C of mass flow through the check valves 163 and 166; for IRIS, the mass flows are combined for a direct comparison with SPES3). The trend and value of the RI-DC check valve mass flow is strictly related to the core flow, Fig.9. 49.

The fast RV depressurization rapidly causes flashing of the primary circuit and void begins at the core outlet at 171 s in SPES3 and 186 s in IRIS, Fig.9. 52, Fig.9. 53. The low liquid fraction period in the core lasts until about 5000 s in IRIS and 6000 s in SPES3.



### *LM-Signal: EHRS-C, ADS Stage-I and EBT actuation*

The LM-Signal (LOCA mitigation) occurs at 190.99 s in SPES3 and 174 s in IRIS when the low PRZ pressure set-point (11.72e6 Pa) is reached, Fig.9. 7.

The LM-signal actuates the EHRS-C in SPES3 and EHRS-2 and 4 in IRIS, opens the ADS stage-I, and opens the EBT actuation valves.

The SPES3 EHRS-C and the IRIS EHRS 2 and 4 are actuated by opening in 2 s the related isolation valves. The peak flow rate of 0.549 kg/s is reached at 194 s in SPES3 while the IRIS peak of 0.580 kg/s is reached at 190 s. After the peak, a quite steady natural circulation flow of about 0.35 kg/s is reached in SPES3 between 700 s and 9000 s, while in IRIS the mass flow decreases until about 2000 s showing later oscillations around 0.2 kg/s until about 10000 s, Fig.9. 37, Fig.9. 38. The SPES3 and IRIS mass flows are similar in the long term, Fig.9. 38.

Power removed by SPES3 EHRS-C and IRIS EHRS 2 and 4 is shown in Fig.9. 39, Fig.9. 40. The SPES3 EHRS-C peak of removed power occurs at 331 s with a value of 728 kW, while the IRIS EHRS 2 and 4 power peak occurs at 325 s with a value of 636 kW. The average power removed by the SPES3 EHRS-C in the long term is 20.2 kW, while that removed by IRIS EHRS 2 and 4 is 18 kW.

The Stage-I of the ADS trains are actuated contemporarily on LM-signal (190.99 s in SPES3 and 174 s in IRIS) both in SPES3 and IRIS. The SPES3 mtrvlv 153 on the Single Train (ST) and 143 on the Double Train (DT) are fully open in 10 s and so do the three IRIS ADS train valves. The ADS Stage-I mass flows are shown in Fig.9. 12 and Fig.9. 13. For a direct comparison between SPES3 and IRIS, two of the IRS trains are condensed in one. SPES3 and IRIS show similar trends. Both IRIS and SPES3 show a two-peak trend flow, with the first SPES3 peak of 1.344 kg/s at 201 s and the second peak of 1.998 kg/s at 229 s and the first IRIS peak of 1.301 kg/s at 186 s and the second peak of 1.988 kg/s at 245 s.

When the ADS intervene, the PRZ is empty in SPES3 and almost empty in IRIS, Fig.9. 45, and the ADS flow peak is due to steam flowing toward the QT. At the ADS intervention, water is sucked upwards and the PRZ level increases. The second ADS mass flow peak is caused by an increasing liquid void fraction at the PRZ top that decreases when the PRZ empties.

The ADS integral flow is shown in Fig.9. 54, Fig.9. 55 and mass exited from the RV through the ADS in IRIS is about 1.2 times that exited from SPES3, until about 2000 s. Around 65000 s mass restarts to exit the RV through the ADS Stage-I in IRIS, but this is not observed in SPES3.

The RV mass is shown in Fig.9. 56. The trend is very similar in the two plants, with a certain delay in SPES3 in the early 30000 s. The final value of mass in the RV is around 2350 kg in both plants.

The LM-signal triggers the EBT actuation. Both in SPES3 and IRIS, the EBT actuation valves are fully open in 15 s. The EBT injection mass flows are shown in Fig.9. 57 and Fig.9. 58 and they are similar in SPES3 and IRIS until about 1800 s. The EBT injection into the broken DVI is initially about 14 times larger than injection into the intact DVI, due to the presence of the break. In SPES3, the EBT injection continues until both EBTs are empty, Fig.9. 60 while in IRIS the intact loop EBT interrupts its injection between 1810 s and 7600 s and between 17480 s and 21900 s to completely empty at 33200 s, Fig.9. 61. The trend of injection is related to the RV mass that in IRIS increases more than in SPES3 thanks to the stronger LGMS injection until about 18000 s, Fig.9. 56, Fig.9. 68.

Soon after the EBT actuation, a liquid circulation from the RV toward the EBT starts at the EBT to RV connections, Fig.9. 59, then, after such connection is uncovered, steam replaces water contained in the EBT top lines and tanks. The SPES3 broken loop EBT is empty at 482 s while the corresponding IRIS EBT is empty at 605 s. The SPES3 intact loop EBT is empty at 3000 s while IRIS's one at 35500 s, Fig.9. 60, Fig.9. 61.

The EBT actuation, starting at 191 s in SPES3 and at 174 s in IRIS, is responsible for the mass flow through the break line, containment side, Fig.9. 1. The EBT injected mass enters the RV through the intact DVI, while a reverse flow occurs through the broken DVI towards the break, Fig.9. 62, Fig.9. 63. Such reverse flow lasts

until the RV and containment pressures equalize, Fig.9. 9, Fig.9. 10. After that, the DVI mass flow in SPES3 and IRIS is driven by the differential pressure between RV and containment and by the amount of water in one or the other side of the plant.

#### *RV saturation*

The RV mass decreases due to the loss of mass from the break, Fig.9. 56. The fast RV depressurization leads to reach the saturation conditions (core inlet T = core outlet T) at 250 s in SPES3 and 245 s in IRIS. Two-phase mixture occurs in the core, Fig.9. 52, but the natural circulation through the RI-DC check valves allows to remove the decay heat and a temperature difference establishes again between core inlet and outlet when the core is under liquid single-phase, after 4000 s in IRIS and 6000 s in SPES3. The inlet and outlet core temperatures are shown in Fig.9. 64 and Fig.9. 65. The SPES3 core temperatures establish at a higher value than IRIS when PRZ pressure is higher, then the situation reverts.

The core heater rod temperatures are shown in Fig.9. 66 and Fig.9. 67. Notwithstanding the core liquid void fraction decrease, the rod surface temperatures never overcomes the maximum steady state temperature. Corresponding to the fluid temperature, even the heater rod temperatures stabilize at a higher value in SPES3 than IRIS, when PRZ pressure is higher and vice-versa.

#### *Low DP RV-Containment signal, LGMS and RC to DVI valve actuation*

The containment pressure peak of 0.910 MPa occurs at 2230 s in SPES3 and of 0.936 MPa at 1405 s in IRIS, Fig.9. 4.

The “Low DP RV-Containment” signal set point of 50 kPa is reached at 2225.7 s in SPES3 and 1585 s in IRIS.

The combination of LM-signal AND Low DP RV-Containment signal actuates the LGMSs and opens the valves on the lines connecting the RC to the DVIs.

The SPES3 and IRIS LGMS isolation valves are fully open in 2 s as well as the RC to DVI line isolation valves.

The LGMS injection is related both to gravity and to LGMS air space pressurization (through PSS to LGMS balance lines) by non-condensable gas entering the PSS from the DW. The broken loop LGMS injection into the DVI starts at 2260 s in SPES3 and 1585 in IRIS, while the intact loop LGMS injection into the DVI starts at 2230 s in SPES3 and 1670 in IRIS. The LGMS injection mass flow is shown in Fig.9. 68. Consequently to the LGMS injection into the broken DVI, a mass flow from the DEG break line restarts around 2260 s in SPES3 and 1585 s in IRIS, lasting until the LGMS is empty, Fig.9. 2, Fig.9. 3.

Fig.9. 68 shows that a difference exists between the IRIS and SPES3 LGMS injection trend. The SPES3 mass flow is stronger than IRIS in the first phase of injection (~0.14 kg/s in SPES3 and ~0.1 kg/s in IRIS) and then it decreases to about one fourth of its value until the LGMS are empty. In IRIS, the injection starts and then the mass flow decreases gradually until the LGMS are empty, Fig.9. 69. The reason is the different pressurization of LGMS with respect to DVI due to the emptying of the PSS vent pipes in SPES3 and non-emptying of the same pipe in IRIS (see section *Steam dumping into PSS*), Fig.9. 70, Fig.9. 71.

#### *Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV*

The RV and containment pressure equalize at 2340 s in SPES3 and 1730 s in IRIS, Fig.9. 9. After this, the loss of mass through the break, RV side, depends on the periods when the RV pressure is higher than the containment pressure, Fig.9. 2, Fig.9. 3, Fig.9. 9, Fig.9. 10.

After the peak, the containment pressure decreases for steam condensation on the containment wall and for LGMS injection. After the RV and containment pressure are coupled, pressures decreases due to the EHRS heat removal from the primary side, Fig.9. 39. At 2140 s (PSSA) and 2530 s (PSSB) in SPES3 and 1650 s in IRIS, the DW pressure decreases below the PSS pressure, Fig.9. 23. When the differential pressure between PSS and DW is sufficient to overcome the hydrostatic head of the PSS vent pipes, a reverse flow starts from the PSS to the DW through the vent lines, lasting between 2310 s and 4050 s in IRIS and 3250 s to 4310 s in SPES3, Fig.9. 14.

The RC level, initially increased for break and ADS mass flow collection, rapidly increases in correspondence of the PSS injection up to the complete fill-up at 4190 s in SPES3 and 14891 s in IRIS (11 m level from bottom in SPES3 and 11.75 m in IRIS), Fig.9. 26.

When the RC level is above the DVI connection (3910 s in SPES3 and 5000 s in IRIS) and the containment pressure overcomes the RV pressure, water enters the RV through the RC to DVI connections, Fig.9. 72, Fig.9. 73. The mass injected from RC to DVI is shown in Fig.9. 74. In SPES3 the injection occurs soon after the RC to DVI valves are open, instead in IRIS it begins only around 70000 s, Fig.9. 72, when the containment pressure is higher than the RV pressure, Fig.9. 11. The total mass injected at the end of the transient is higher in IRIS than SPES3.

The QT, initially empty, is partially filled-up by the ADS discharge in SPES3, while in IRIS it is completely filled-up, Fig.9. 75. The later SPES3 fill-up around 10000 s is related to the rapid increase of the DW level after the RC fill-up, Fig.9. 26, Fig.9. 27.

#### *Low LGMS mass signal: ADS Stage-II actuation*

The intact loop LGMS low mass signal is reached at 18183.27 s in SPES3 (LGMS-A) when mass reaches 198 kg (20% of 1 m<sup>3</sup> water at 48.9 °C) and at 13171 s in IRIS (LGMS-2) when residual mass is 185 kg . The broken loop signal is reached at 24708.87 s in SPES3 (LGMS-B) and 14120 s in IRIS (LGMS-1), Fig.9. 69.

The reaching of both LGMS low mass signals actuates the ADS Stage-II valves, fully open in 10 s both in SPES3 and IRIS, to allow steam circulation between RV and DW in the upper part of the plant and enhance condensation on the SG tubes in the long term, Fig.9. 76, Fig.9. 77. According to the pressure difference between DW and RV, Fig.9. 11, a little and oscillating mass flow is observed in IRIS after about 60000 s, instead SPES3 shows oscillations around zero, as DW and RV pressure are very similar.

The SPES3 RWST-A/B begins to heat-up at 52 s (after the EHRS-A and B actuation at 32.09 s) while IRIS RWST-1 begins to heat up only at 256 s contemporarily to RWST-2 (after EHRS-2 and 4 actuation at 174 s). The SPES3 RWST-C begins to heat-up at 222 s (after the EHRS-C actuation at 190.99 s). In SPES3, water reaches saturation around 80000 s and in IRIS around 95000 s. Anyway, in IRIS saturation temperature establishes around 107 °C, corresponding to a higher RWST pressure, Fig.9. 78.

The RWST mass is shown in Fig.9. 79 and pressure in Fig.9. 80. Both in SPES3 and IRIS, the trend of mass is similar and both decrease sensibly when water reaches saturation. Actually, in SPES3 a loss of mass is evidenced even before saturation, Fig.9. 81, Fig.9. 82, for modeling reasons, but it is acceptably low as explained in Paragraph 7.1.

Power transferred from the EHRS to RWST is shown in Fig.9. 83 and Fig.9. 84. SPES3 RWST power is higher than IRIS one in the early 10000 s, but they are similar in the last part of the transient. In the long term, between 145000 s and 150000 s, total power transferred to the RWST in IRIS is 32.27 kW while total power in SPES3 is 40.56 kW. The difference is mostly related to the higher water temperature in IRIS.

The SPES3 and IRIS containment pressure is affected by the DW heat structures, larger in SPES3 than IRIS. Power transferred to the DW structures is reported in Fig.9. 85 and Fig.9. 86. Power transfer occurs until a thermal equilibrium is reached on the walls, Fig.9. 87 and Fig.9. 88. At the peak, the SPES3 power (1.2 MW) is about 11 times the IRIS power (0.112 MW) transferred to the DW structures putting in evidence



the influence of the SPES3 larger heat transfer surface. This delays the SPES3 pressure rise that anyway is not so far from IRIS one, Fig.9. 4.

Fig.9. 87 and Fig.9. 88 show the SPES3 and IRIS DW wall temperatures at the inner and outer surface. In SPES3, inside temperatures are indicated with label 01 and outside ones with label 13. Moreover, temperatures are taken at various axial levels in the DW (lower 01, intermediate 07, and upper 17). In IRIS, TA is the inside temperature and TB the outside one with heat structure 01 for the lower shell, 02 for the concrete and 03 for the upper shell. The SPES3 DW is thermally insulated with the environment and the outer surface temperature is almost constant during the transient, while IRIS is not insulated and the inner and outer surface temperatures are very similar.

Starting from different heat structure initial temperature (48.9 °C in IRIS and 84°C in SPES3), the IR IS DW temperatures increase up to similar values around 2000 s, then the IRIS DW temperature decrease more rapidly due to heat losses to the environment and to lower pressure in the containment, Fig.9. 87, Fig.9. 88, Fig.9. 5.

### 9.1.2 Primary to secondary to RWST heat transfer

As for SPES3-146 case, a general agreement between SPES3-147 and IRIS HT6\_rwstc sequence of events has come out of the transient analysis. Notwithstanding the SPES3-147 SG tube number new scaling, very similar results to SPES3-146 are obtained. The global heat transfer capabilities appears slightly more similar to IRIS in SPES3-147 than SPES3-146, but the differences are almost negligible.

Attention has been put on the heat transfer at the SG and at the EHRS.

A sort of "global heat transfer coefficient" ( $h * S$ ) has been estimated for the Primary to Secondary side and for the EHRS to RWST heat transfer, according to the following process.

#### Primary to Secondary circuit

The primary side saturation temperature has been obtained versus pressurizer pressure

$P (PRZ) \Rightarrow T_{sat} (P PRZ);$

The secondary side saturation temperature has been obtained versus steam generator pressure

$P (SG) \Rightarrow T_{sat} (PSG);$

The temperature difference between primary and secondary side has been obtained as difference of the above saturation temperatures

$DT1 = T (PRZ-SG);$

A global heat transfer coefficient has been obtained by the ratio between the SG total power and the above temperature difference

$SG \text{ tot power} / DT1 = h * S (SG) \quad \text{heat transfer coefficient} * \text{Surface}$

#### EHRS to RWST

The EHRS saturation temperature has been obtained versus EHRS inlet pressure

$P (EHRS) \Rightarrow T_{sat} (P EHRS);$

The RWST temperature is directly available

$T RWST;$

The temperature difference between EHRS and RWST has been obtained as difference of the above temperatures:

$DT2 = T \text{ (EHRS-RWST)}$ ;

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$\text{EHRS tot power} / DT2 = h * S \text{ (EHRS)}$  heat transfer coefficient \* Surface

### Primary to RWST (global heat transfer)

The temperature difference between primary and RWST is obtained from the variables described above:

$DT3 = T \text{ (PRZ-RWST)}$

A global heat transfer coefficient has been obtained by the ratio between the EHRS total power and the above temperature difference

$\text{EHRS tot power} / DT3 = h * S \text{ (Global)}$  heat transfer coefficient \* Surface

Comparing SPES3 and IRIS:

- an opposite operation is observed at SG: in SPES3 there is higher DT and lower  $h*S$  than in IRIS between 30000 s and 100000 s, Fig.9. 89 and Fig.9. 90;
- the same behaviour is observed at EHRS where DT and  $h*S$  are very similar in SPES3 and IRIS, Fig.9. 91 and Fig.9. 92;
- globally in SPES3 there is a higher DT and a lower  $h * S$  than in IRIS, Fig.9. 93 and Fig.9. 94, that makes removed power similar.

As in SPES3-146 case, it appears that, after the EHRS and RWST remodelling according to achievements of Paragraphs 7.2, 7.4 and 7.5, the greatest difference in the heat transfer mode is related to the SG. Part of the difference could be reduced following a finer model synchronization, as for the EHRS-RWST, but part cannot be removed due to the actual geometric (thickness) and material (Inconel, AISI) configuration of the plants. The SG tube scaling refinement has led only to a minimum improvement in the results.

### 9.1.3 Case conclusions

The general good agreement of the SPES3-147 and IRIS HT6\_rwstc results leads to conclude the available data may constitute a suitable data base for the FSA final application.

**Tab.9. 1 – SPES3-147 and IRIS-HT6\_rwstc steady state conditions**

| <b>SPES3-147</b>         | <b>Primary/Core</b>              | <b>SG-A</b>       | <b>SG-B</b>       | <b>SG-C</b>       | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWSTAB</b> | <b>RWSTC</b> |
|--------------------------|----------------------------------|-------------------|-------------------|-------------------|---------------|-----------|-----------|---------------|-----------|----------------|---------------|--------------|
| Pressure (MPa)           | 15.55 (PRZ)<br>0.103 (pump head) | 5.83 (out)        | 5.83 (out)        | 5.88 (out)        | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013        | 0.1013       |
| Tin (°C)                 | 294.6                            | 223.8             | 223.9             | 223.9             | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20            | 20           |
| Tout (°C)                | 331.8                            | 322.5             | 320.2             | 320.0             |               |           |           |               |           |                |               |              |
| DT (°C)                  | 37.2                             | 98.7              | 96.3              | 96.1              |               |           |           |               |           |                |               |              |
| Superheating (°C)        |                                  | 48.8 (Tsat 273.7) | 46.5 (Tsat 273.7) | 45.8 (Tsat 274.2) |               |           |           |               |           |                |               |              |
| Mass flow (kg/s)         | 45.24<br>(2.12 in by-pass)       | 1.25              | 1.25              | 2.5               |               |           |           |               |           |                |               |              |
| Power (MW)               | 10                               | 2.507             | 2.499             | 4.992             |               |           |           |               |           |                |               |              |
| Level (m)<br>-collapsed- | 2.134 (PRZ)                      | 1.56              | 1.70              | 1.73              | 3.14 full     | empty     | empty     | 3.77          | empty     | 2.454          | 6.961         | 6.954        |
| Mass (kg)                | 3285 (RV)                        |                   |                   |                   | 127           |           |           | 1480          |           | 985            | 11869         | 11876        |

| <b>IRIS<br/>HT6_rwstc</b> | <b>Primary/Core</b>                | <b>SG 1</b>              | <b>SG 2</b>              | <b>SG 3</b>              | <b>SG 4</b>              | <b>SG 5</b>              | <b>SG 6</b>              | <b>SG 7</b>              | <b>SG 8</b>              | <b>EBTA/B</b> | <b>QT</b> | <b>DW</b> | <b>PSSA/B</b> | <b>RC</b> | <b>LGMSA/B</b> | <b>RWST1</b> | <b>RWST2</b> |
|---------------------------|------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|---------------|-----------|-----------|---------------|-----------|----------------|--------------|--------------|
| Pressure (MPa)            | 15.5 (PRZ)<br>0.129 (pump<br>head) | 5.81<br>(out)            | 5.79<br>(out)            | 5.79<br>(out)            | 5.78<br>(out)            | 5.78<br>(out)            | 5.79<br>(out)            | 5.79<br>(out)            | 5.81<br>(out)            | Primary       | Cont.     | 0.1013    | Cont.         | Cont.     | Cont.          | 0.1013       | 0.1013       |
| Tin (°C)                  | 291                                | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 223.7                    | 48.9          | 48.9      | 48.9      | 48.9          | 48.9      | 48.9           | 20           | 20           |
| Tout (°C)                 | 329                                | 318.05                   | 316.24                   | 318.22                   | 316.52                   | 316.52                   | 318.22                   | 316.24                   | 318.05                   |               |           |           |               |           |                |              |              |
| DT (°C)                   | 38                                 | 94.35                    | 92.54                    | 94.52                    | 92.82                    | 92.82                    | 94.52                    | 92.54                    | 94.35                    |               |           |           |               |           |                |              |              |
| Superheating<br>(°C)      |                                    | 44.55<br>(Tsat<br>273.5) | 43.04<br>(Tsat<br>273.2) | 45.02<br>(Tsat<br>273.2) | 43.42<br>(Tsat<br>273.1) | 43.42<br>(Tsat<br>273.1) | 45.02<br>(Tsat<br>273.2) | 43.04<br>(Tsat<br>273.2) | 44.55<br>(Tsat<br>273.5) |               |           |           |               |           |                |              |              |
| Mass flow (kg/s)          | 45.24<br>(2.13 in by-<br>pass)     | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    | 1.257                    |               |           |           |               |           |                |              |              |
| Power (MW)                | 10                                 | 1.24                     | 1.26                     | 1.24                     | 1.26                     | 1.26                     | 1.24                     | 1.26                     | 1.24                     |               |           |           |               |           |                |              |              |
| Level (m)<br>-collapsed-  | 2.019 (PRZ)                        | 1.93                     | 1.99                     | 1.92                     | 1.98                     | 1.98                     | 1.92                     | 1.99                     | 1.93                     | 3.14 full     | empty     | empty     | 3.00          | empty     | 2.668          | 9.099        | 9.099        |
| Mass (kg)                 | 3254 (RV)                          |                          |                          |                          |                          |                          |                          |                          |                          | 127           |           |           | 1453          |           | 989            | 11942        | 11942        |

Tab.9. 2 – SPES3-147 and IRIS HT6\_rwstc list of the main events (fatta)

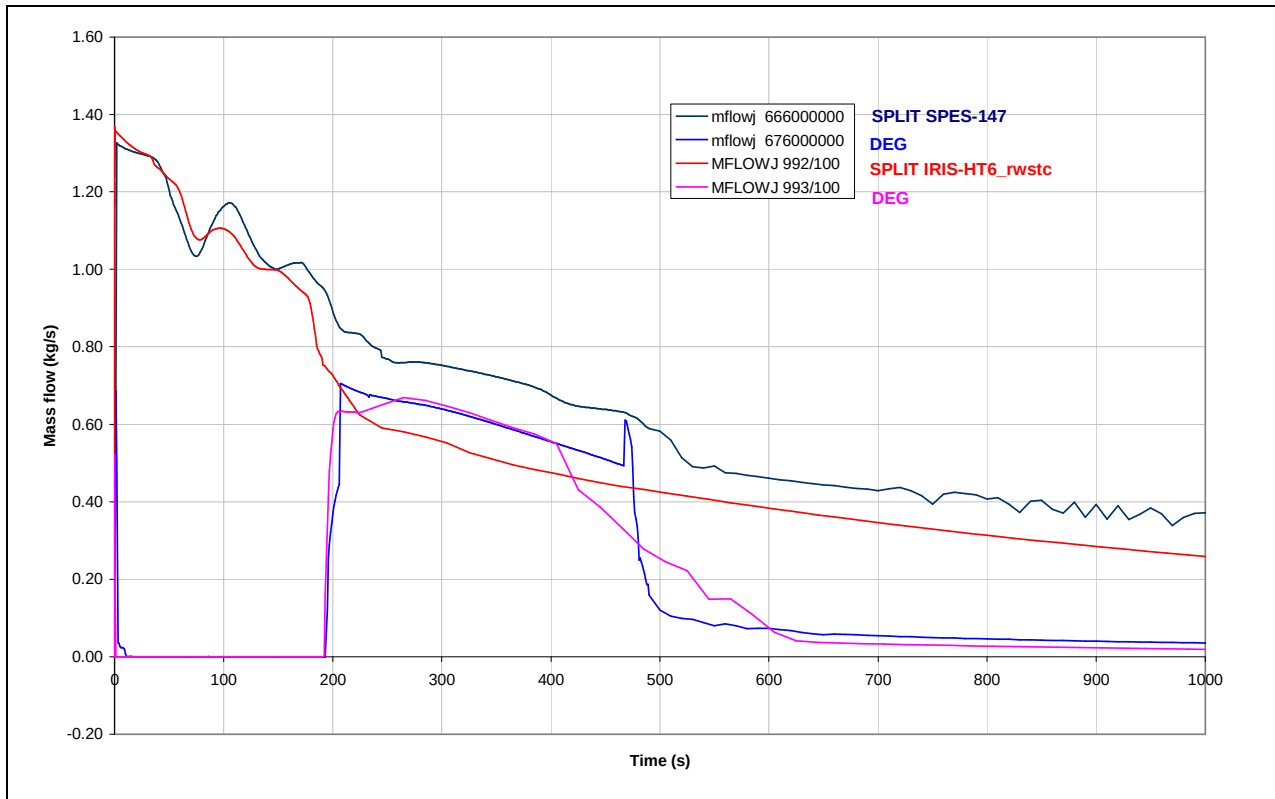
| DVI-B DEG break 2 inch equivalent                                                        |                                                         | SPES3-147      |                                        |                                                          | IRIS HT6_rwstc |                          |                                                                    |
|------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------|----------------------------------------|----------------------------------------------------------|----------------|--------------------------|--------------------------------------------------------------------|
| N.                                                                                       | Phases and events                                       | Time (s)       | Quantity                               | Notes                                                    | Time (s)       | Quantity                 | Notes                                                              |
| <b>Break</b>                                                                             |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 1                                                                                        | Break initiation                                        | 0              |                                        | break valves stroke 2 s                                  | 0              |                          | Instantaneous stroke 0.02 s delay                                  |
| 2                                                                                        | Break flow peak (Containment side)                      | 1              | 0.688 kg/s                             | Break flow = 0 kg/s at 11 s                              | 0.03           | 0.50 kg/s                | Break flow = 0 kg/s at 1.1 s                                       |
| 3                                                                                        | Break flow peak (RV side)                               | 2              | 1.33 kg/s                              |                                                          | 0.06           | 1.35 kg/s                |                                                                    |
| <b>Blowdown, RV depressurization, containment pressurization. Steam dumping into PSS</b> |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 4                                                                                        | Steam-air mixture begins to flow from DW to PSS         | 15             |                                        |                                                          | 22             |                          | 0 to 10 s water empties the vent pipe and moves into the PSS       |
| <b>S-Signal: Reactor scram, secondary loop isolation, EHRS-A and B actuation</b>         |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 5                                                                                        | High Containment pressure signal                        | 32.09          | 1.7e5 Pa                               | S-signal. Set-point for safety analyses                  | 30             | 1.7e5 Pa                 | S-signal. Set-point for safety analyses                            |
| 6                                                                                        | SCRAM begins                                            | 32.09          |                                        |                                                          | 30             |                          |                                                                    |
| 7                                                                                        | MFIV-A,B,C closure start                                | 32.09          |                                        | MFIV-A,B,C stroke 5 s                                    | 30             |                          | MFIV-1,2,3,4 stroke 5 s                                            |
| 8                                                                                        | MSIV-A-B-C closure start                                | 32.09          |                                        | MSIV-A,B,C stroke 5 s.                                   | 30             |                          | MSIV-1,2,3,4 stroke 5 s.                                           |
| 9                                                                                        | EHRS-A and B opening start (EHRS 1 and 3 in IRIS)       | 32.09          |                                        | EHRS-A,B IV stroke 2 s.                                  | 40             |                          | EHRS-1,3 IV stroke 2 s. S-signal + 10 s delay                      |
| 10                                                                                       | EHRS-A and B peak mass flow                             | 38             | 0.265 kg/s                             |                                                          | 45             | 0.287 kg/s               |                                                                    |
| 11                                                                                       | High SG pressure signal                                 | 45.2           | 9e6 Pa                                 |                                                          | 44             | 9e6 Pa                   |                                                                    |
| 12                                                                                       | SG-A high pressure reached                              | 45.2           |                                        |                                                          | 44             |                          |                                                                    |
| 13                                                                                       | SG-B high pressure reached                              | 46.07          |                                        |                                                          | 44             |                          |                                                                    |
| 14                                                                                       | SG-C high pressure reached                              | 45.87          |                                        |                                                          | 44             |                          |                                                                    |
| 15                                                                                       | RWST-A/B begins to heat-up                              | 52             |                                        |                                                          | 256            |                          | Same time as RWST-2                                                |
| 16                                                                                       | EHRS-A power peak                                       | 205            | 369 kW                                 |                                                          | 158            | 335 kW                   | EHRS-1                                                             |
| 17                                                                                       | EHRS-B power peak                                       | 205            | 369 kW                                 |                                                          | 158            | 335 kW                   | EHRS-3                                                             |
| <b>Pump coastdown and primary circulation through RI-DC check valves</b>                 |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 18                                                                                       | Low PRZ water level signal                              | 114.83         | 1.189 m                                |                                                          | 130            | 1.189 m                  |                                                                    |
| 19                                                                                       | RCP costdown starts                                     | 129.83         |                                        | Low PRZ level signal + 15 s delay                        | 145            |                          | Low PRZ level signal + 15 s delay                                  |
| 20                                                                                       | Secondary loop pressure peak                            | 55<br>57<br>61 | 107e5 Pa A<br>110e5 Pa B<br>116e5 Pa C |                                                          | 57             | 110.2e5 Pa<br>108.8e5 Pa | SG-1 to 4<br>SG-5 to 8                                             |
| 21                                                                                       | Natural circulation begins through shroud valves        | 139, 142       |                                        | SG-A,B 139 s,<br>SG-C 142 s                              | 185            |                          | SG-1+2, 5+6+7+8 185 s,<br>SG-3+4 185 s                             |
| 22                                                                                       | Flashing begins at core outlet                          | 171            | voidf 110 (core)                       | <1                                                       | 186            | voidf 110 (core)         | <1                                                                 |
| <b>LM-Signal: EHRS-C, ADS Stage-I and EBT actuation. RV saturation</b>                   |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 23                                                                                       | Low PRZ pressure signal                                 | 190.99         | 11.72e6 Pa                             | LM-Signal (High P cont + Low P PRZ)                      | 174            | 11.72e6 Pa               | LM-Signal (High P cont + Low P PRZ)                                |
| 24                                                                                       | EHRS-C opening start (EHRS 2 and 4 in IRIS)             | 190.99         |                                        | EHRS-C IV stroke 2 s.                                    | 174            |                          | EHRS-2+4 IV stroke 2 s.                                            |
| 25                                                                                       | EHRS-C peak mass flow                                   | 194            | 0.549 kg/s                             |                                                          | 190            | 0.580 kg/s               | EHRS-2+4                                                           |
| 26                                                                                       | RWST-C begins to heat-up                                | 222            |                                        |                                                          | 256            |                          | Same time as RWST-1                                                |
| 27                                                                                       | EHRS-C power peak                                       | 331            | 728 kW                                 |                                                          | 325            | 636 kW                   |                                                                    |
| 28                                                                                       | ADS Stage I start opening (3 trains)                    | 190.99         |                                        | ADS valve stroke 10 s                                    | 174            |                          | ADS valve stroke 10 s                                              |
| 29                                                                                       | ADS Stage I first peak flow (3 trains)                  | 201            | 1.344 kg/s                             | ST 0.457 kg/s;<br>DT 0.887 kg/s                          | 186            | 1.301 kg/s               | ST (1) 0.433 kg/s;<br>DT (2+3) 0.872 kg/s                          |
| 30                                                                                       | ADS Stage I second peak flow (3 trains)                 | 269            | 1.998 kg/s                             | ST 0.628 kg/s;<br>DT 1.370 kg/s. Due to liquid fraction. | 245            | 1.988 kg/s               | ST (1) 0.678 kg/s;<br>DT (2+3) 1.332 kg/s. Due to liquid fraction. |
| 31                                                                                       | EBT-A and B valve opening start                         | 190.99         |                                        | EBT valve stroke 15 s                                    | 174            |                          | EBT valve stroke 15 s                                              |
| 32                                                                                       | Break flow peak (Containment side)                      | 201            | 0.703 kg/s                             | Due to EBT intervention                                  | 203            | 0.633 kg/s               | Due to EBT intervention                                            |
| 33                                                                                       | EBT-RV connections uncovered                            | 227, 262       |                                        | EBT-B, EBT-A                                             | 385            |                          |                                                                    |
| 32                                                                                       | Natural circulation interrupted at SGs top              | 249            |                                        | Pump inlet uncovered (voidf 176-01 ~0)                   | 265            |                          | Mass flow = 0 at SG top (mflowj 201-01 ~0)                         |
| 36                                                                                       | Core in saturation conditions                           | 250            |                                        |                                                          | 245            |                          |                                                                    |
| 37                                                                                       | EBT-B empty (broken loop)                               | 640            |                                        | 500 s almost empty (640 s completely empty)              | 625            |                          |                                                                    |
| <b>Low DP RV-Containment signal, LGMS and RC to DVI valve actuation</b>                  |                                                         |                |                                        |                                                          |                |                          |                                                                    |
| 38                                                                                       | Containment pressure peak                               | 2230           | 9.35e5 Pa                              |                                                          | 1405           | 9.36e5 Pa                |                                                                    |
| 39                                                                                       | Low DP RV-Containment                                   | 2225.69        | 50e3 Pa                                |                                                          | 1585           | 50e3 Pa                  |                                                                    |
| 40                                                                                       | LGMSA/B valve opening start                             | 2225.69        |                                        | LM + low DP RV-cont . LGMS valve stroke 2 s.             | 1585           |                          | LM + low DP RV-cont . LGMS valve stroke 2 s.                       |
| 41                                                                                       | RC to DVI line valve opening                            | 2225.69        |                                        | RC to DVI valve stroke 2 s.                              | 1585           |                          | RC to DVI valve stroke 2 s.                                        |
| 42                                                                                       | LGMS-B starts to inject into RC through DVI broken loop | 2260           |                                        |                                                          | 1585           |                          | LGMS-1 broken loop                                                 |
| 43                                                                                       | LGMS-A starts to inject into RV through DVI intact loop | 2230           |                                        |                                                          | 1670           |                          | LGMS-2 intact loop                                                 |

....continues

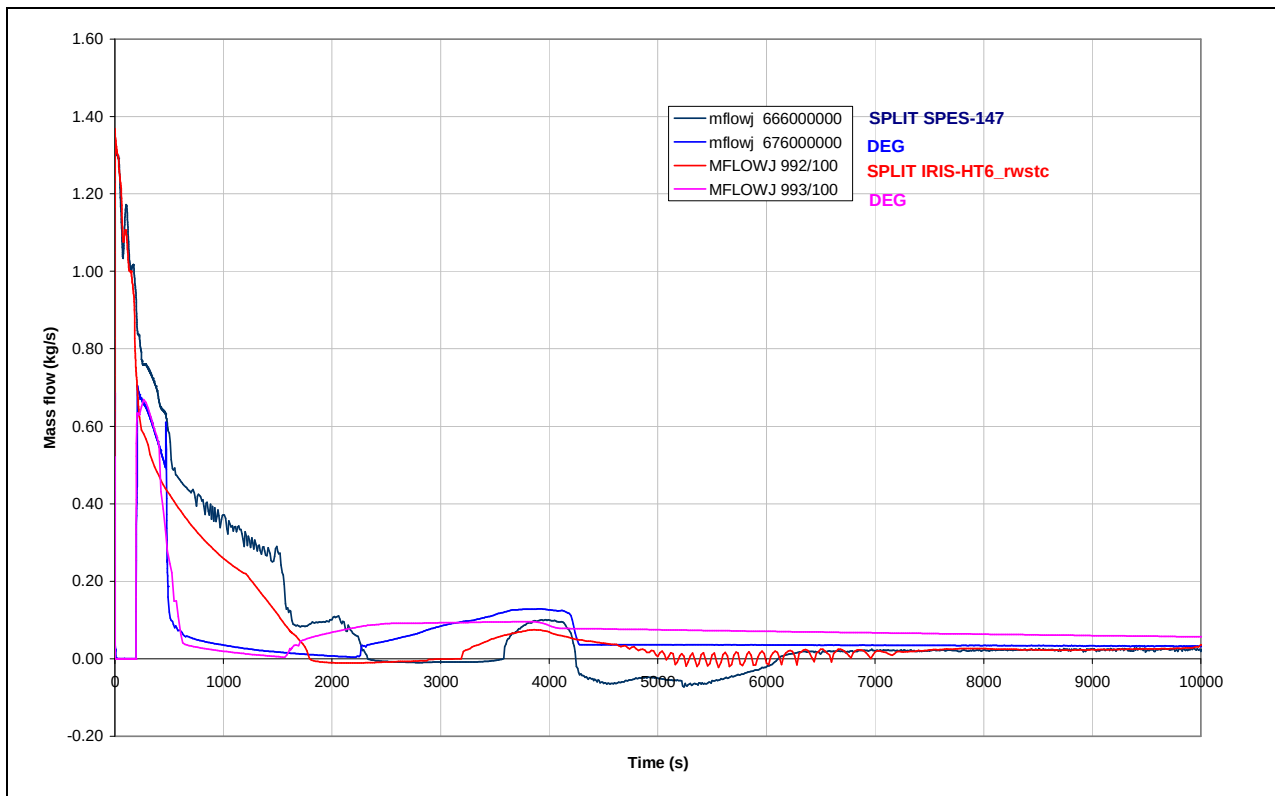
....continued

|                                                                                                                         | <b>DVI-B break 2 inch equivalent DEG</b>        | <b>SPES3-147</b> |                      |                                                                | <b>IRIS-<br/>HT6_rwstc</b> |          |                                                   |
|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|------------------|----------------------|----------------------------------------------------------------|----------------------------|----------|---------------------------------------------------|
| N.                                                                                                                      | Phases and events                               | Time (s)         | Quantity             | Notes                                                          | Time (s)                   | Quantity | Notes                                             |
| <b>Containment and RV pressure equalization, PSS water flow to DW, RC flooding, reverse flow from containment to RV</b> |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 44                                                                                                                      | Containment and RV pressure equalization        | 2340             |                      |                                                                | 1730                       |          |                                                   |
| 45                                                                                                                      | Mixture starts to flow from RC to DVI-A         | 2340             |                      |                                                                | -                          |          | Negligible until 59000 s.                         |
| 46                                                                                                                      | DW pressure lower than PSS pressure             | 2140, 2530       |                      | PSS-A, PSS-B                                                   | 1650                       |          |                                                   |
| 47                                                                                                                      | EBT-A empty (intact loop)                       | 3000             |                      |                                                                | 35500                      |          |                                                   |
| 48                                                                                                                      | Water starts to flow from PSS to DW             | 3230 - 3370      |                      | PSS A, PSS-B                                                   | 2310                       |          |                                                   |
| 49                                                                                                                      | Steam and gas mixture flows again from RV to QT | 2350             |                      | 2350 to 3600 s<br>(RV P > DW P)                                | 3640                       |          | 3640 to 4100 s<br>(RV P > DW P). Negligible flow  |
| 50                                                                                                                      | RC level at DVI elevation                       | 3910             |                      |                                                                | 5000                       |          |                                                   |
| 51                                                                                                                      | RC full of water                                | 4190             |                      |                                                                | 14891                      |          |                                                   |
| 52                                                                                                                      | QT fill-up starts from DW connection            | 9550             |                      |                                                                | -                          |          | QT full at 2650 s for ADS Stage-I<br>intervention |
| <b>Low LGMS mass signal: ADS Stage-II actuation</b>                                                                     |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 53                                                                                                                      | <b>Low LGMS mass</b>                            | 18183.27         | 20% mass<br>(198 kg) | LGMS A (intact loop)                                           | 13171                      | (185 kg) | LGMS-2 (intact loop)                              |
| 54                                                                                                                      |                                                 | 24708.87         | 20% mass<br>(198 kg) | LGMS B (broken loop)                                           | 14120                      | (185 kg) | LGMS-1 (broken loop)                              |
| 55                                                                                                                      | ADS stage-II start opening                      | 24708.87         |                      | ADS stage II valve<br>stroke 10 s.                             | 14120                      |          | ADS stage II valve stroke 10 s.                   |
| 56                                                                                                                      | LGMS-A empty (intact loop)                      | 37715            |                      |                                                                | 20450                      |          | LGMS-2 (intact loop).                             |
| 56                                                                                                                      | LGMS-B empty (broken loop)                      | 40000            |                      | 33 kg at 40000 s.<br>~20kg residual mass<br>70000 to 150000 s. | 20450                      |          | LGMS-1 (broken loop).                             |
| 57                                                                                                                      | Flow from RC to RV (intact loop) stable         | 32400            |                      |                                                                | 65414                      |          | Strong oscillations                               |
| <b>Long Term conditions</b>                                                                                             |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 58                                                                                                                      | Core power (kW)                                 | 100000           | 46.25                | Aver 95000 - 100000 s                                          | 100000                     | 52.04    | Aver 95000 - 100000 s                             |
| 59                                                                                                                      | SG tot power (kW)                               | 100000           | 45.27                |                                                                | 100000                     | 38.91    |                                                   |
| 60                                                                                                                      | RWST tot power (kW)                             | 100000           | 40.70                |                                                                | 100000                     | 36.01    |                                                   |
| 61                                                                                                                      | RWST-A/B temperature (°C)                       | 100000           | 101                  | saturated                                                      | 1 00000                    | 107      | Saturated at 97300 s                              |
| 62                                                                                                                      | RWST-C temperature (°C)                         | 100000           | 101                  | saturated                                                      | 100 000                    | 107      | Saturated at 97300 s                              |
|                                                                                                                         |                                                 |                  |                      |                                                                |                            |          |                                                   |
| 63                                                                                                                      | Core power                                      | 150000           | 45.76                | Aver. 145000-150000 s                                          | 150000                     | 47.05    | Aver. 145000-150000 s                             |
| 64                                                                                                                      | SG tot power                                    | 150000           | 45.27                |                                                                | 150000                     | 34.06    |                                                   |
| 65                                                                                                                      | RWST tot power                                  | 150000           | 40.56                |                                                                | 150000                     | 32.27    |                                                   |
| 66                                                                                                                      | RWST-A/B temperature                            | 150000           | 100                  | saturated                                                      | 150000                     | 107      | saturated                                         |
| 67                                                                                                                      | RWST-C temperature                              | 150000           | 100                  | saturated                                                      | 150000                     | 107      | saturated                                         |

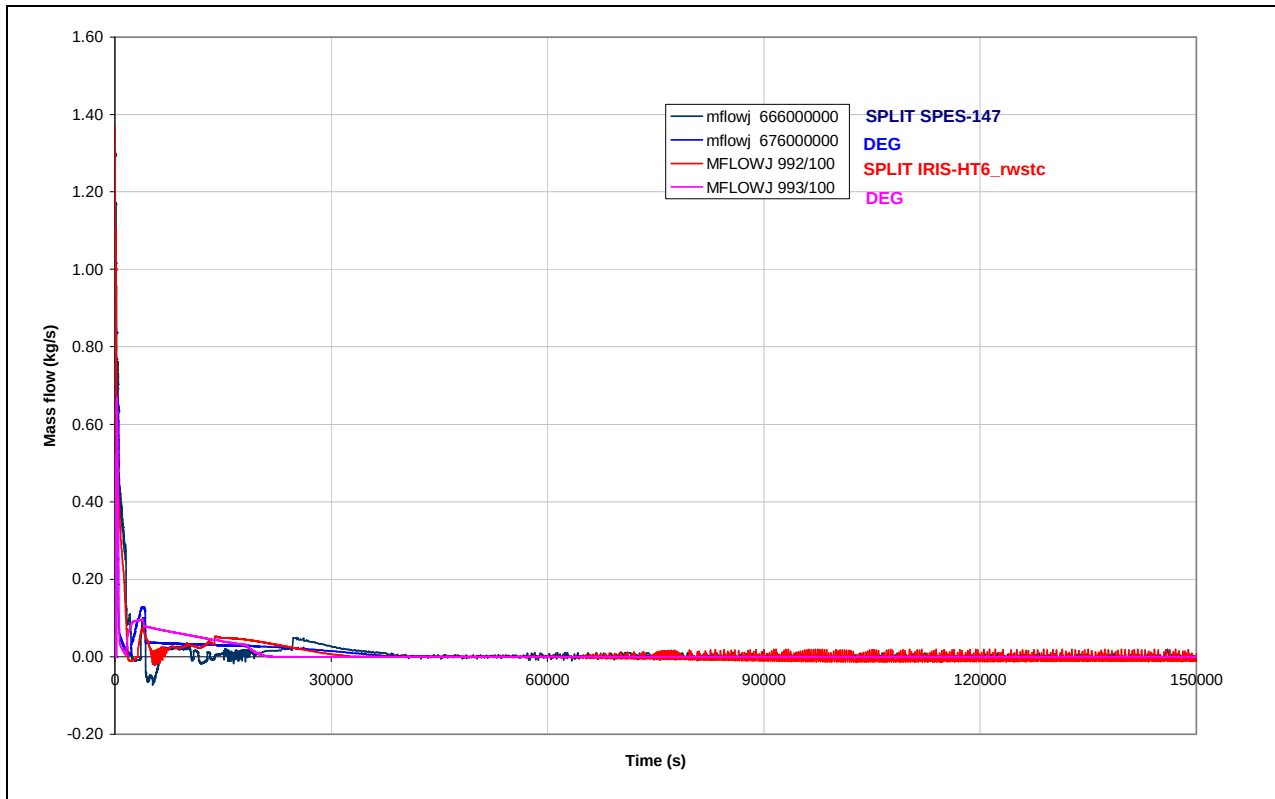
**Fig.9. 1 - SPES3-147 and IRIS HT6\_rwstc DVI break flow (window)**



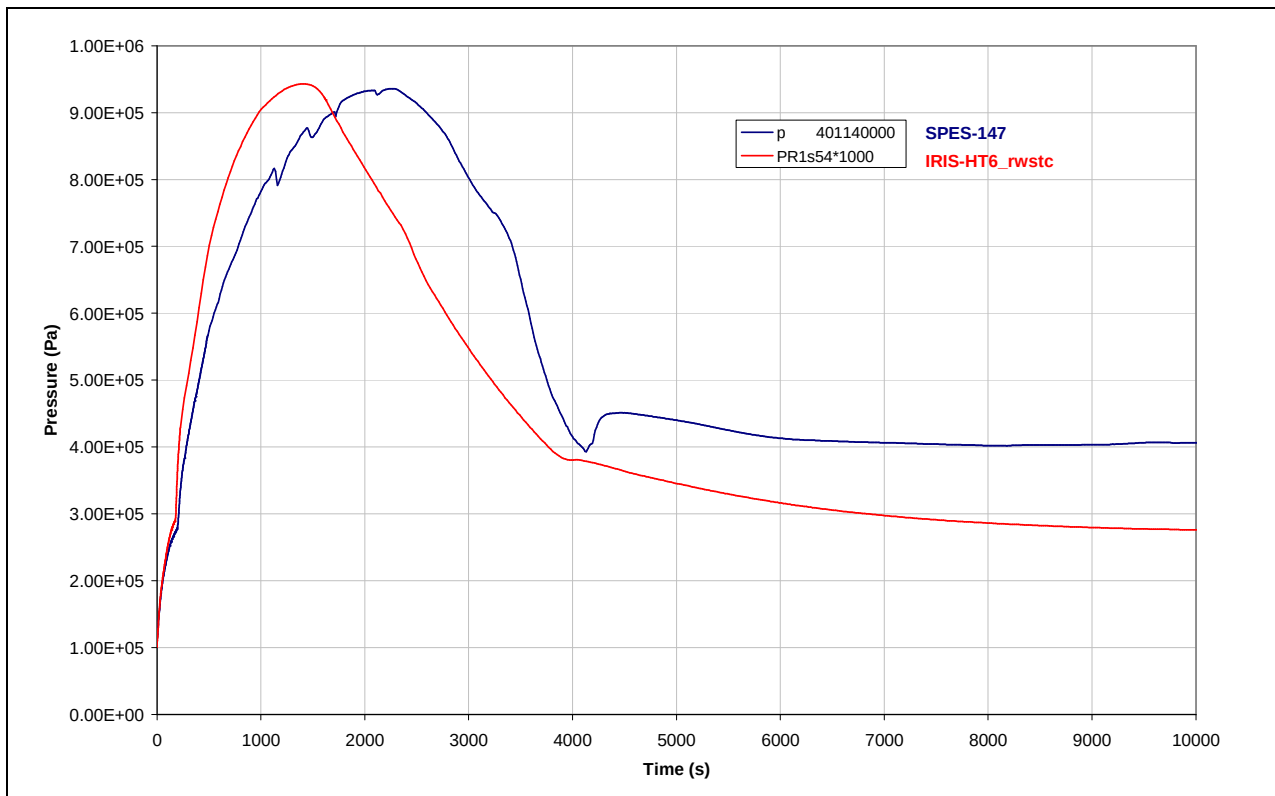
**Fig.9. 2 - SPES3-147 and IRIS HT6\_rwstc DVI break flow (window)**



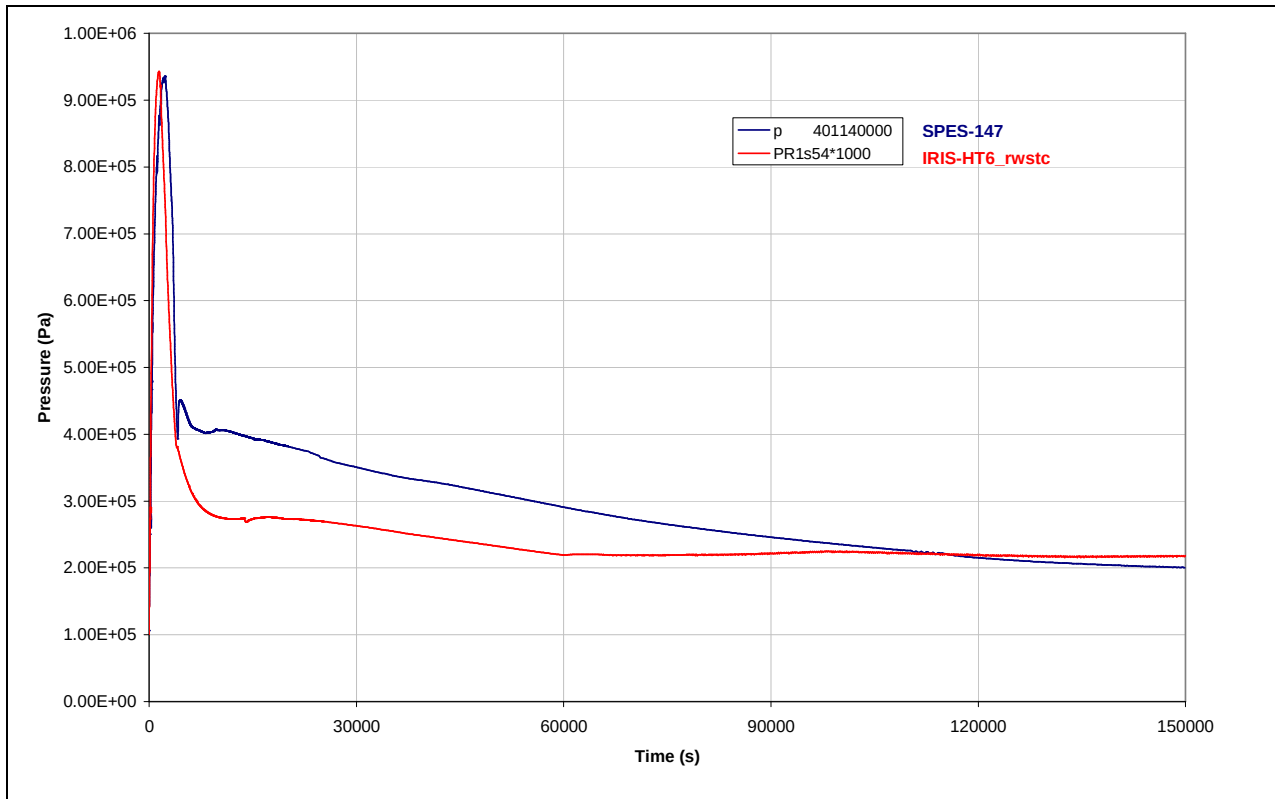
**Fig.9. 3 - SPES3-147 and IRIS HT6\_rwstc DVI break flow**



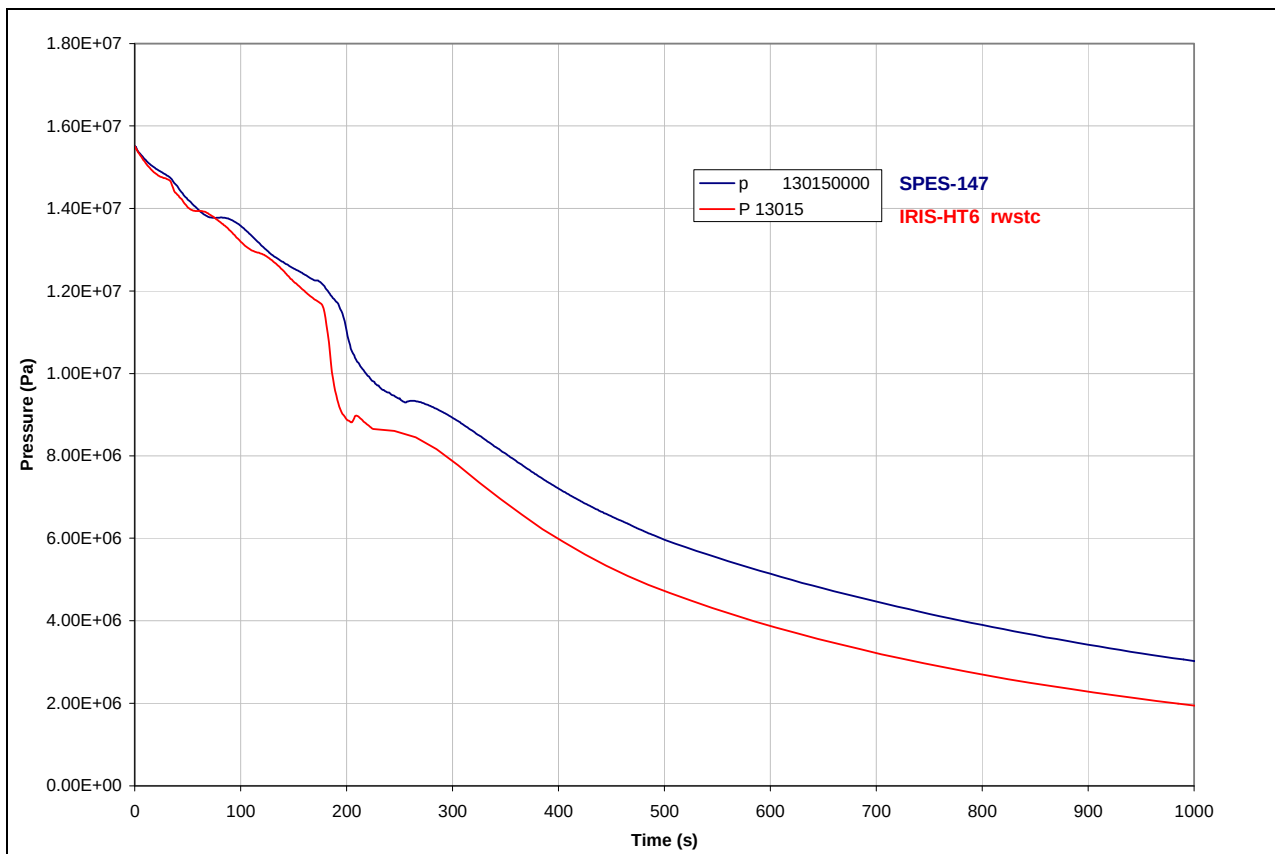
**Fig.9. 4 - SPES3-147 and IRIS HT6\_rwstc DW pressure (window)**



**Fig.9. 5 – SPES3-147 and IRIS HT6\_rwstc DW pressure**

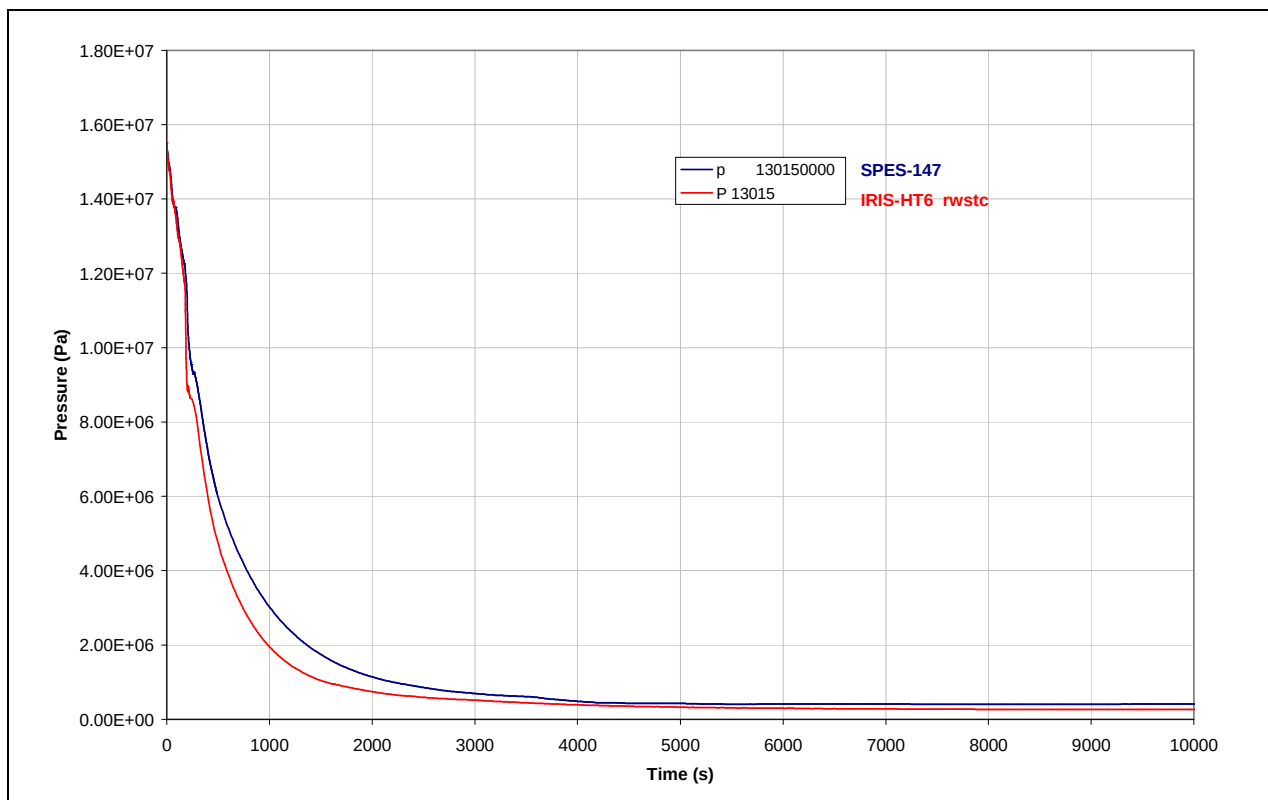


**Fig.9. 6 – SPES3-147 and IRIS HT6\_rwstc PRZ pressure (windows)**

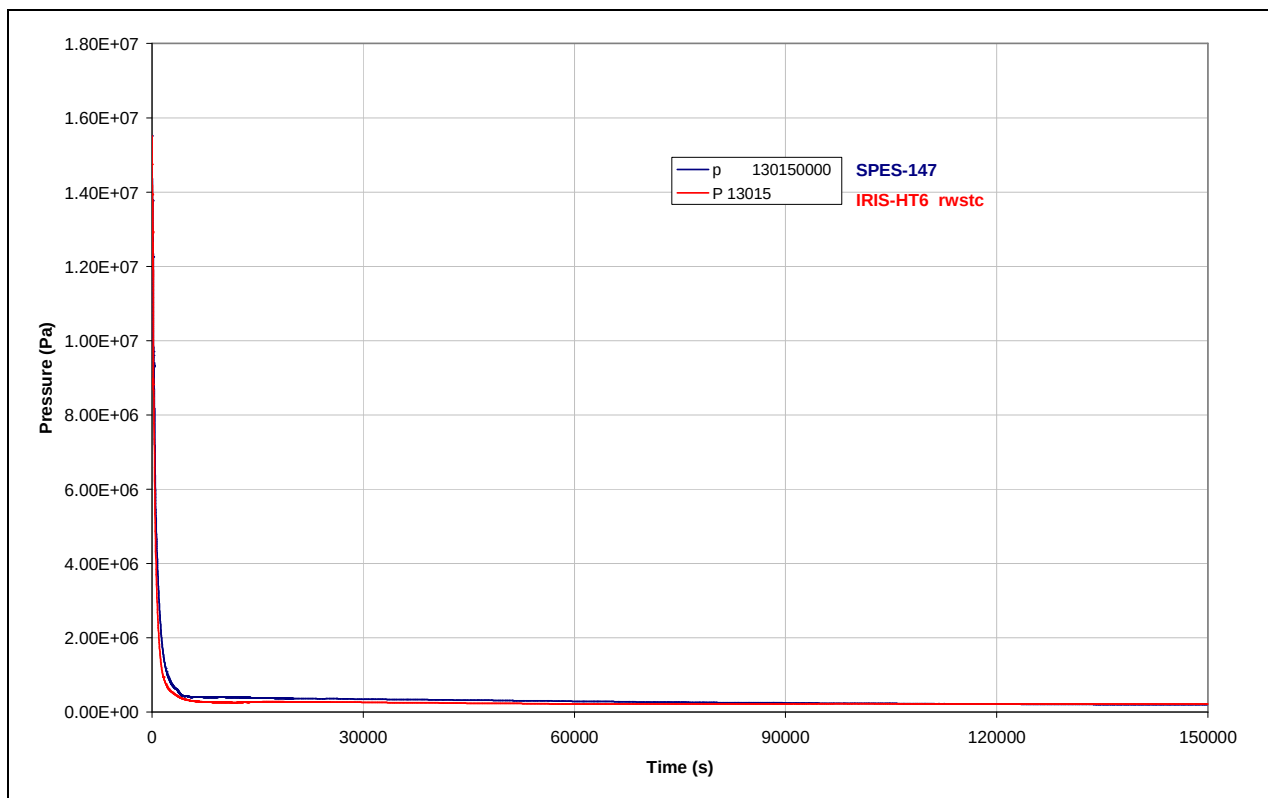




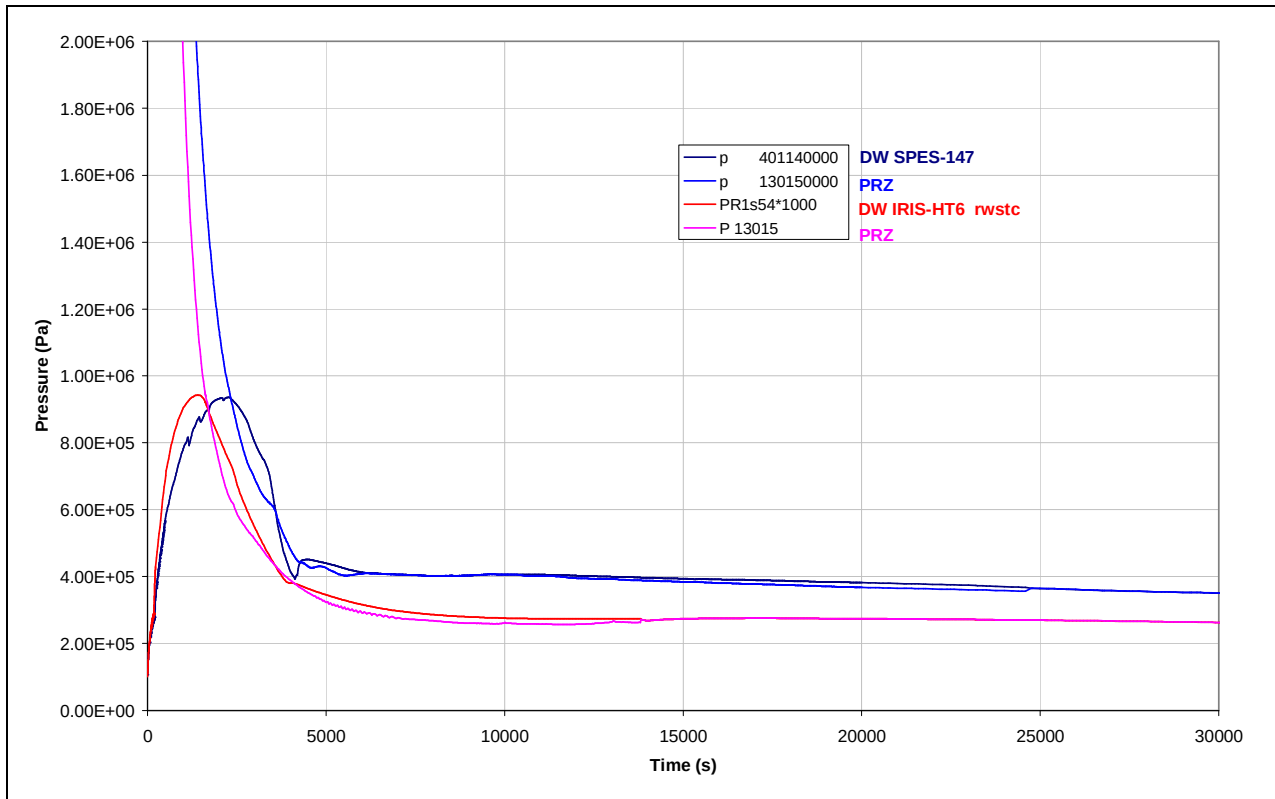
**Fig.9. 7 – SPES3-147 and IRIS HT6\_rwstc PRZ pressure (windows)**



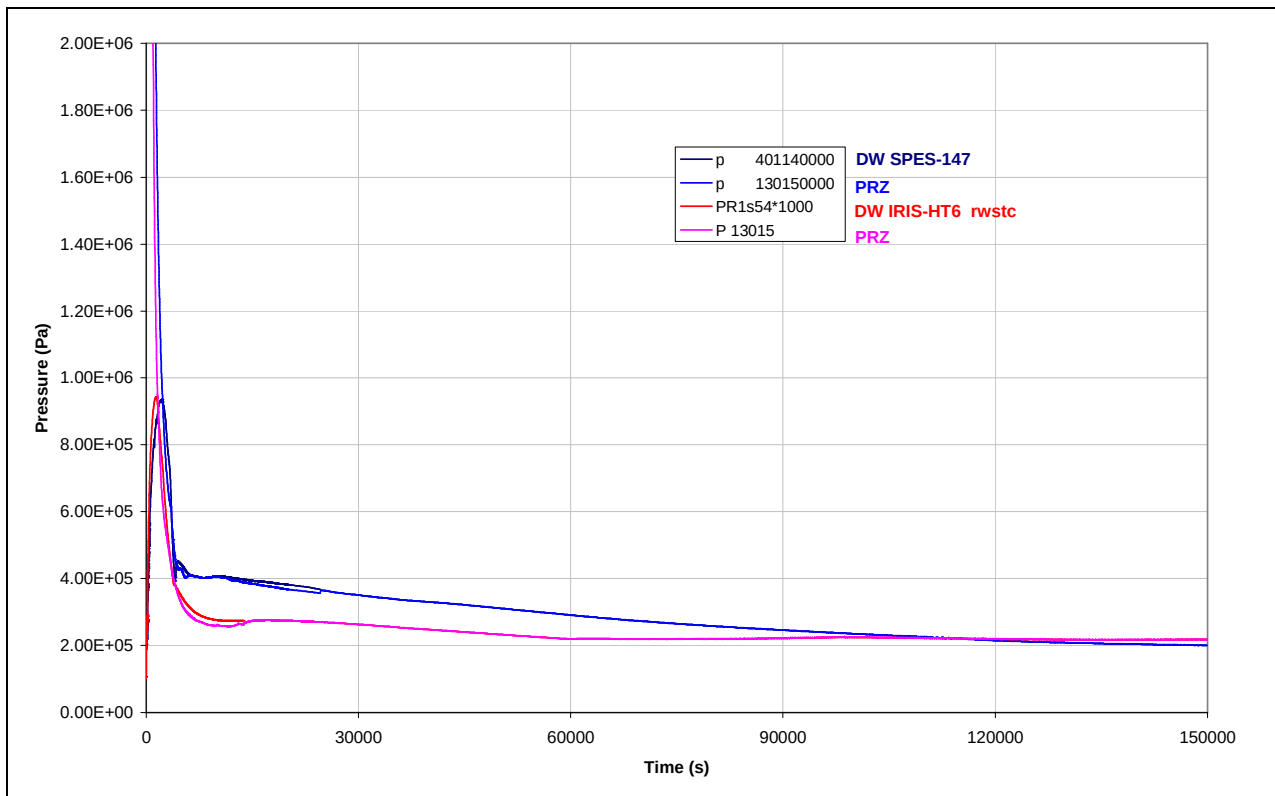
**Fig.9. 8 – SPES3-147 and IRIS HT6\_rwstc PRZ pressure**



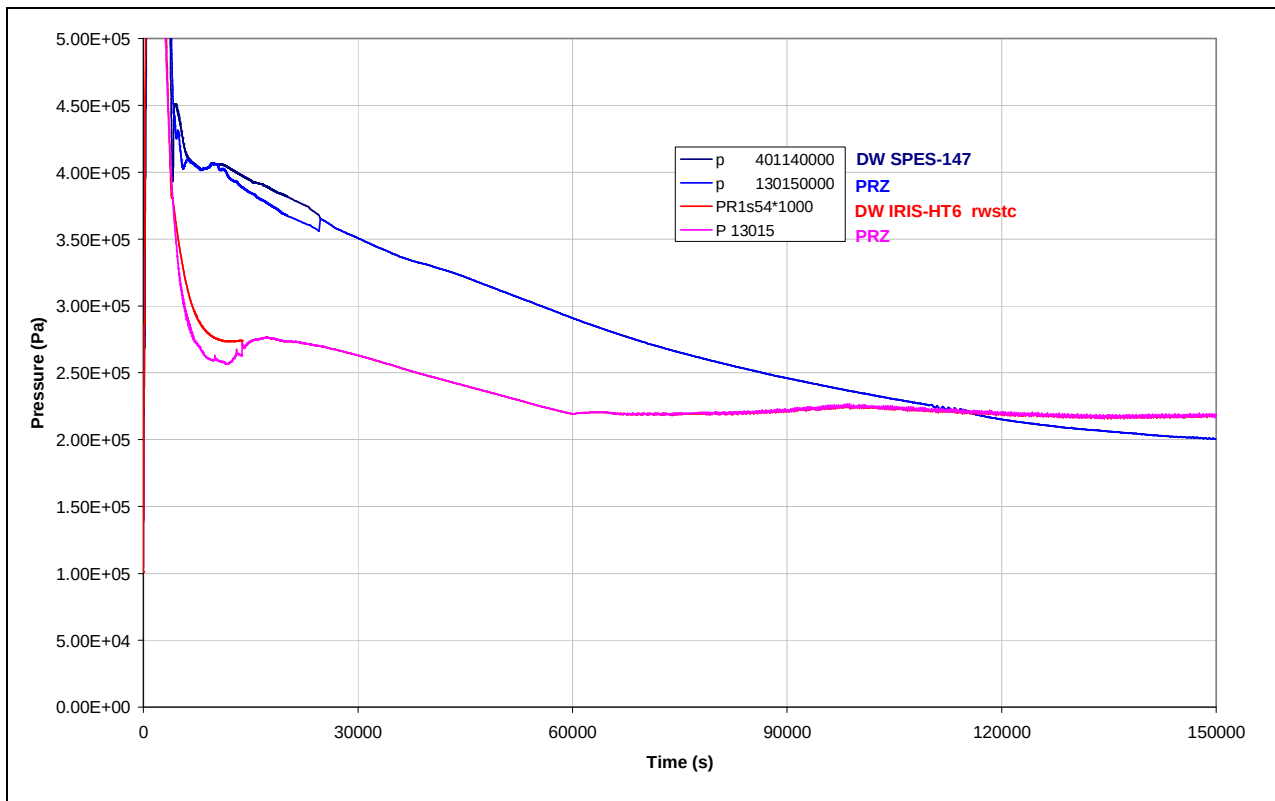
**Fig.9. 9 – SPES3-147 and IRIS HT6\_rwstc PRZ and DW pressures (window)**



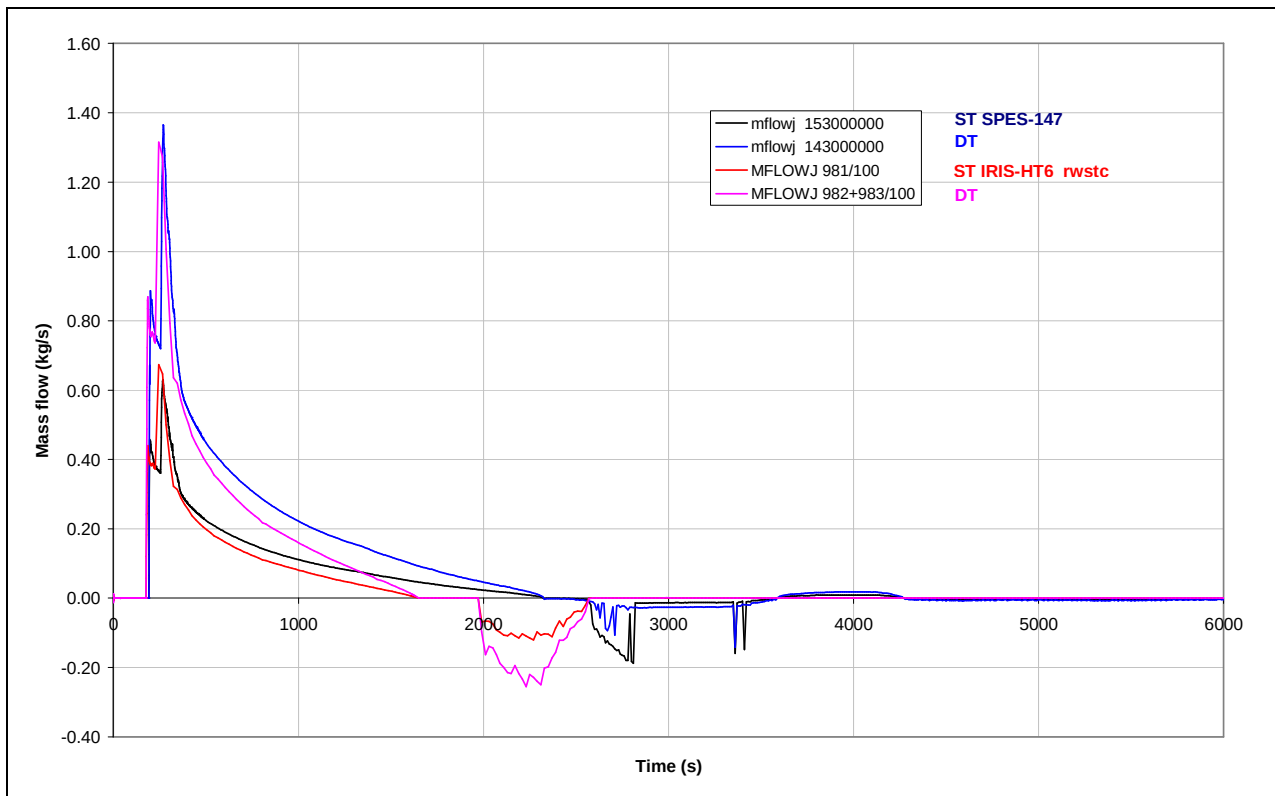
**Fig.9. 10 – SPES3-147 and IRIS HT6\_rwstc PRZ and DW pressures**



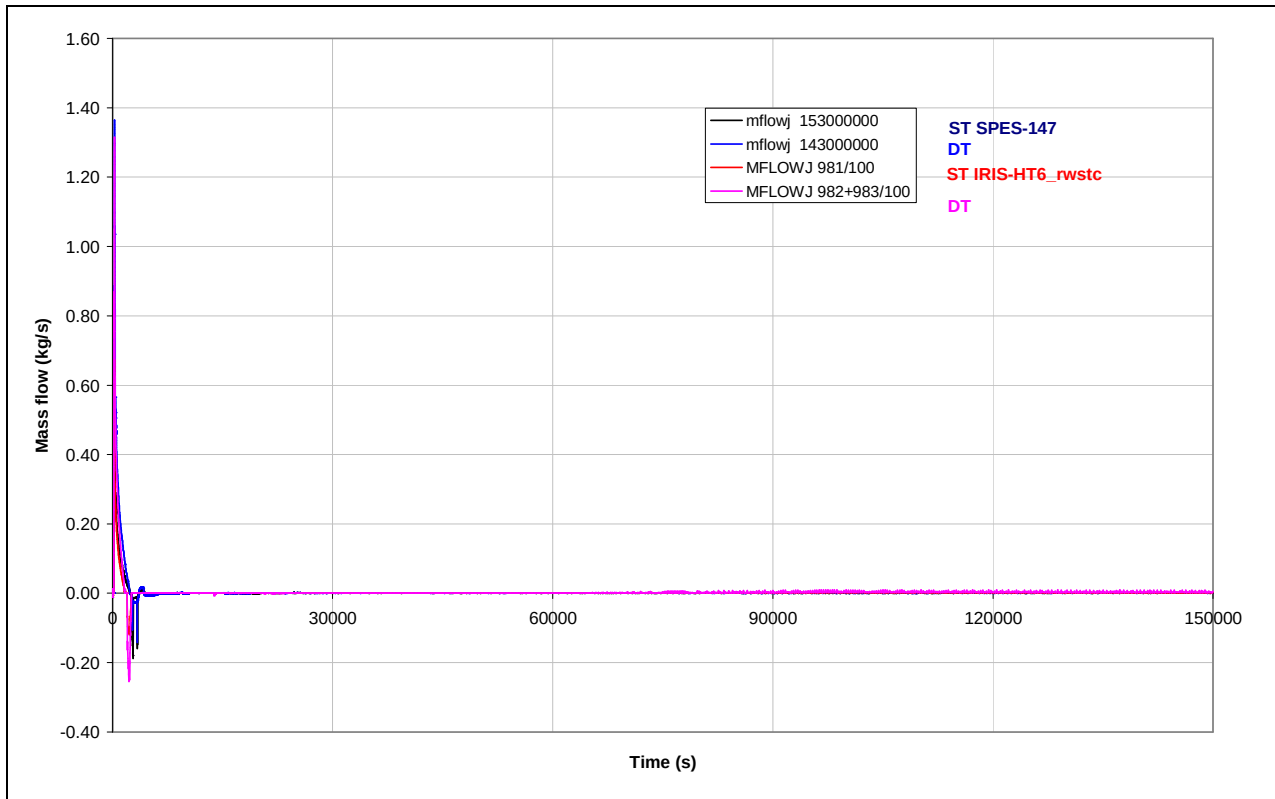
**Fig.9. 11 – SPES3-147 and IRIS HT6\_rwstc PRZ and DW pressures (detail)**



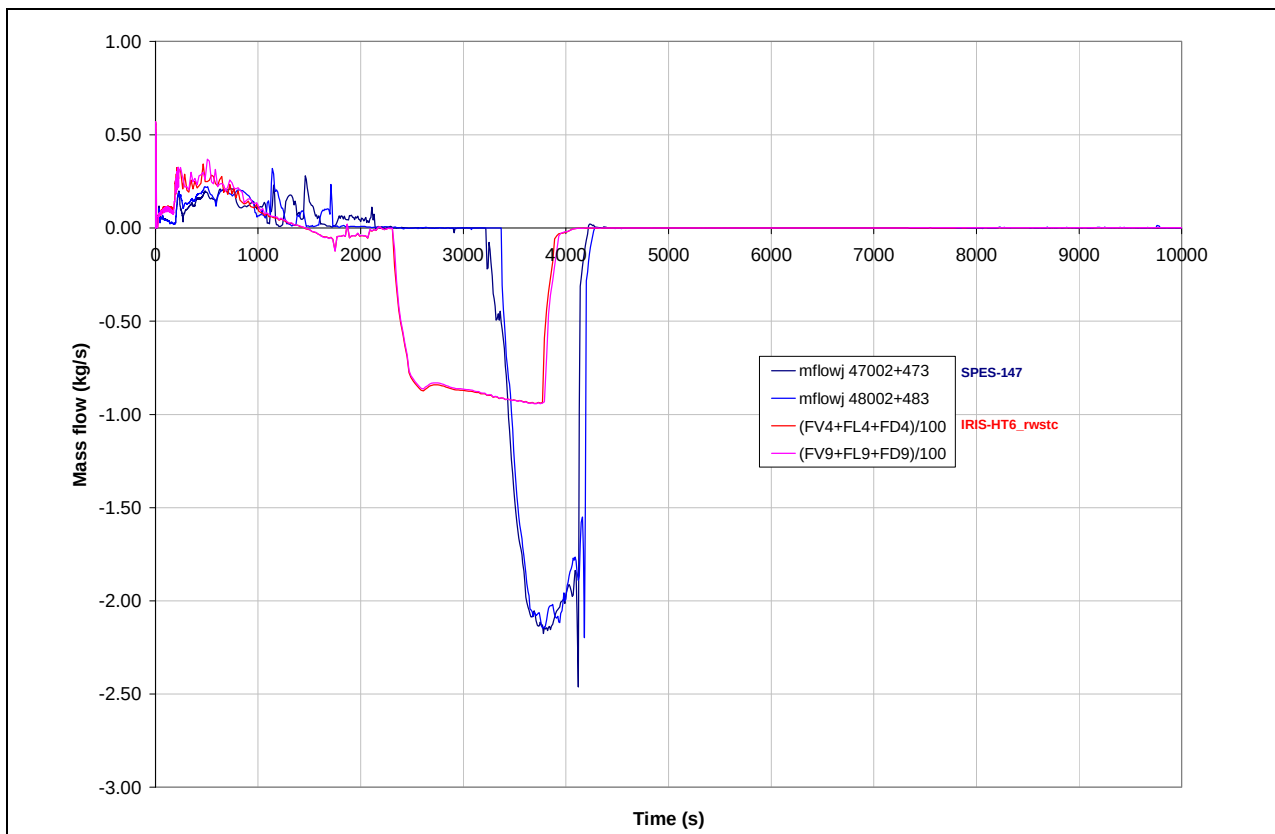
**Fig.9. 12 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-I mass flow (window)**



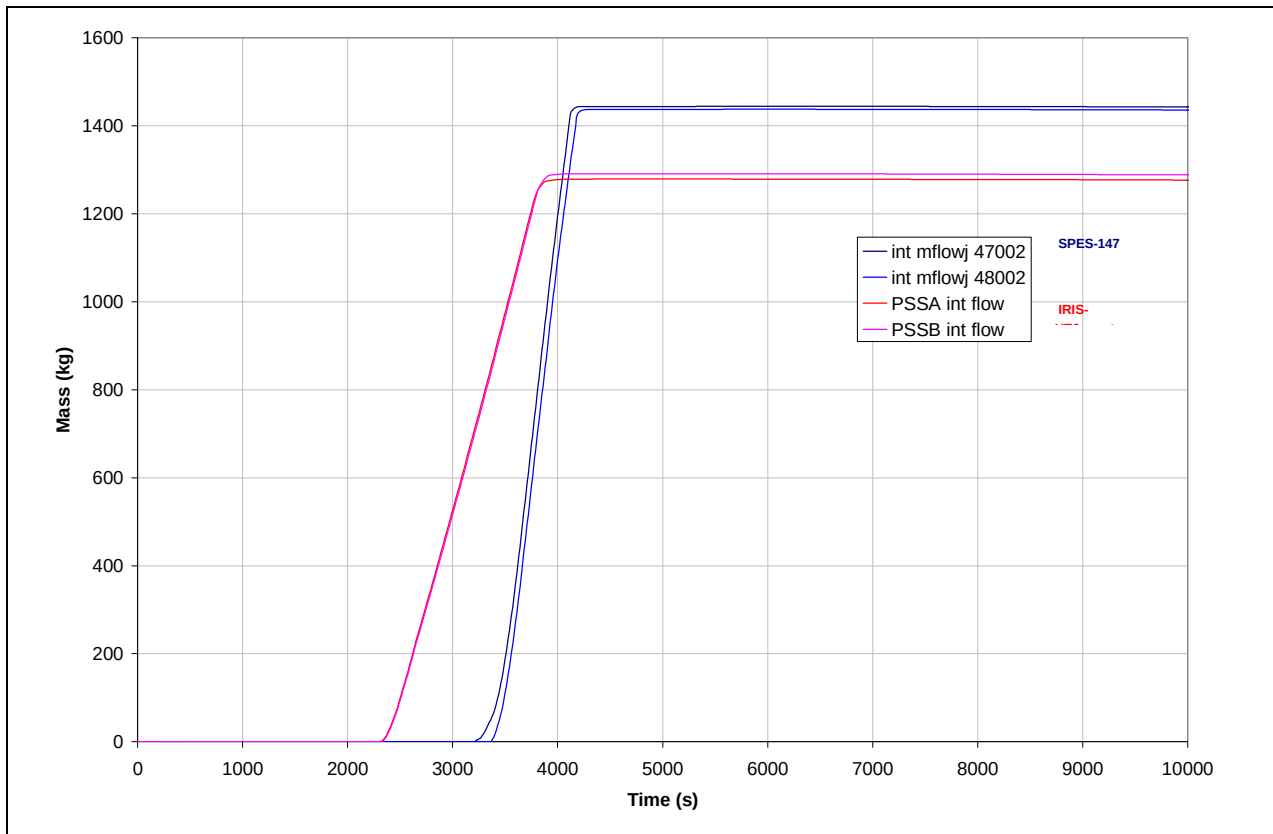
**Fig.9. 13 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-I mass flow**



**Fig.9. 14 – SPES3-147 and IRIS HT6\_rwstc DW to PSS mass flow (window)**



**Fig.9. 15 – SPES3-147 and IRIS HT6\_rwstc PSS to DW integral flow (window)**



**Fig.9. 16 – SPES3-147 and IRIS HT6\_rwstc PSS level (window)**

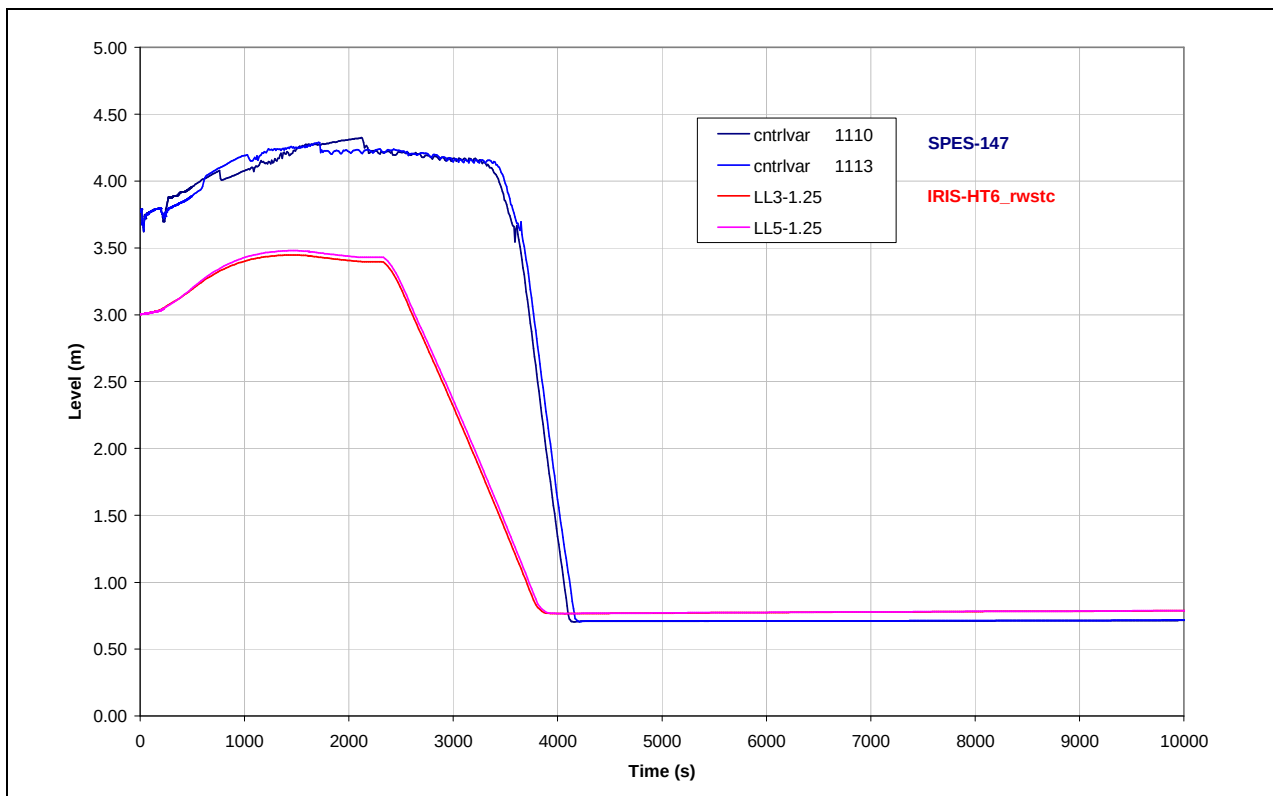


Fig.9. 17 – SPES3-147 and IRIS HT6\_rwstc DW non-condensable gas quality (window)

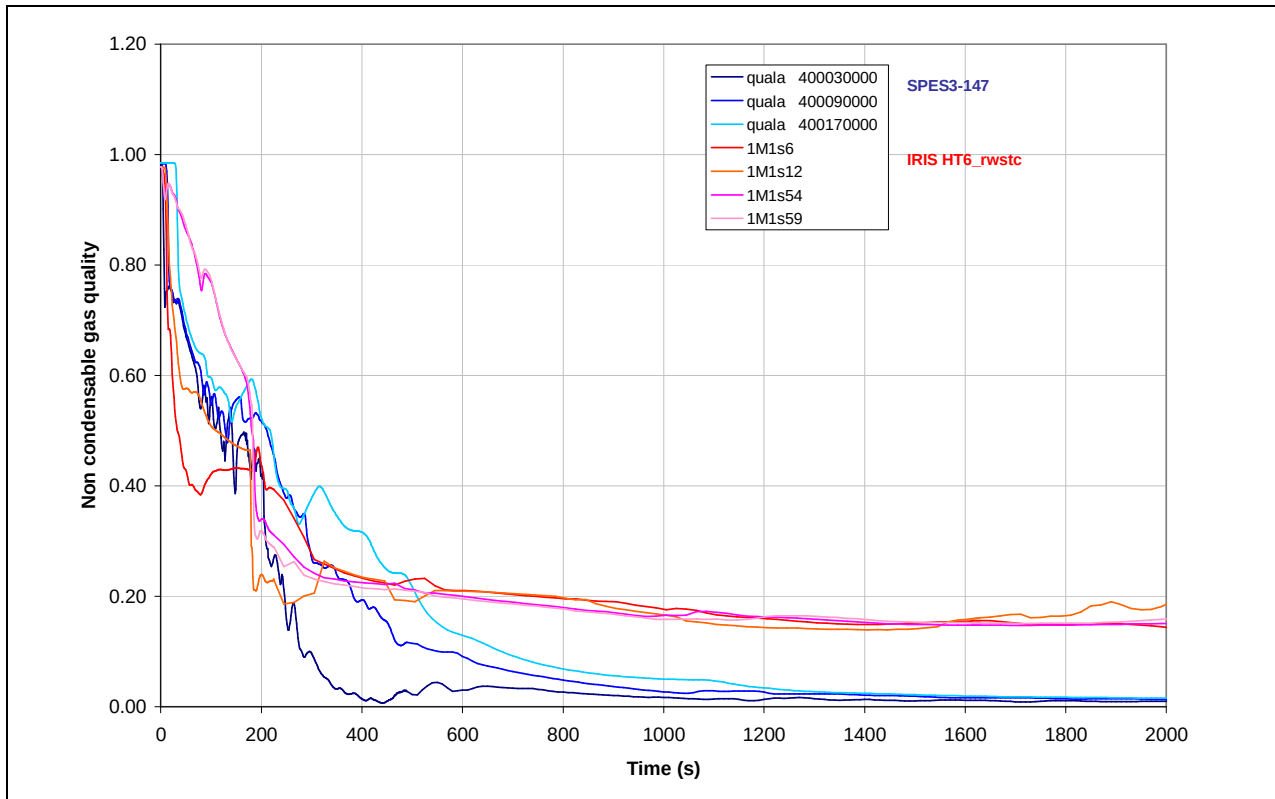
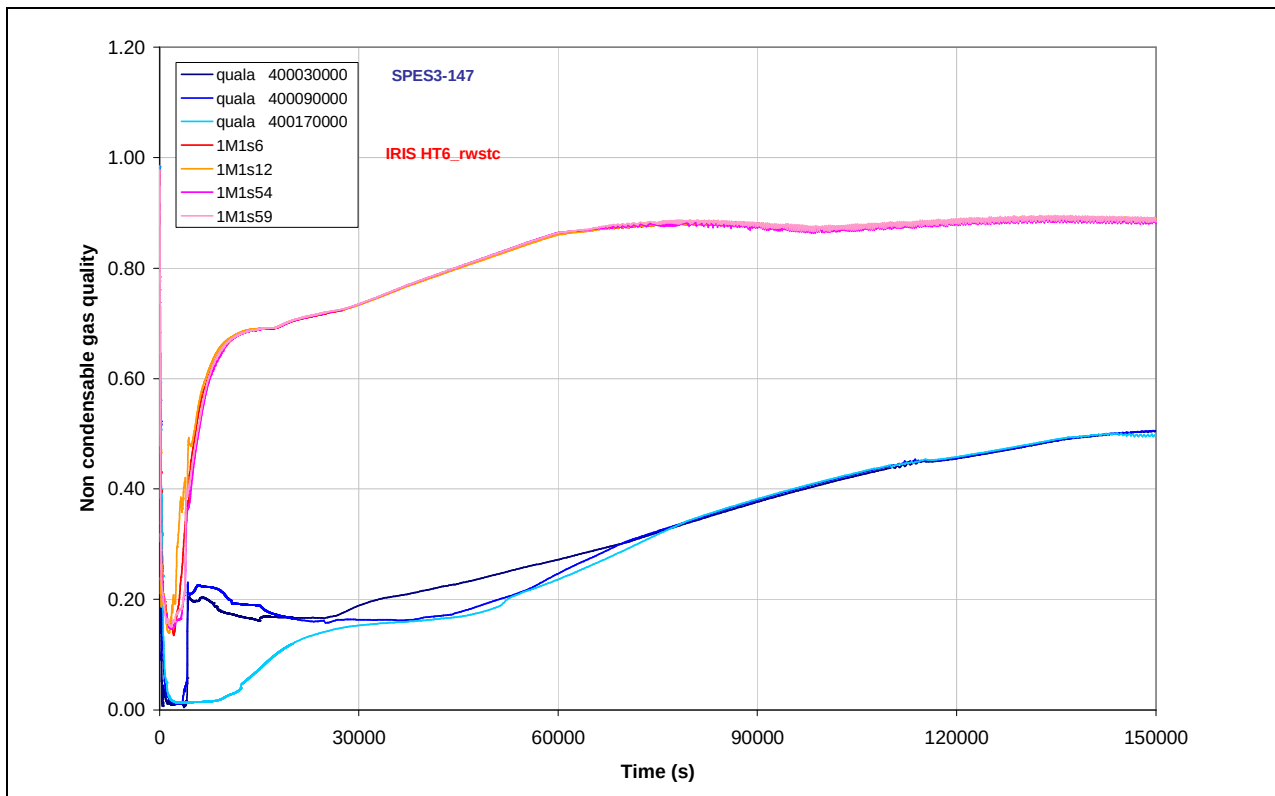
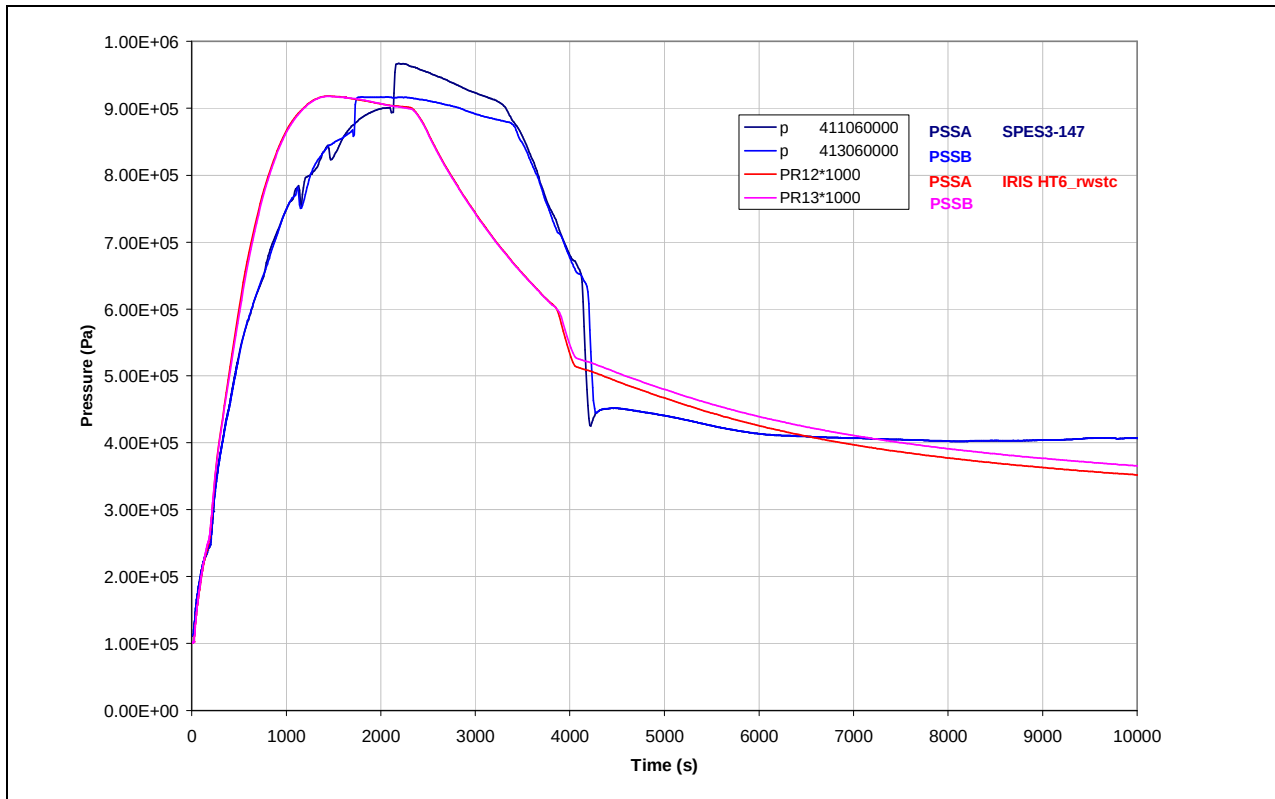


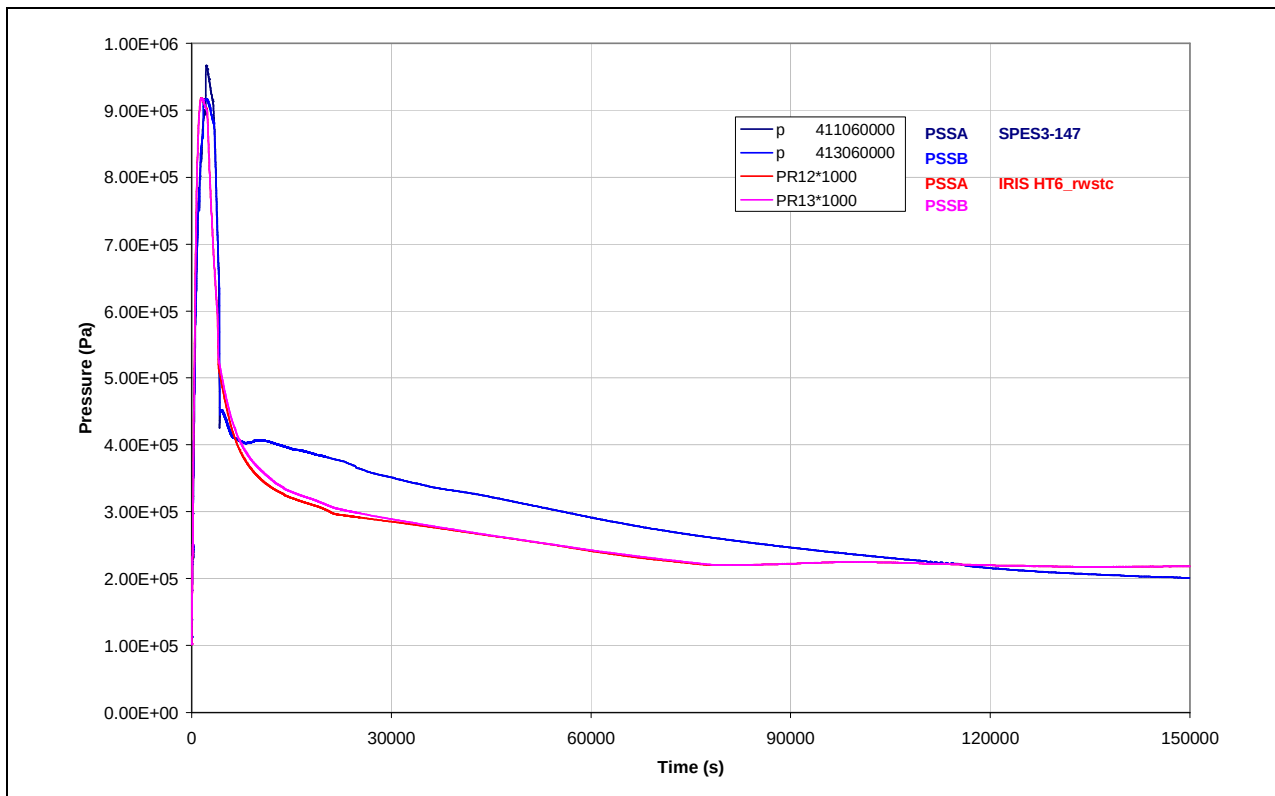
Fig.9. 18 – SPES3-147 and IRIS HT6\_rwstc DW non-condensable gas quality



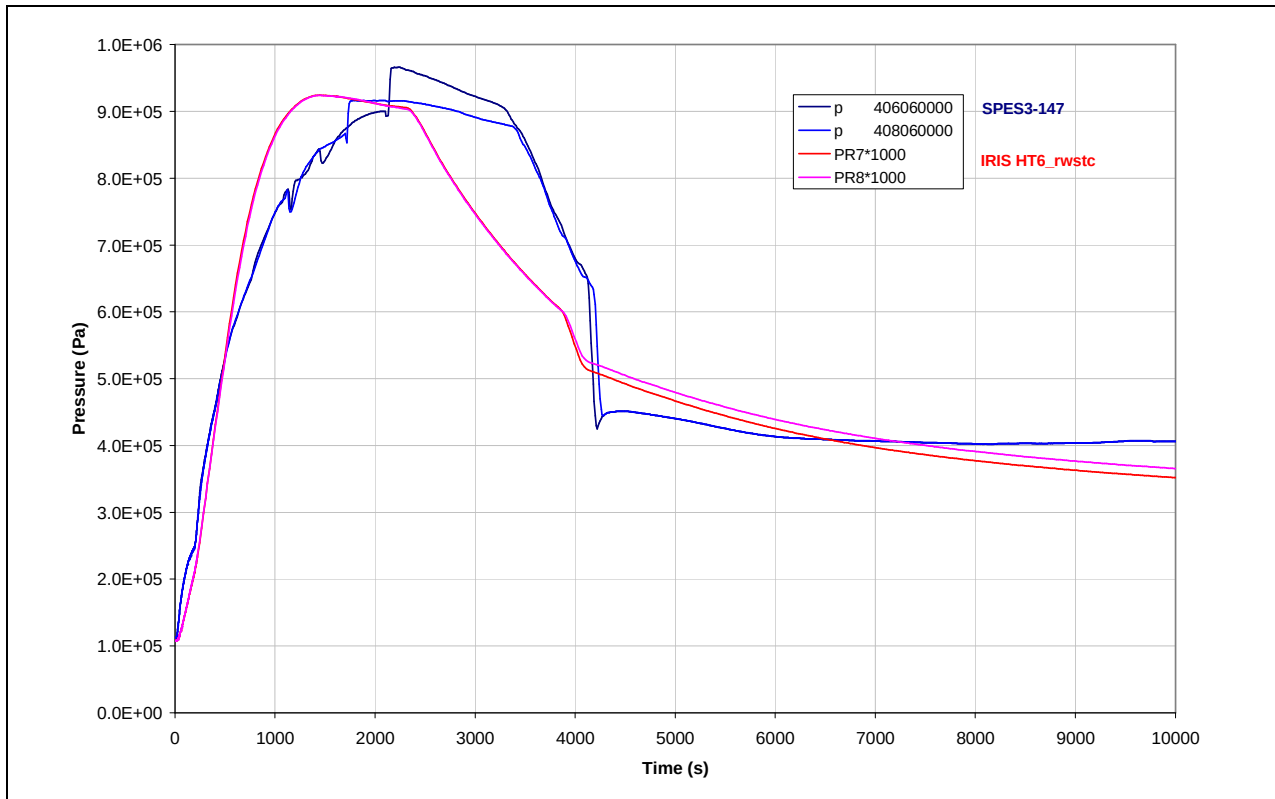
**Fig.9. 19 – SPES3-147 and IRIS HT6\_rwstc PSS pressure (window)**



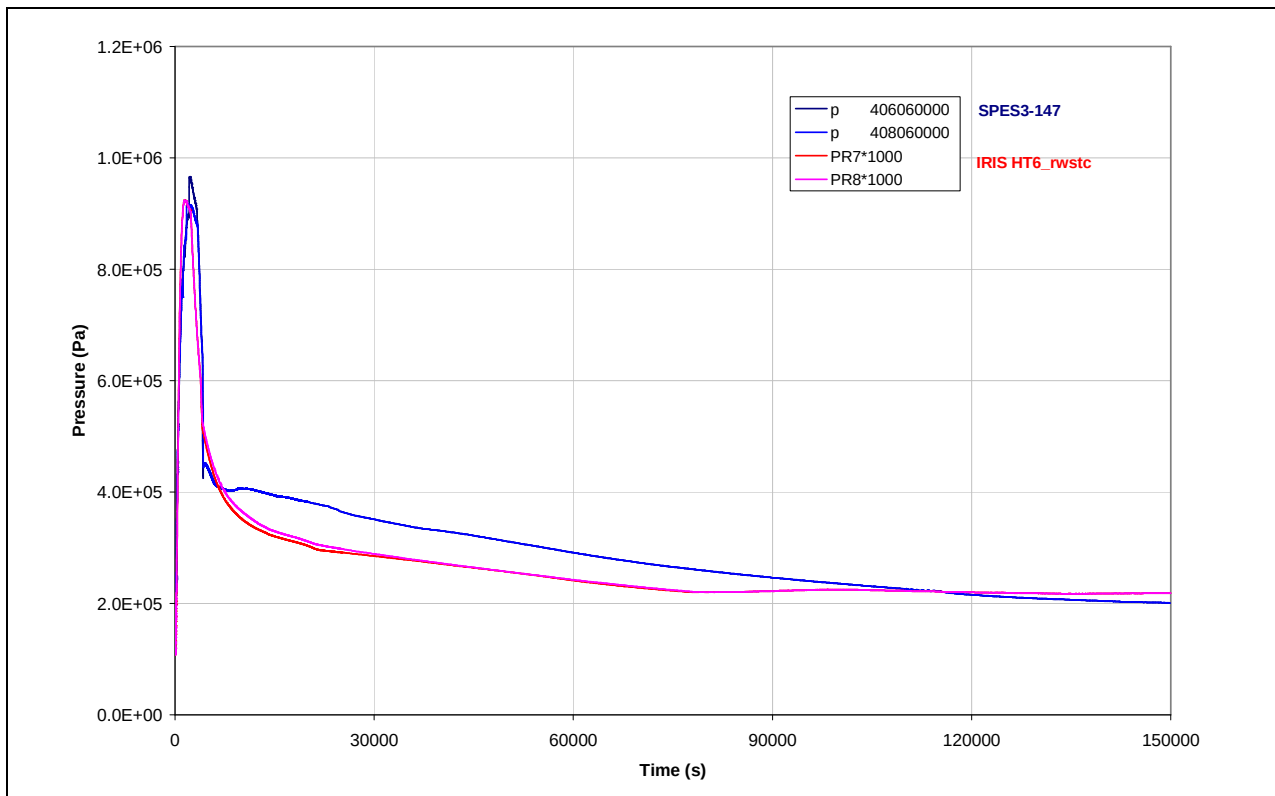
**Fig.9. 20 – SPES3-147 and IRIS HT6\_rwstc PSS pressure**



**Fig.9. 21 – SPES3-147 and IRIS HT6\_rwstc LGMS pressure (window)**

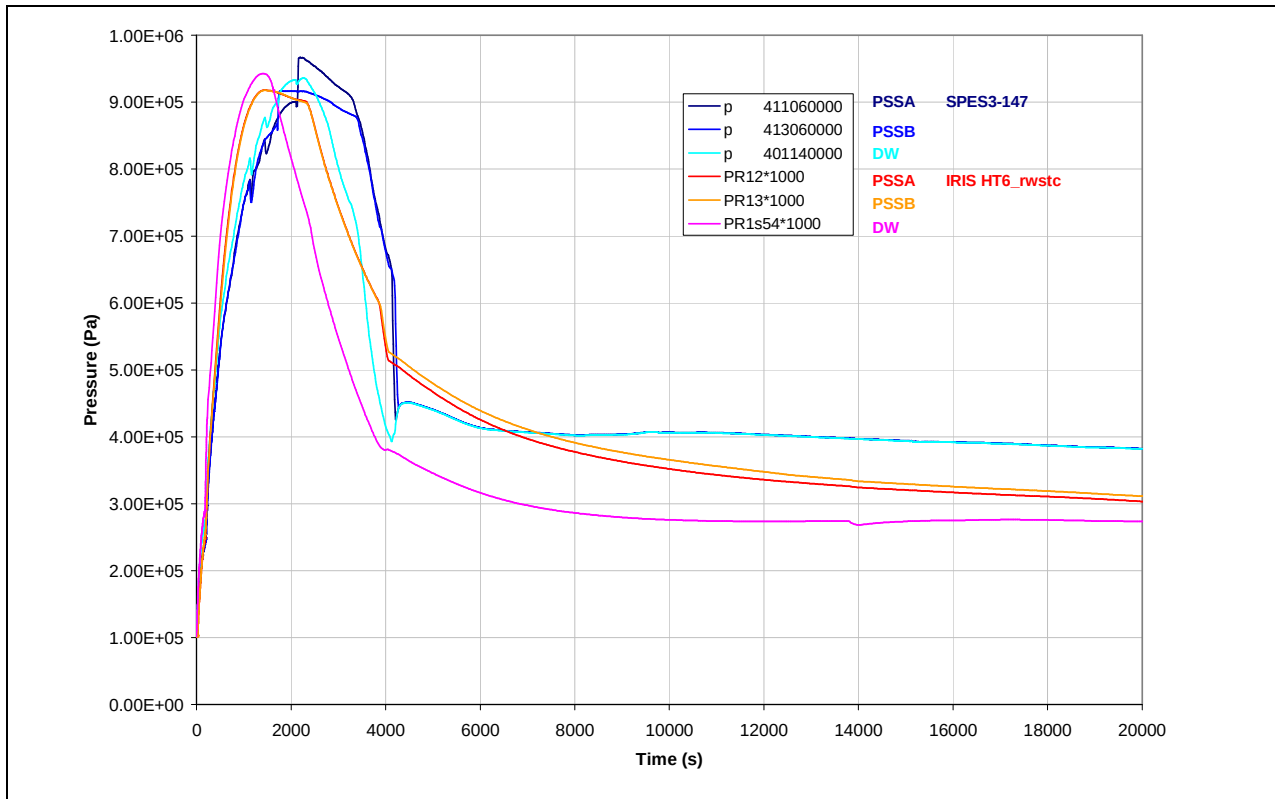


**Fig.9. 22 – SPES3-147 and IRIS HT6\_rwstc LGMS pressure**

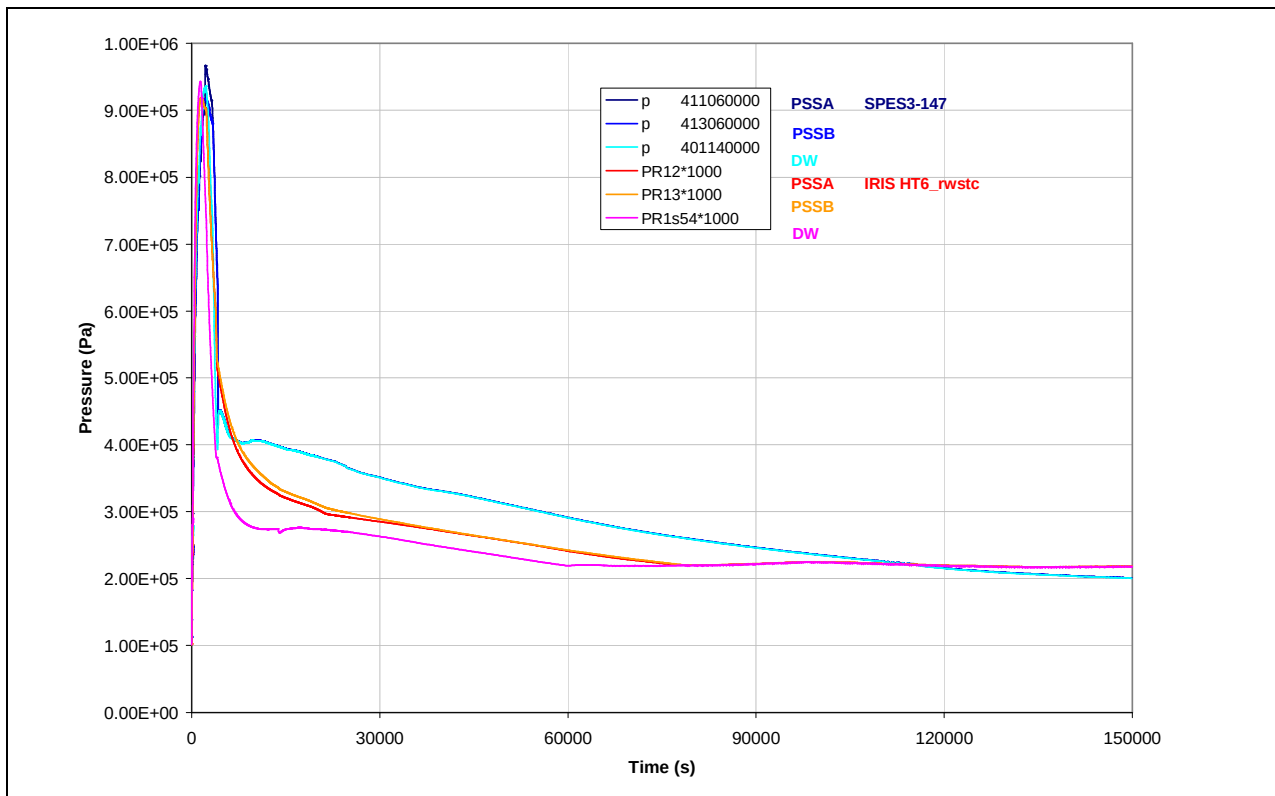




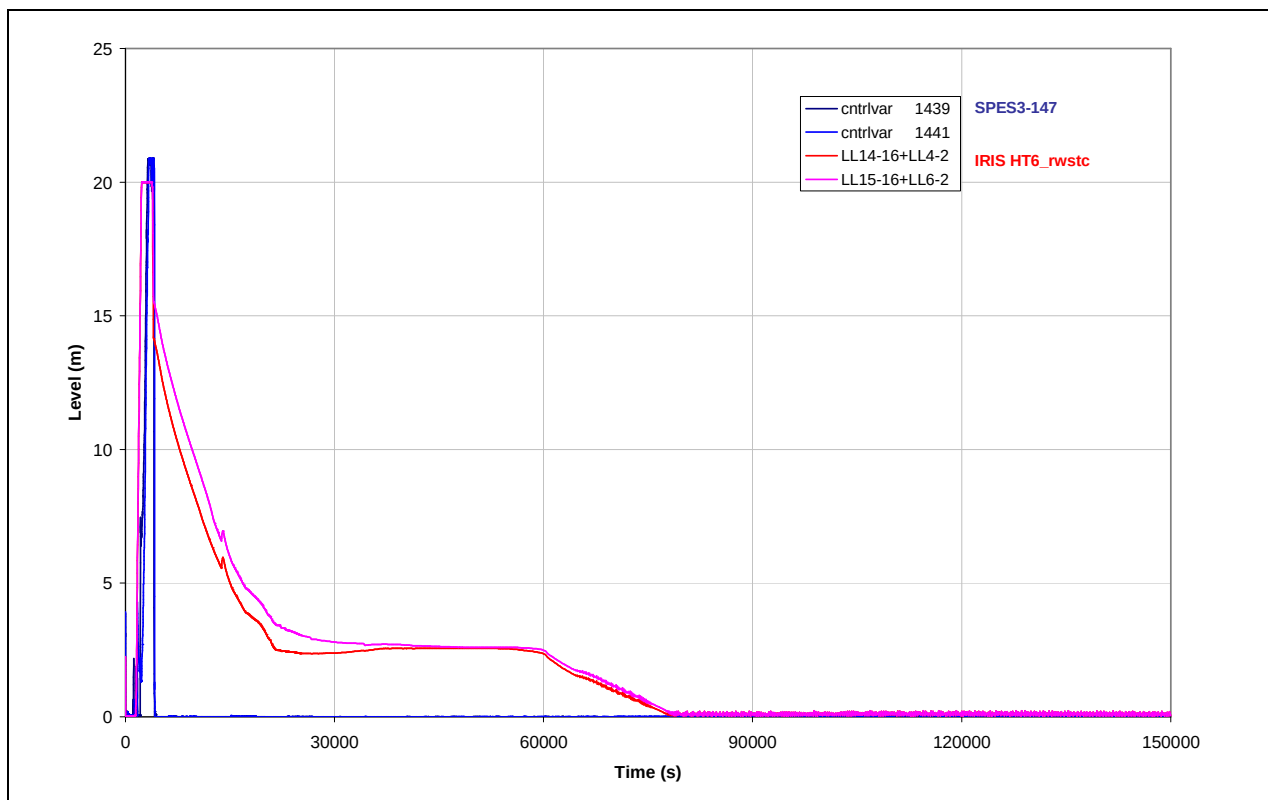
**Fig.9. 23 – SPES3-147 and IRIS HT6\_rwstc DW and PSS pressure (window)**



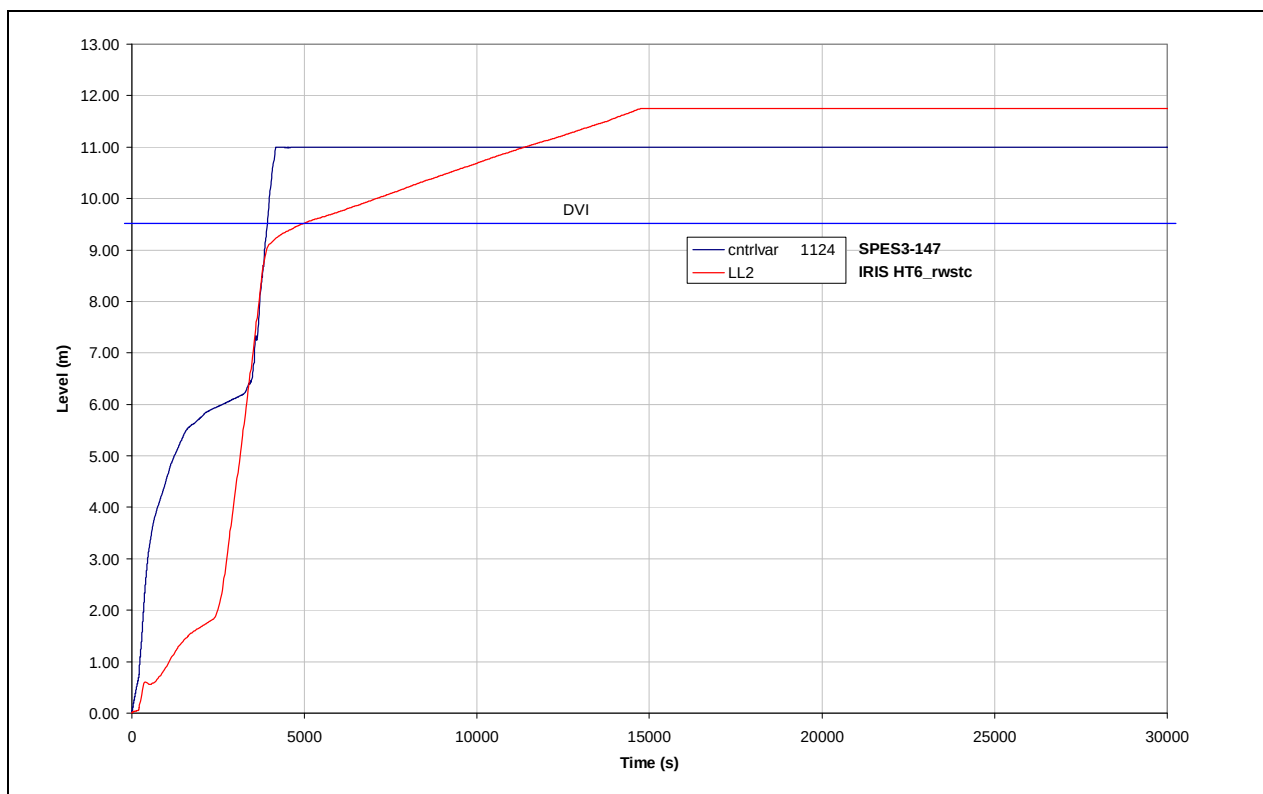
**Fig.9. 24 – SPES3-147 and IRIS HT6\_rwstc DW and PSS pressure**



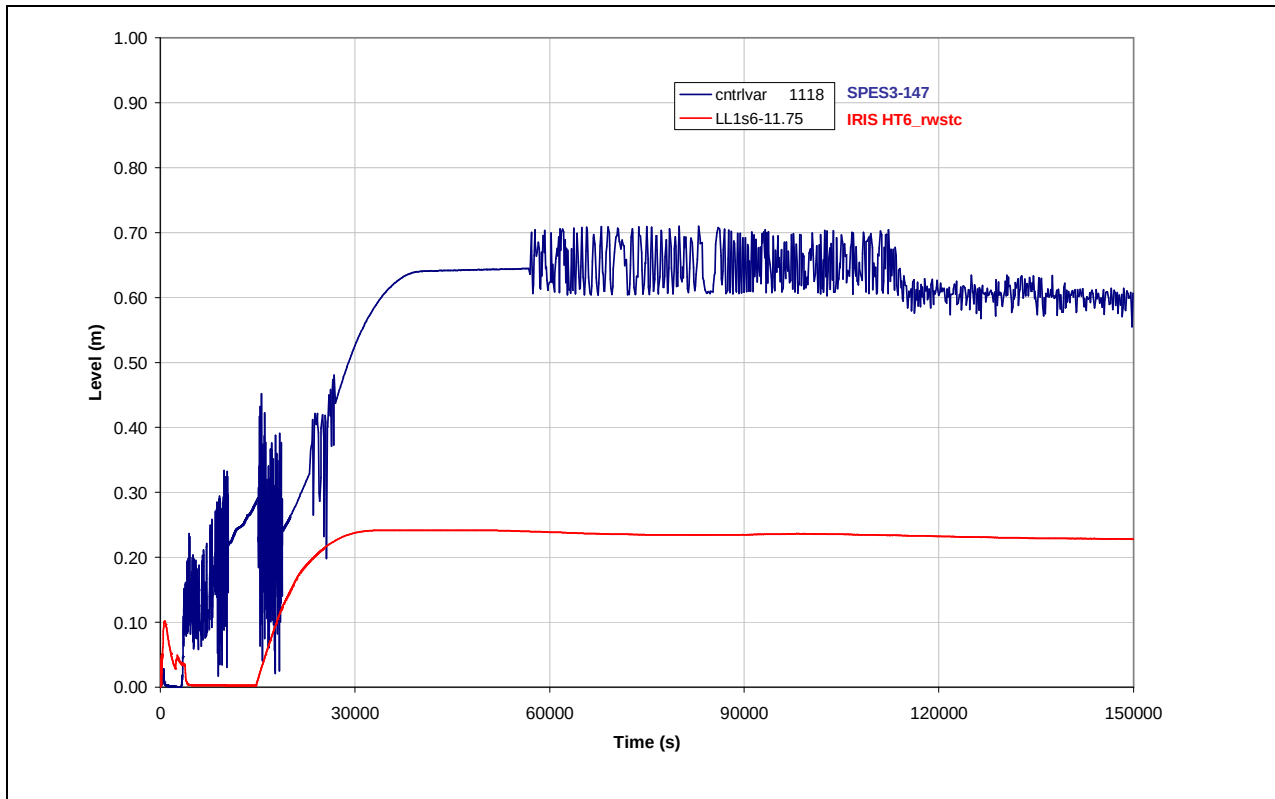
**Fig.9. 25 – SPES3-147 and IRIS HT6\_rwstc PSS to DW pipe level**



**Fig.9. 26 – SPES3-147 and IRIS HT6\_rwstc RC level (window)**



**Fig.9. 27 – SPES3-147 and IRIS HT6\_rwstc DW level**



**Fig.9. 28 – SPES3-147 and IRIS HT6\_rwstc PSS liquid and gas temperature (window)**

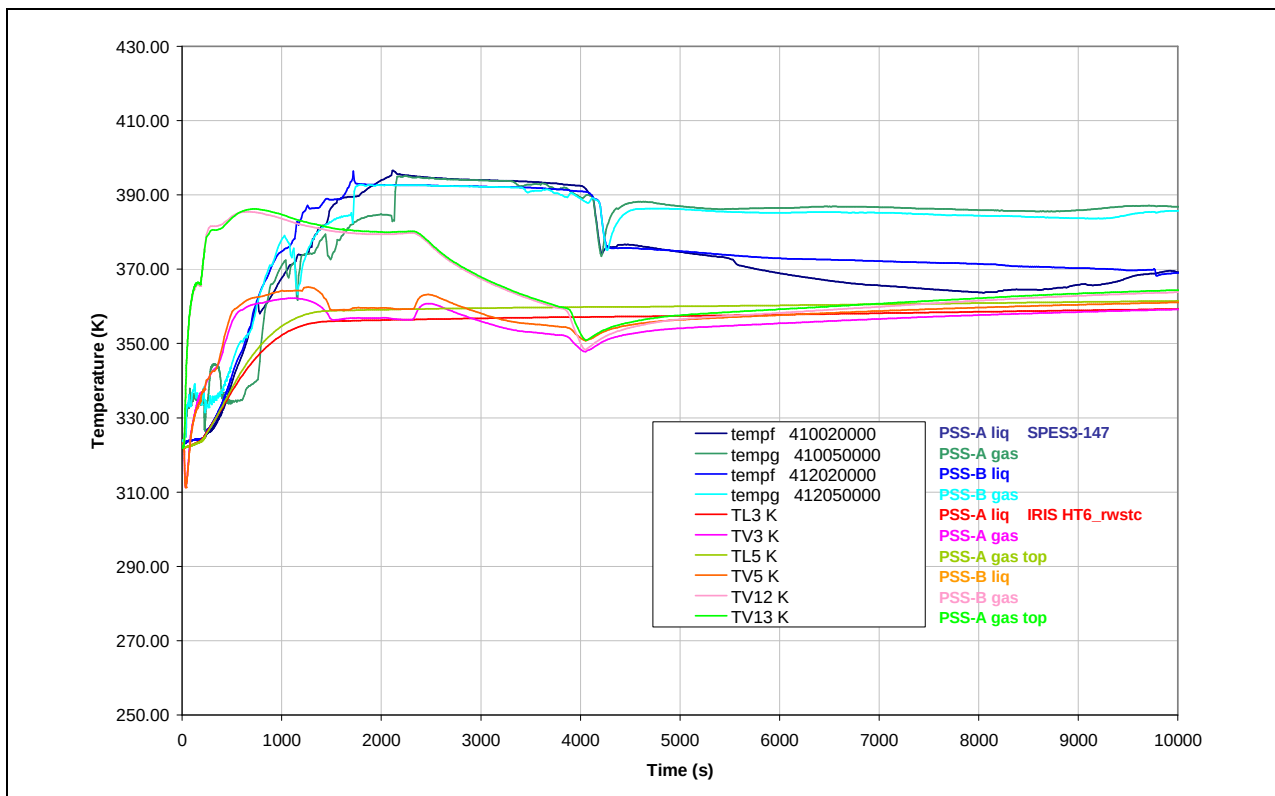


Fig.9. 29 – SPES3-147 and IRIS HT6\_rwstc PSS liquid and gas temperature

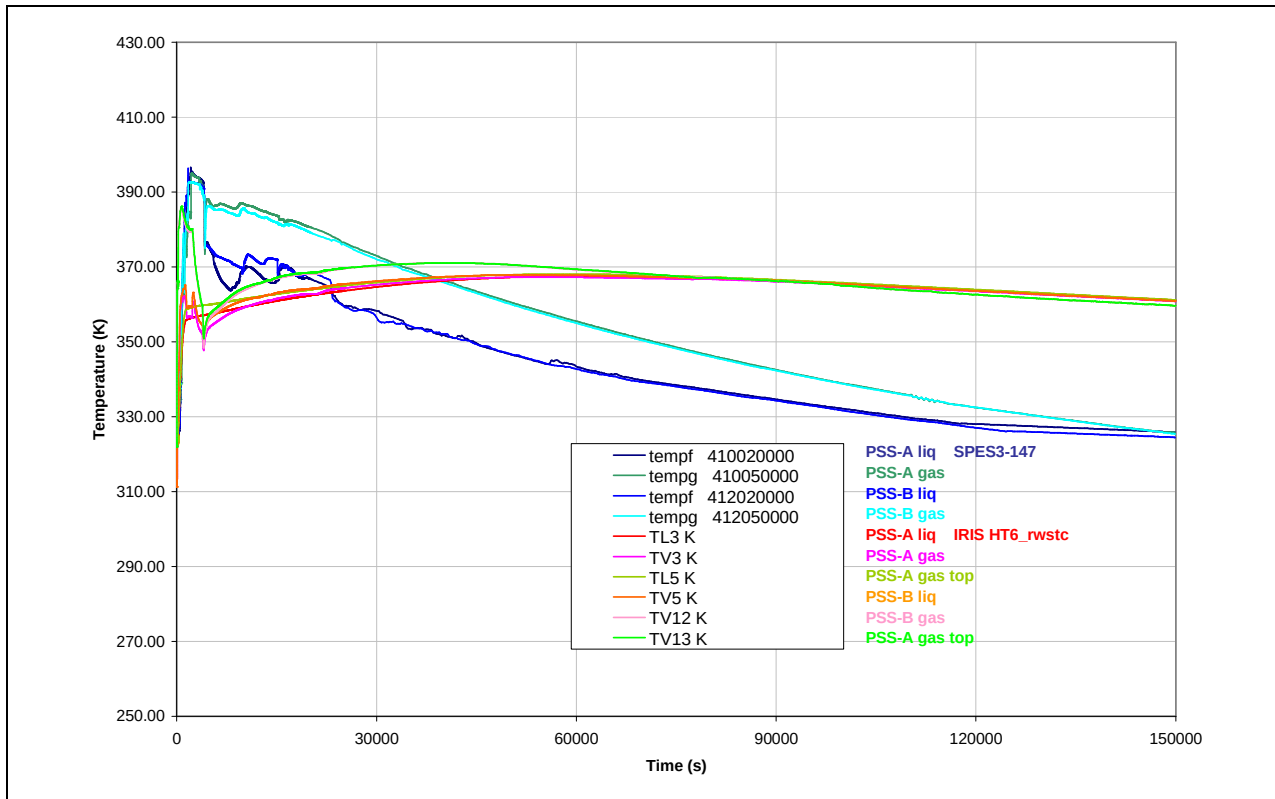
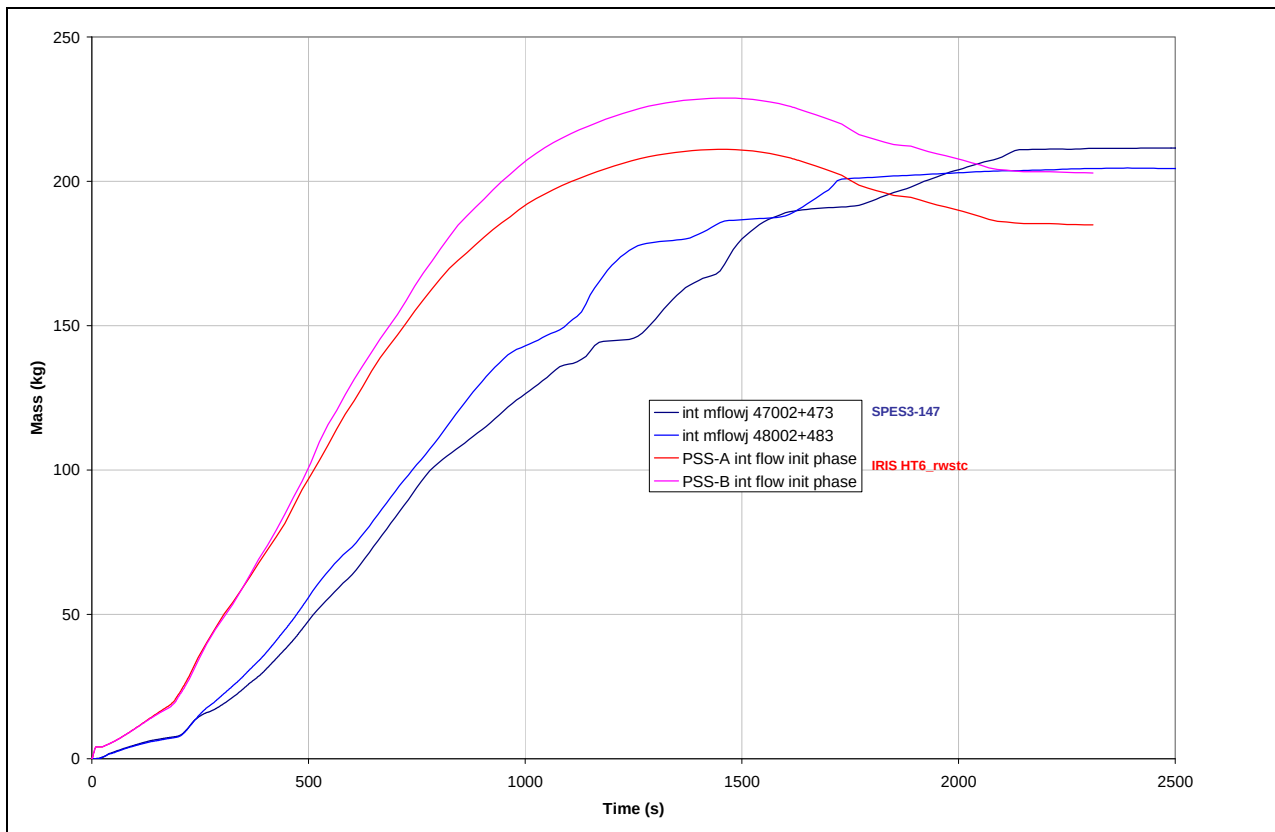
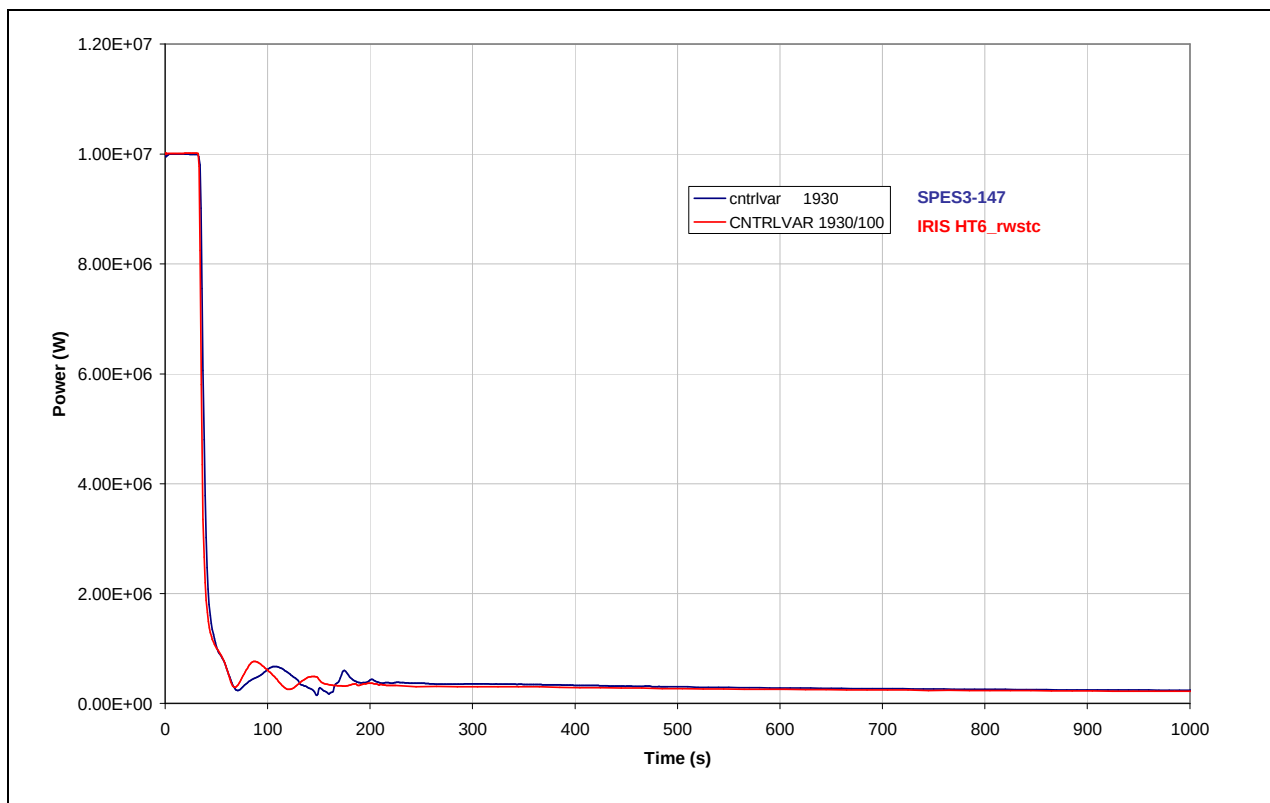


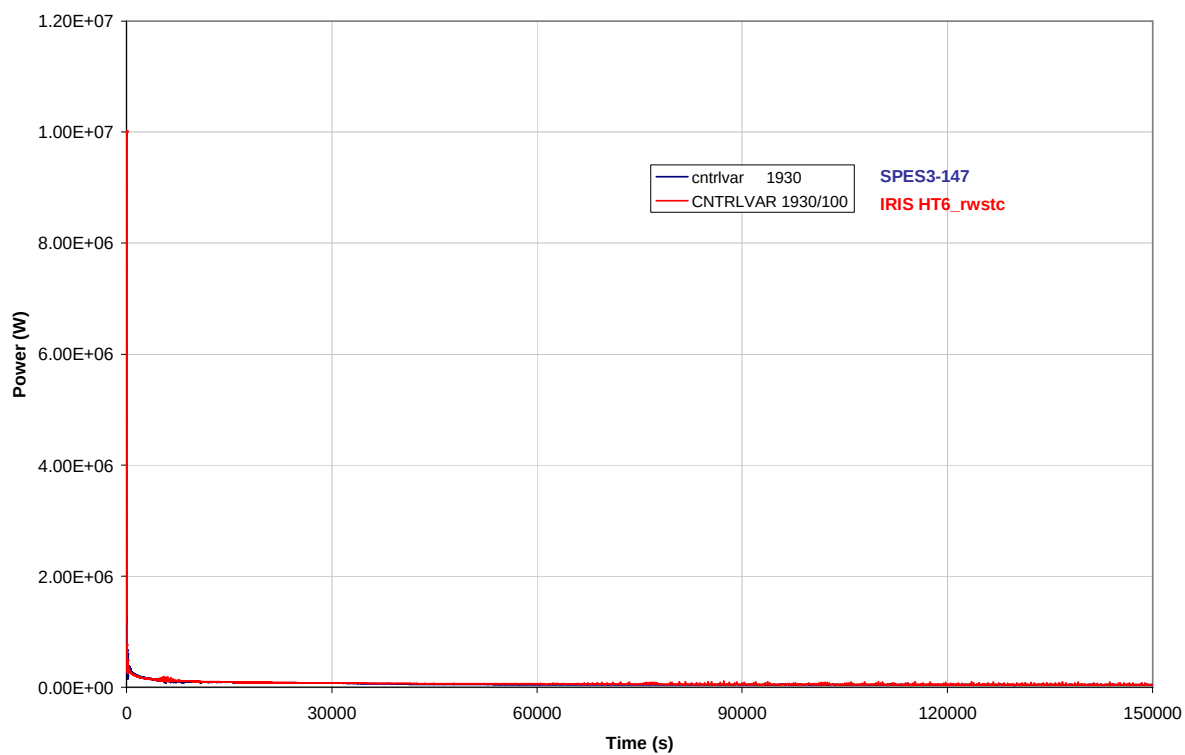
Fig.9. 30 – SPES3-147 and IRIS HT6\_rwstc DW to PSS integral flow (first phase of injection)



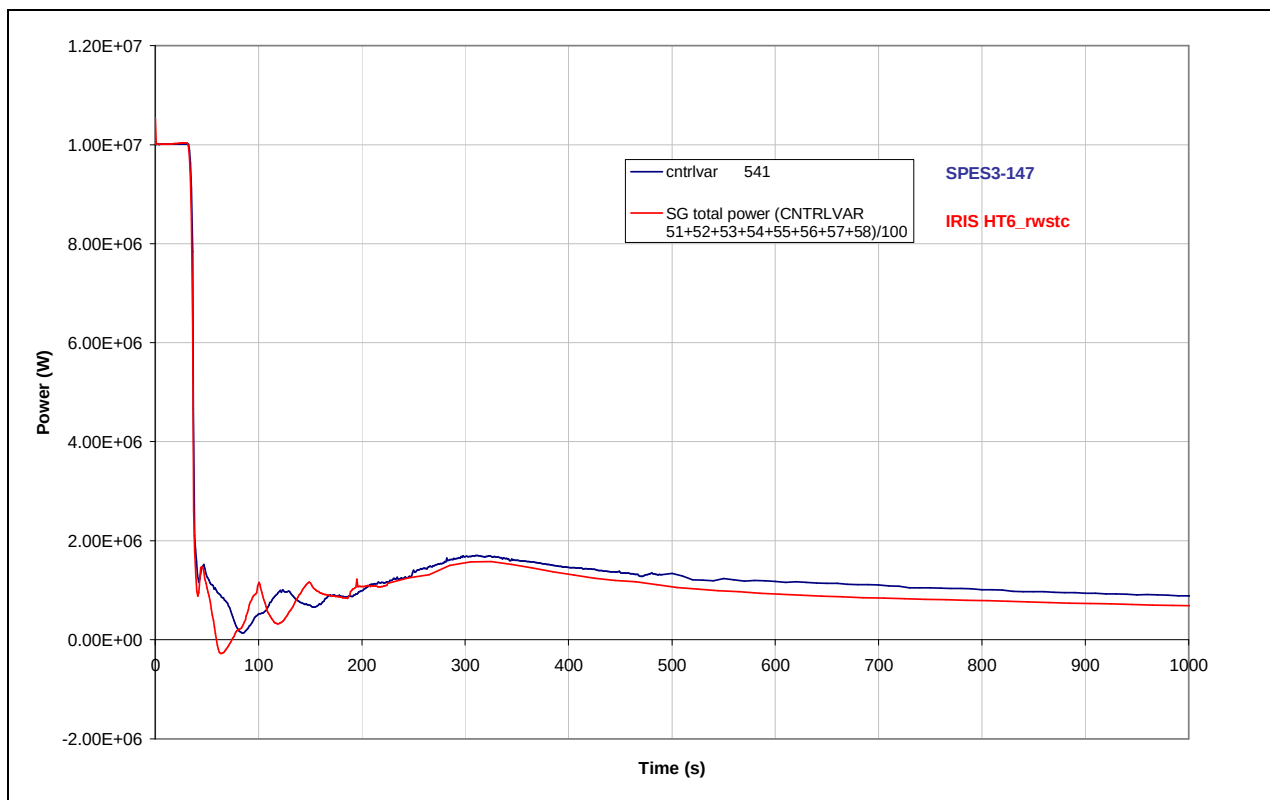
**Fig.9. 31 – SPES3-147 and IRIS HT6\_rwstc core power (window)**



**Fig.9. 32 – SPES3-147 and IRIS HT6\_rwstc core power**



**Fig.9. 33 – SPES3-147 and IRIS HT6\_rwstc SG power (window)**



**Fig.9. 34 – SPES3-147 and IRIS HT6\_rwstc SG power**

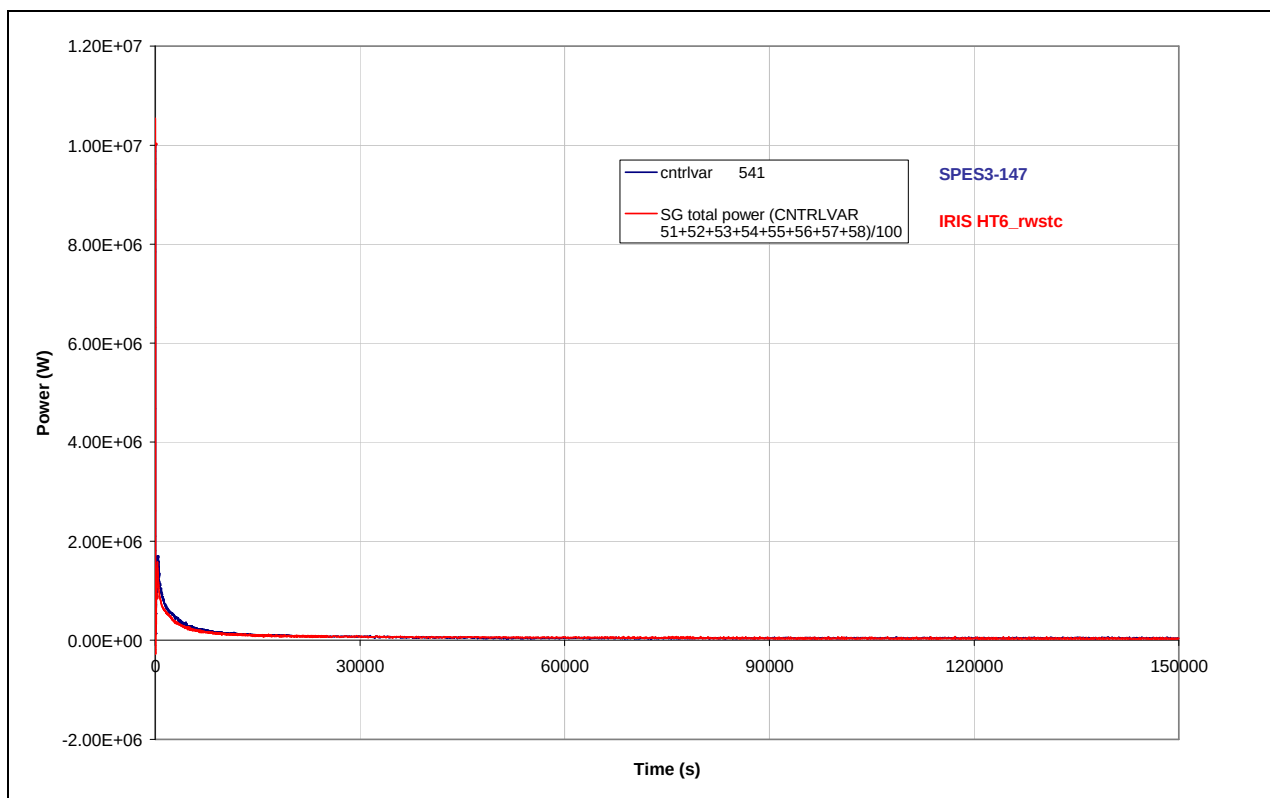


Fig.9. 35 – SPES3-147 and IRIS HT6\_rwstc SG ss mass flow (window)

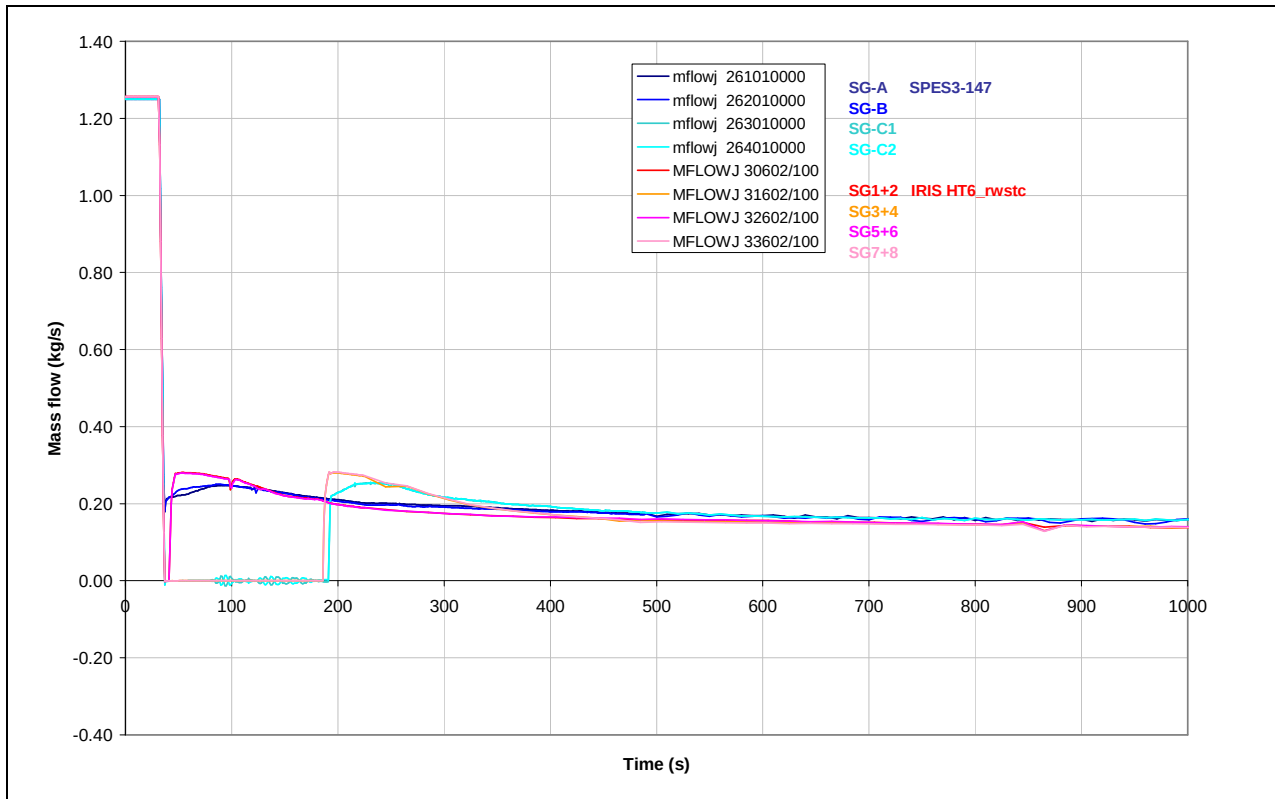


Fig.9. 36 – SPES3-147 and IRIS HT6\_rwstc SG ss mass flow

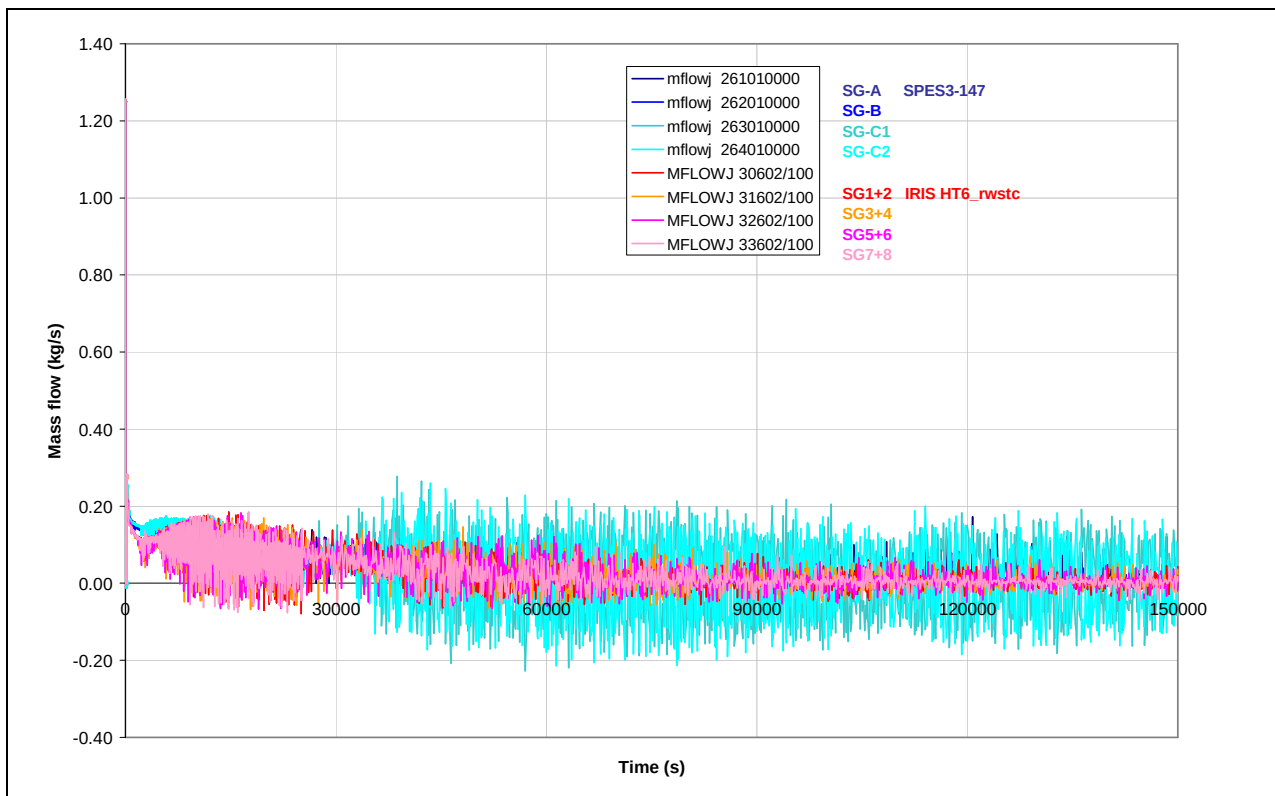


Fig.9. 37 – SPES3-147 and IRIS HT6\_rwstc EHRS cold leg mass flow (window)

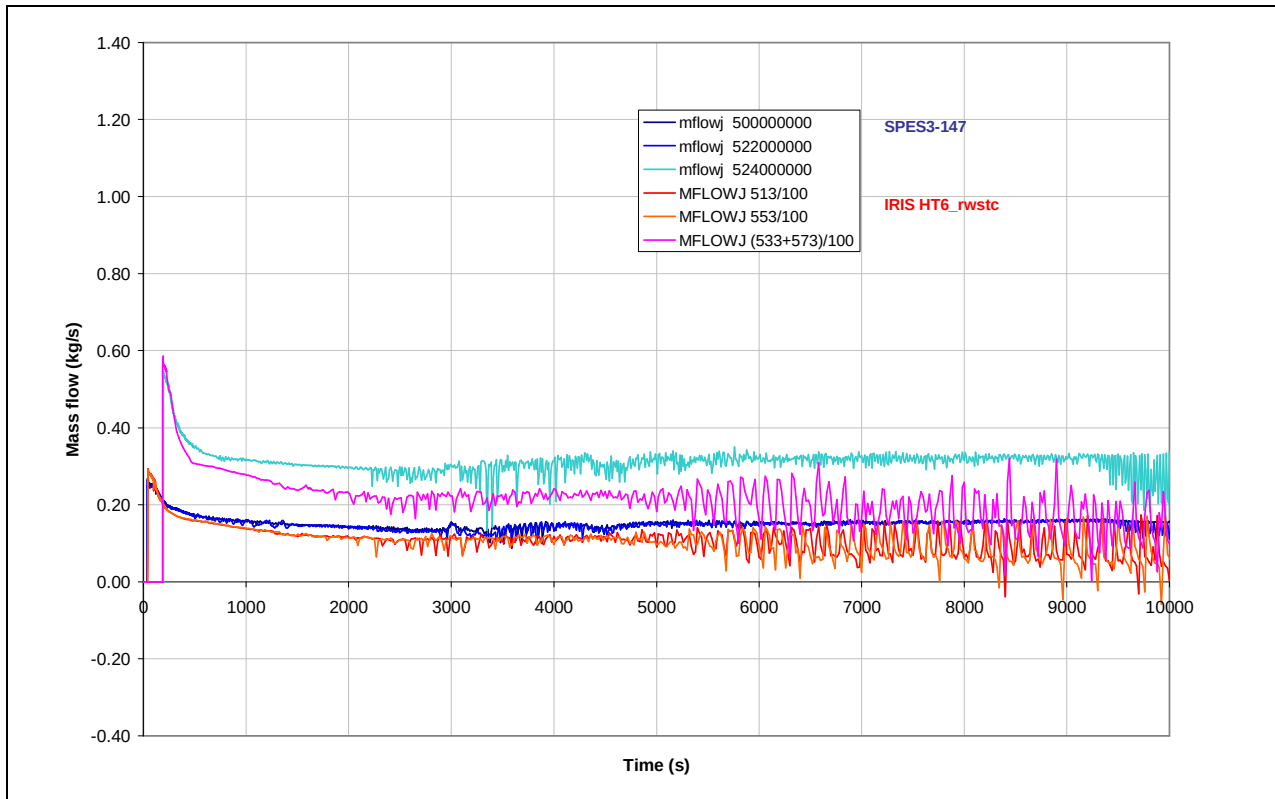


Fig.9. 38 – SPES3-147 and IRIS HT6\_rwstc EHRS cold leg mass flow

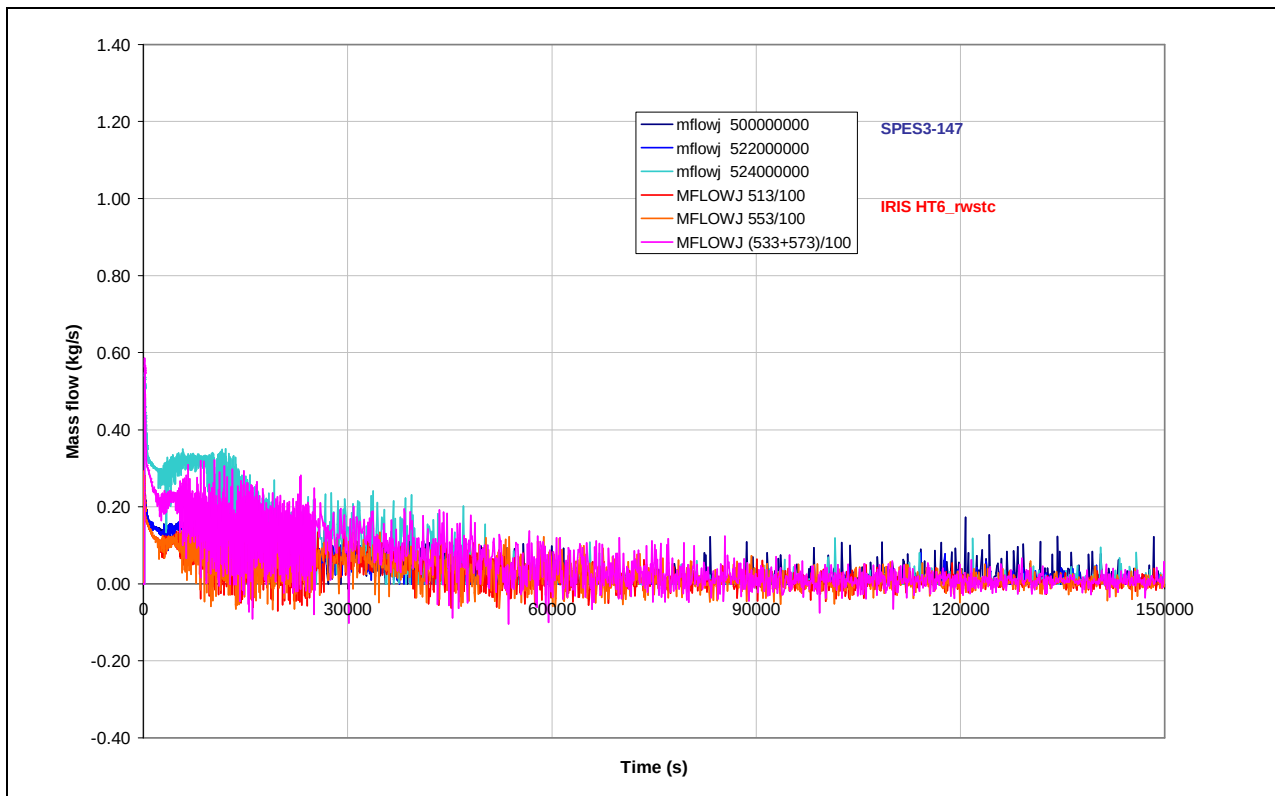




Fig.9. 39 – SPES3-147 and IRIS HT6\_rwstc EHRS power (window)

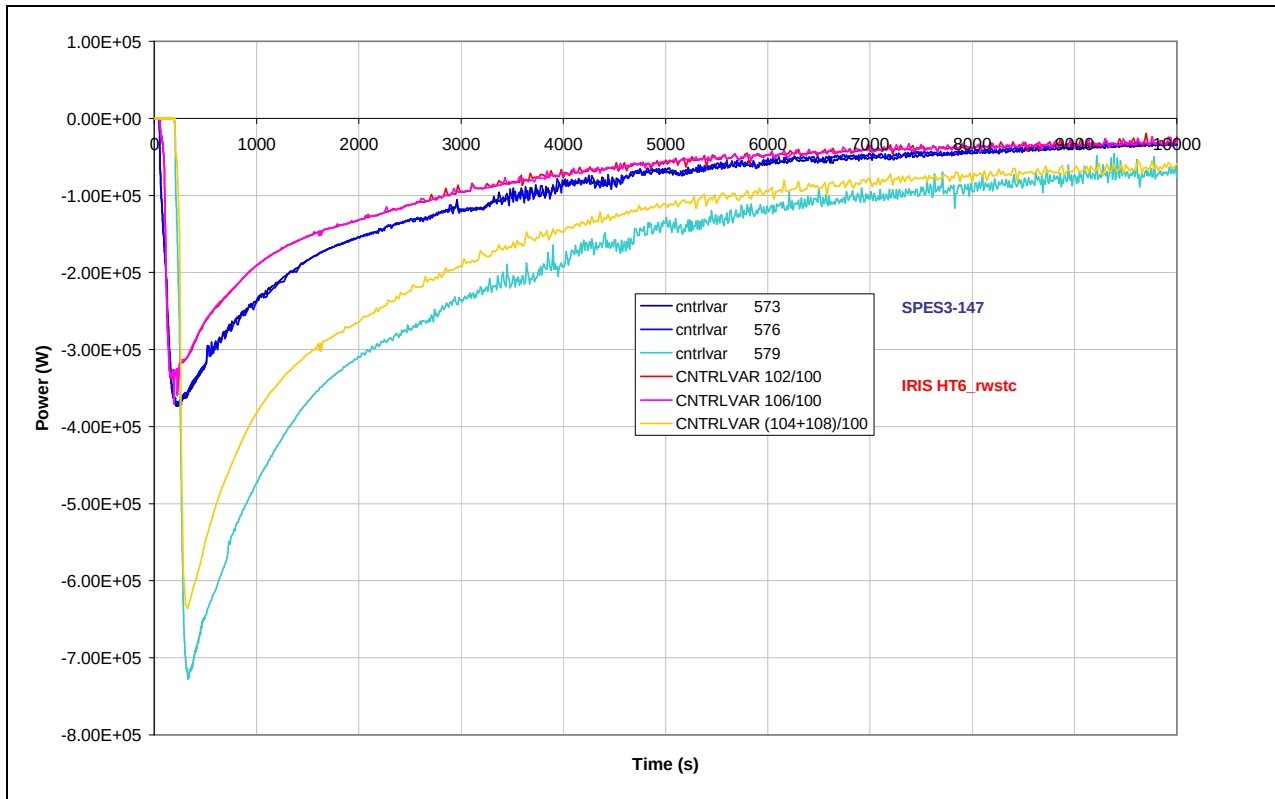
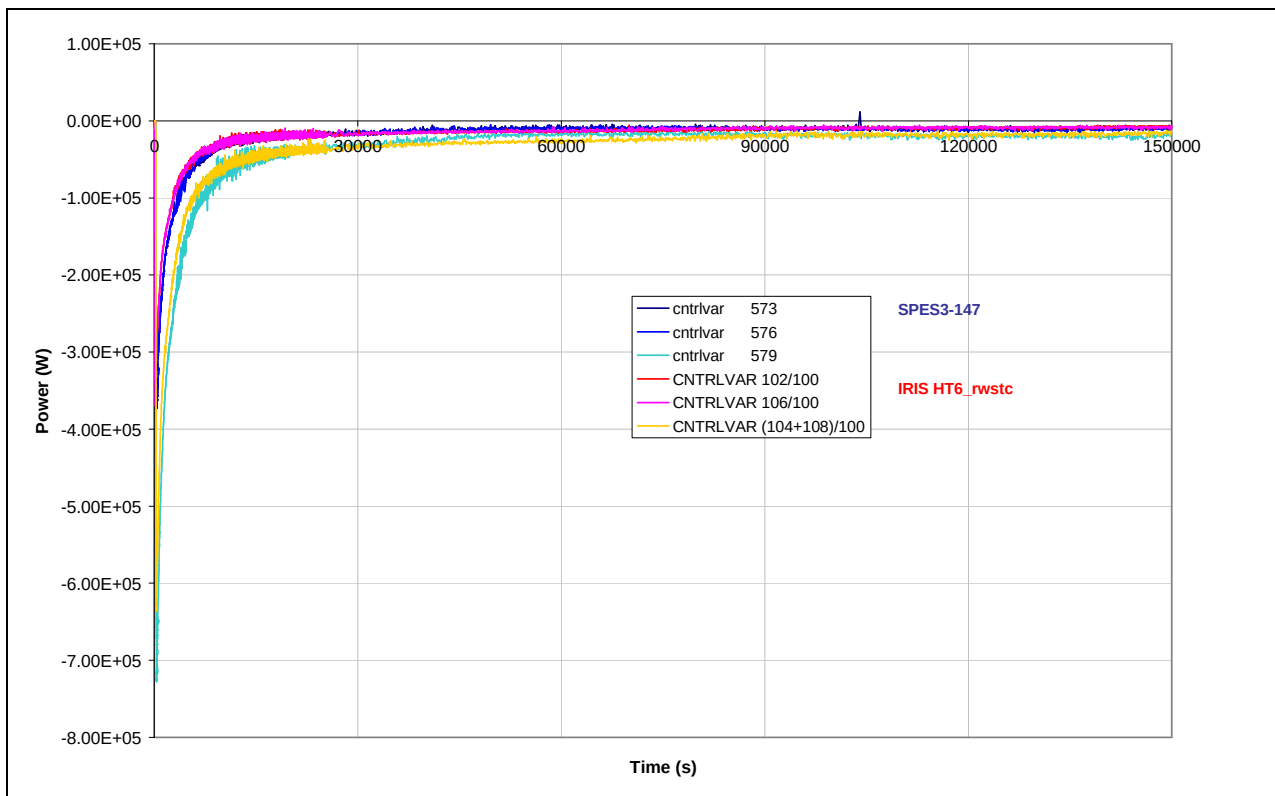
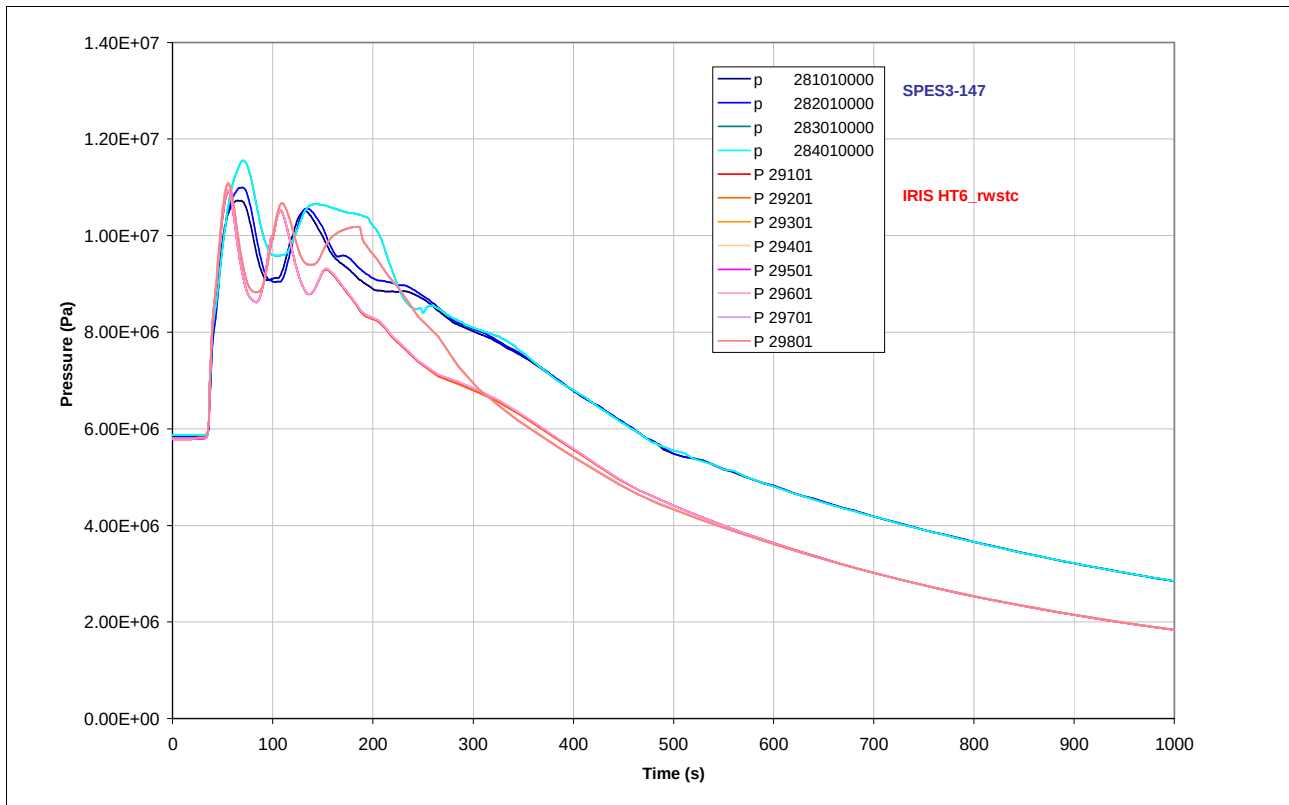


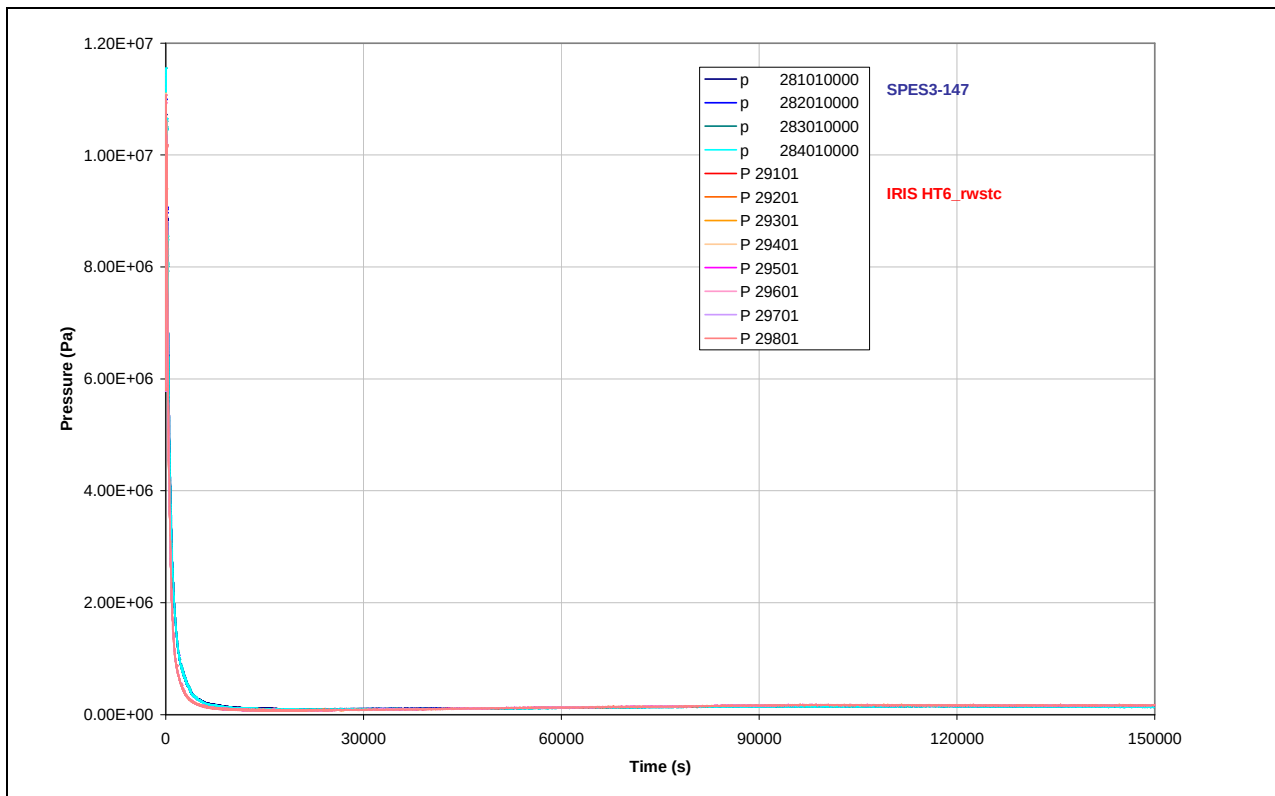
Fig.9. 40 – SPES3-147 and IRIS HT6\_rwstc EHRS power



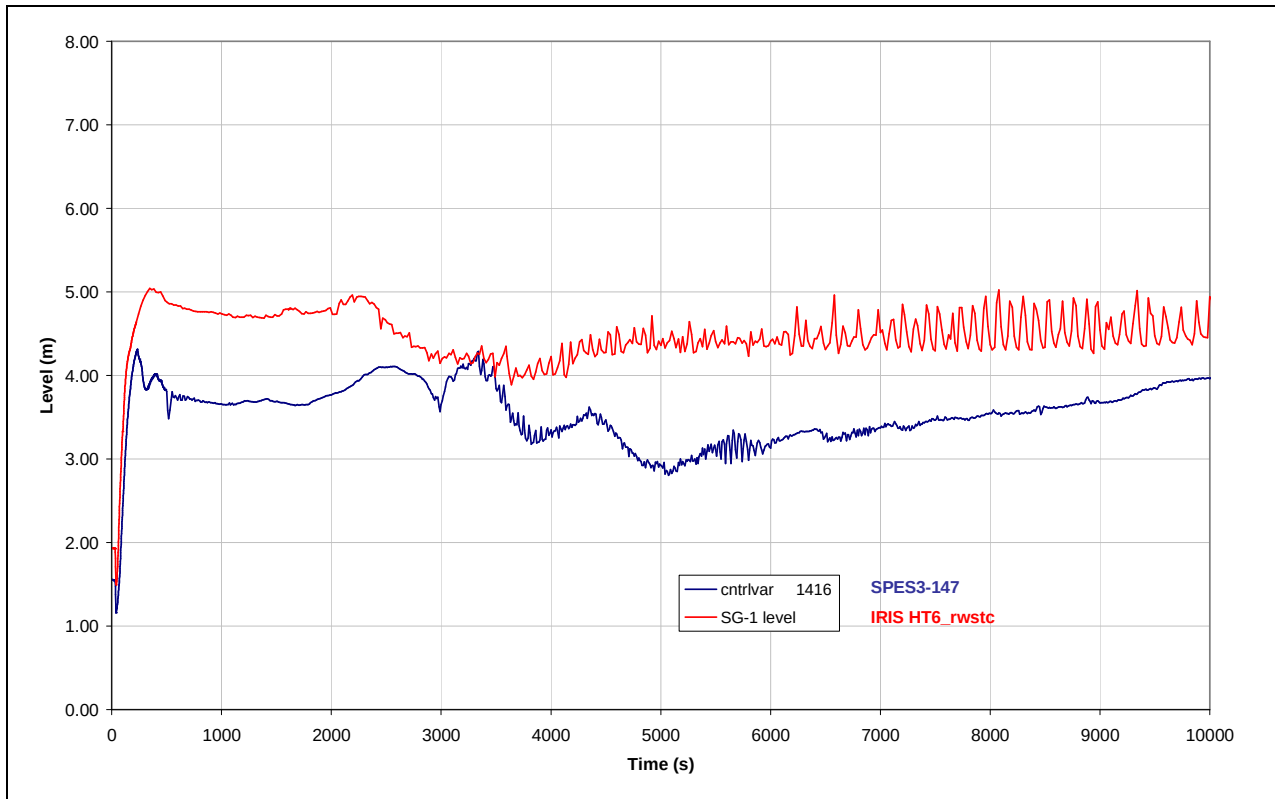
**Fig.9. 41 – SPES3-147 and IRIS HT6\_rwstc SG ss outlet pressure (window)**



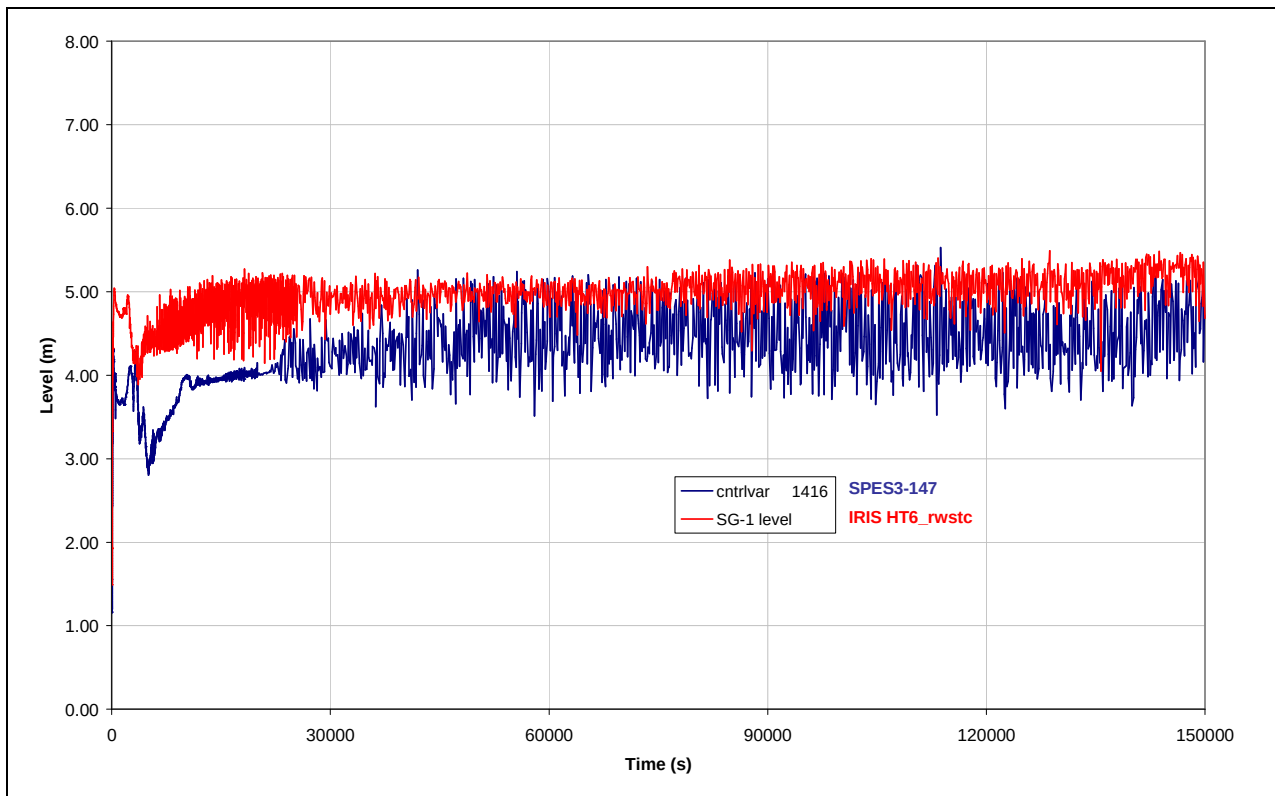
**Fig.9. 42 – SPES3-147 and IRIS HT6\_rwstc SG ss outlet pressure**



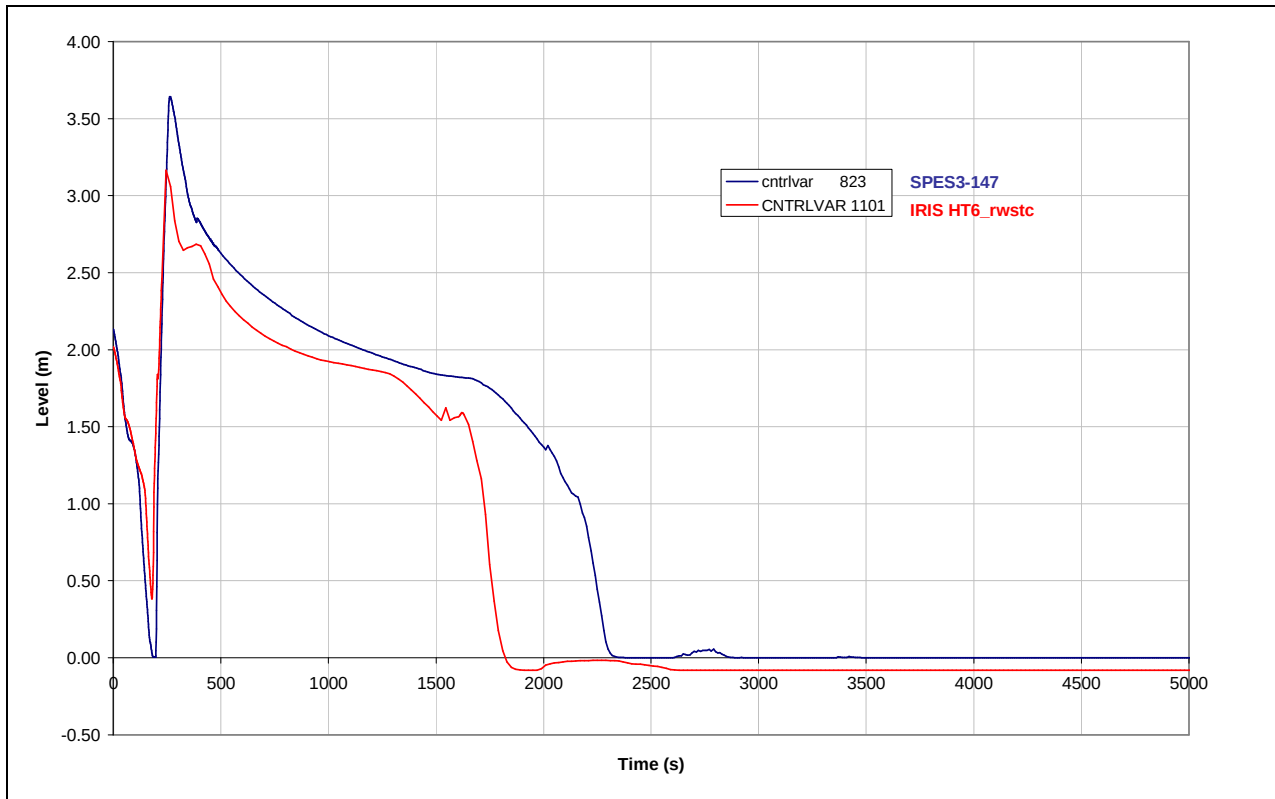
**Fig.9. 43 – SPES3-147 and IRIS HT6\_rwstc SG-1ss collapsed level (window)**



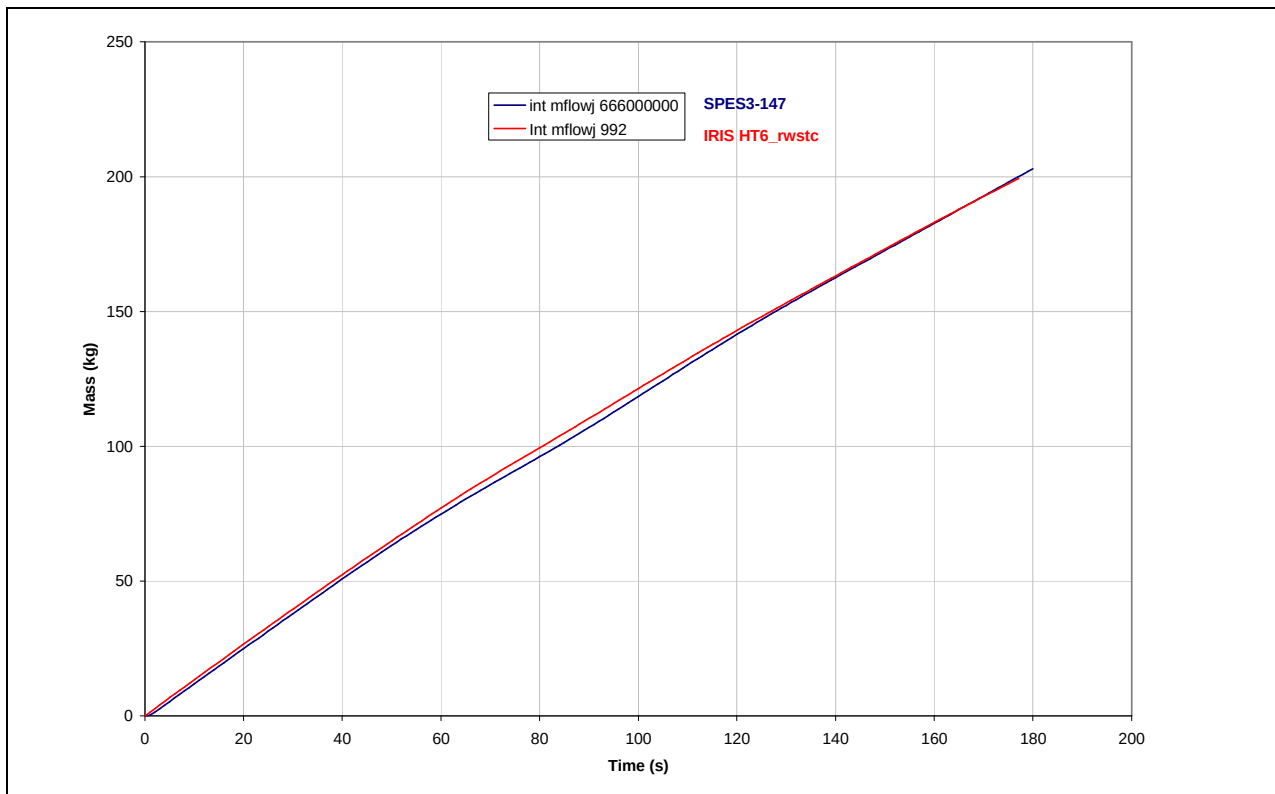
**Fig.9. 44 – SPES3-147 and IRIS HT6\_rwstc SG-1ss collapsed level**



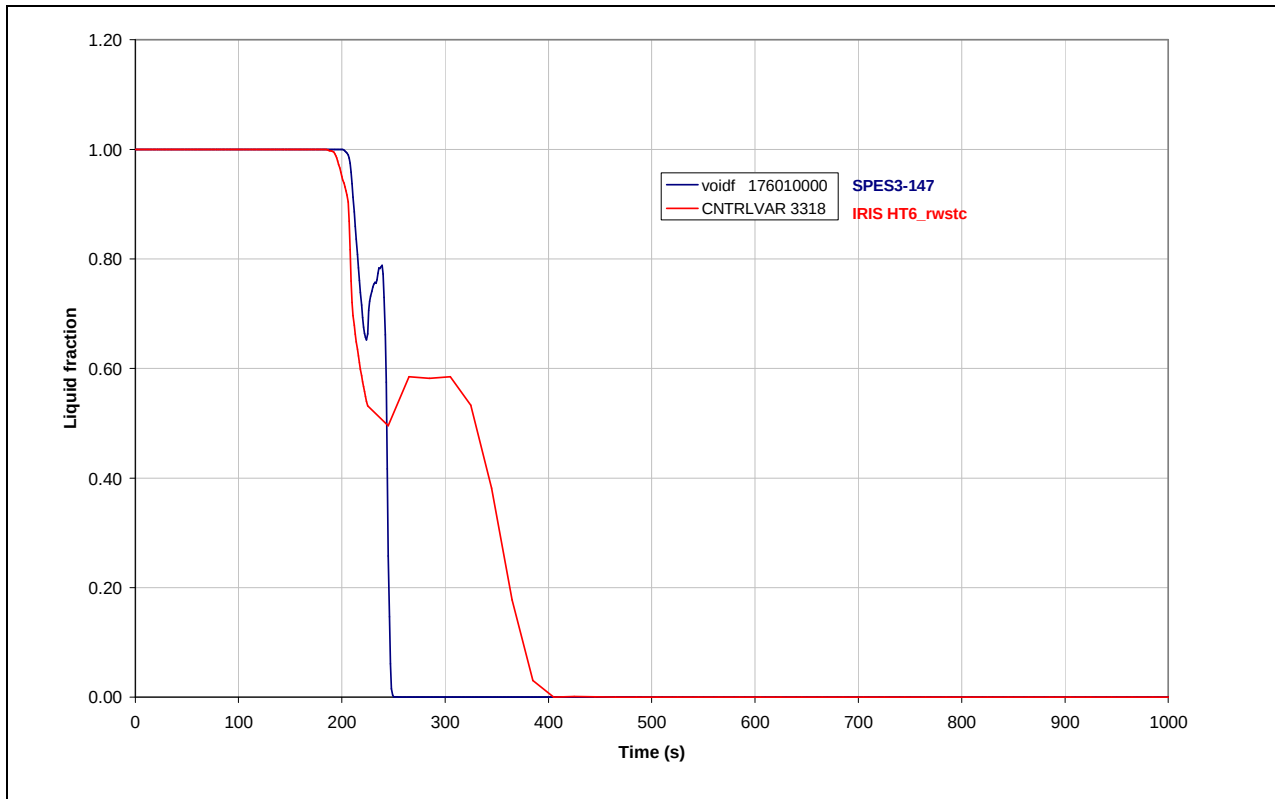
**Fig.9. 45 – SPES3-147 and IRIS HT6\_rwstc PRZ level**



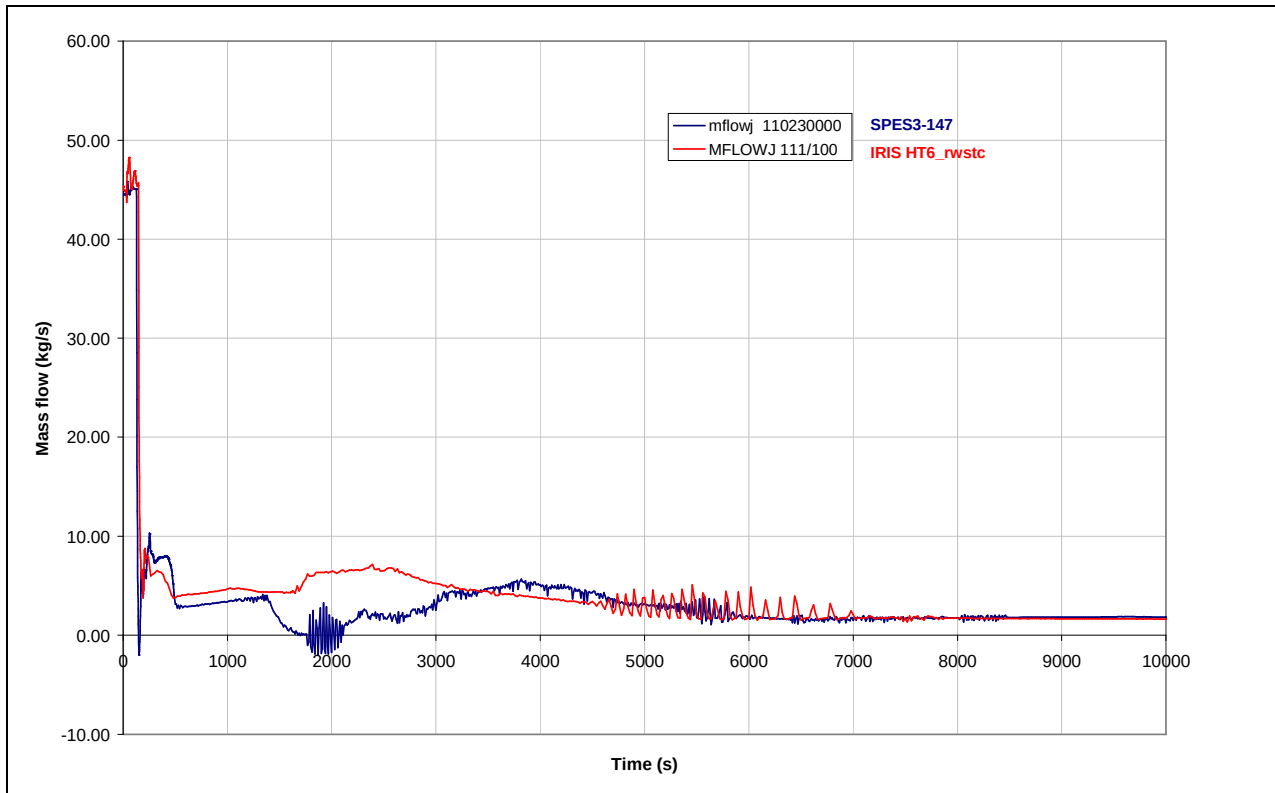
**Fig.9. 46 – SPES3-147 and IRIS HT6\_rwstc DVI break SPLIT integral flow**



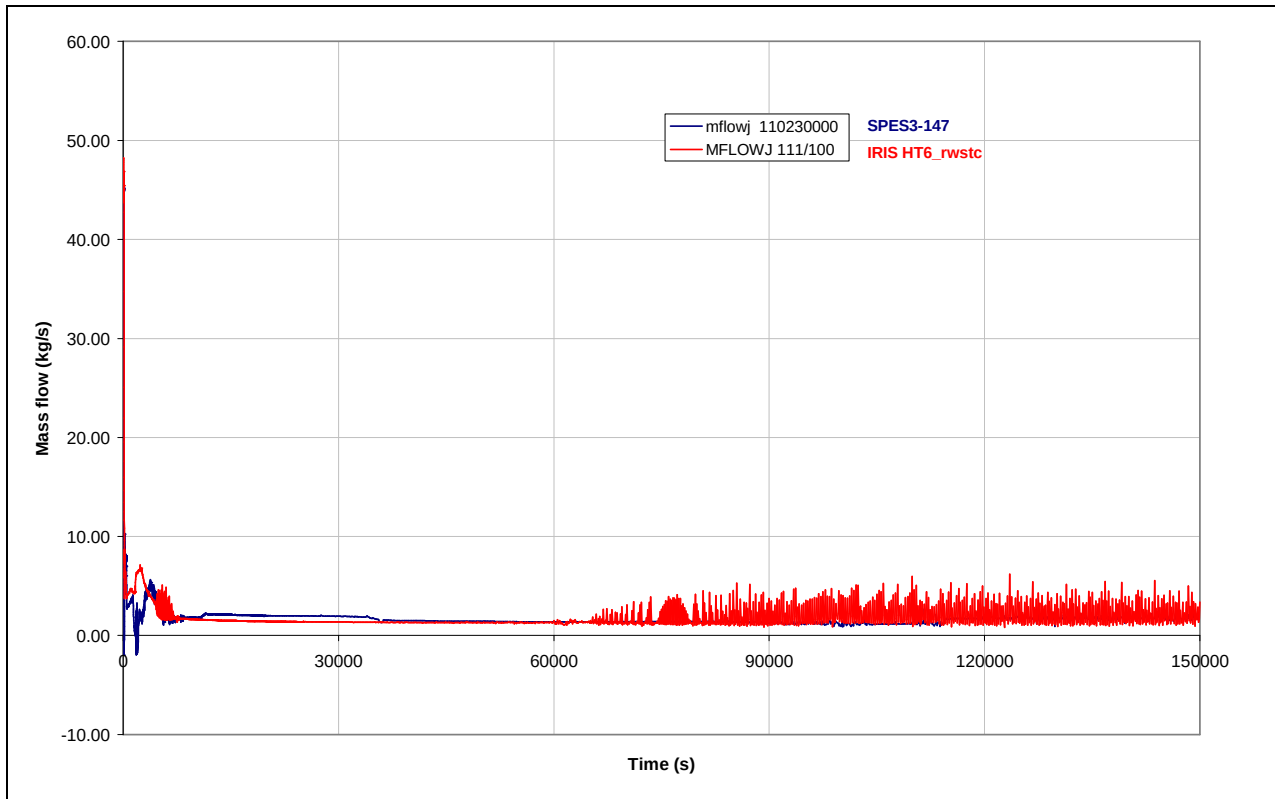
**Fig.9. 47 – SPES3-147 and IRIS HT6\_rwstc pump inlet liquid fraction**



**Fig.9. 48 – SPES3-147 and IRIS HT6\_rwstc core outlet flow (window)**



**Fig.9. 49 – SPES3-147 and IRIS HT6\_rwstc core outlet flow**



**Fig.9. 50 – SPES3-147 and IRIS HT6\_rwstc RI-DC check valve mass flow (window)**

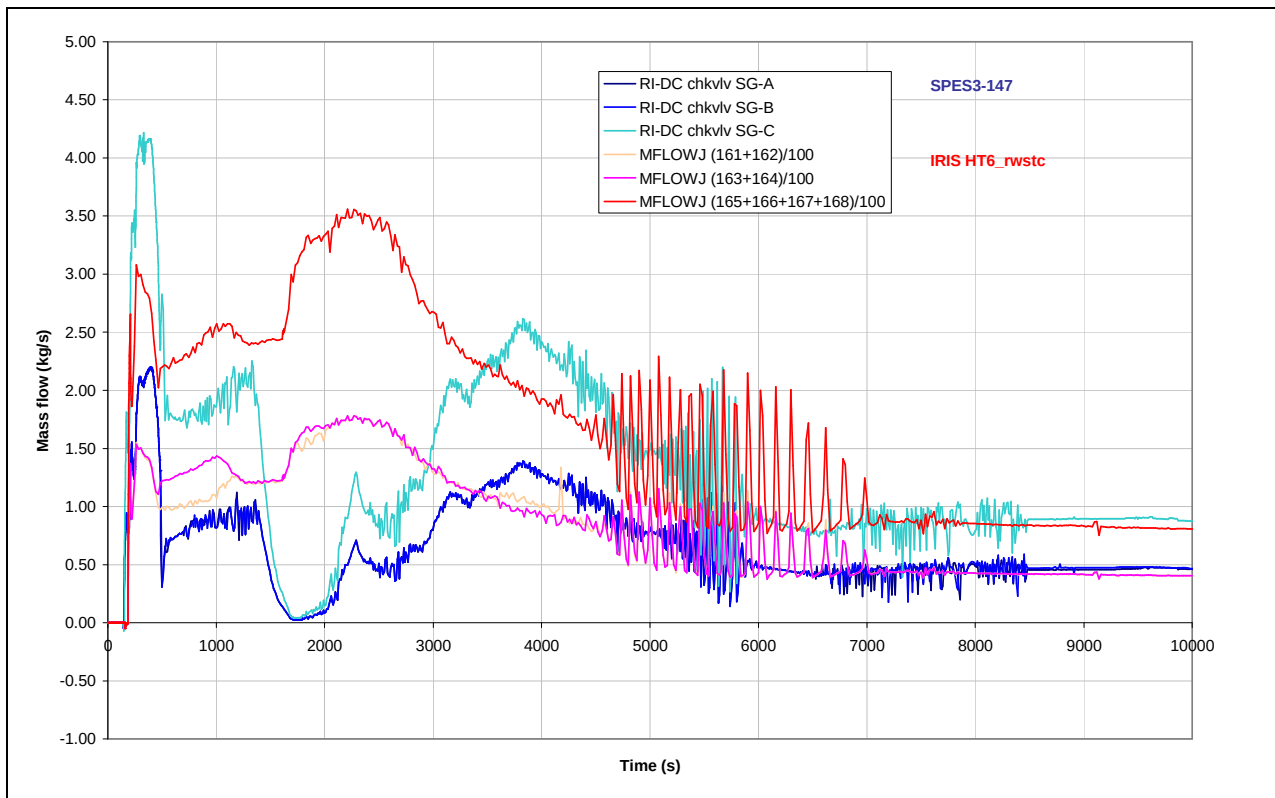


Fig.9. 51 – SPES3-147 and IRIS HT6\_rwstc RI-DC check valve mass flow

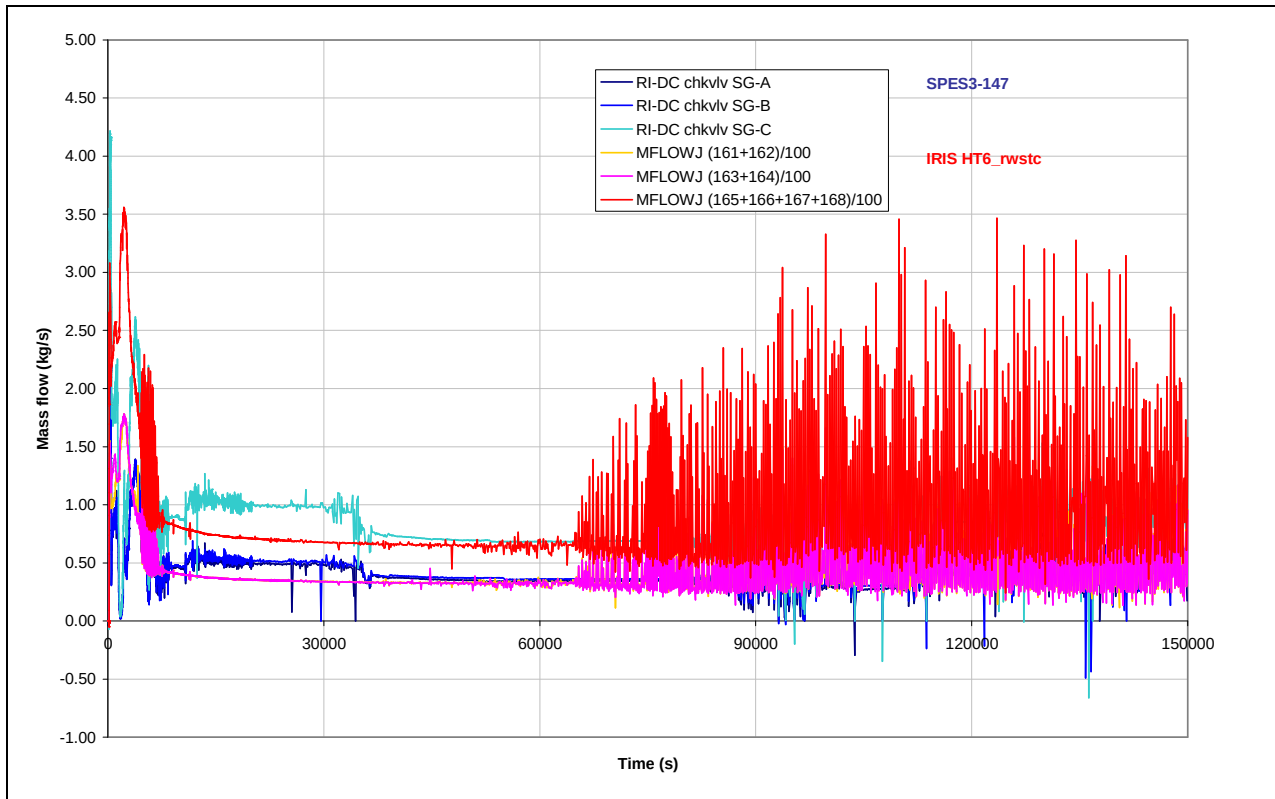
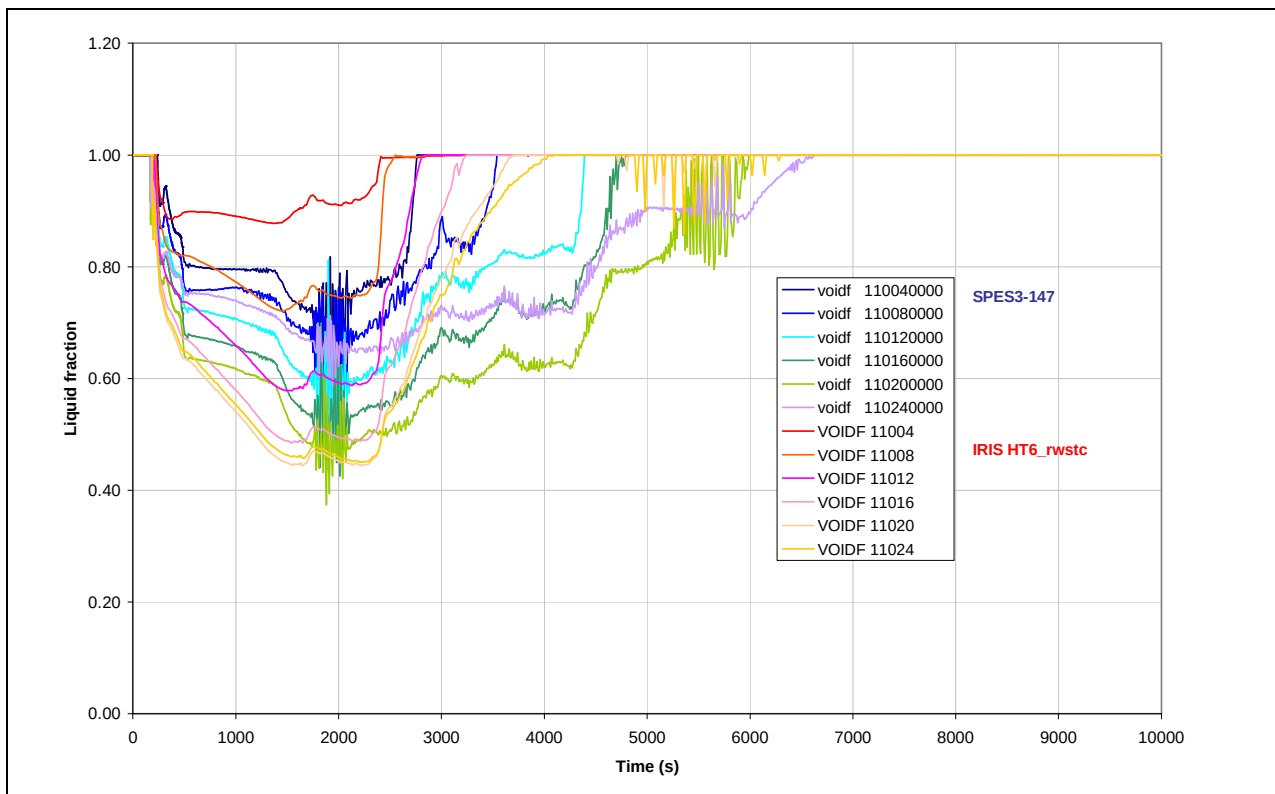
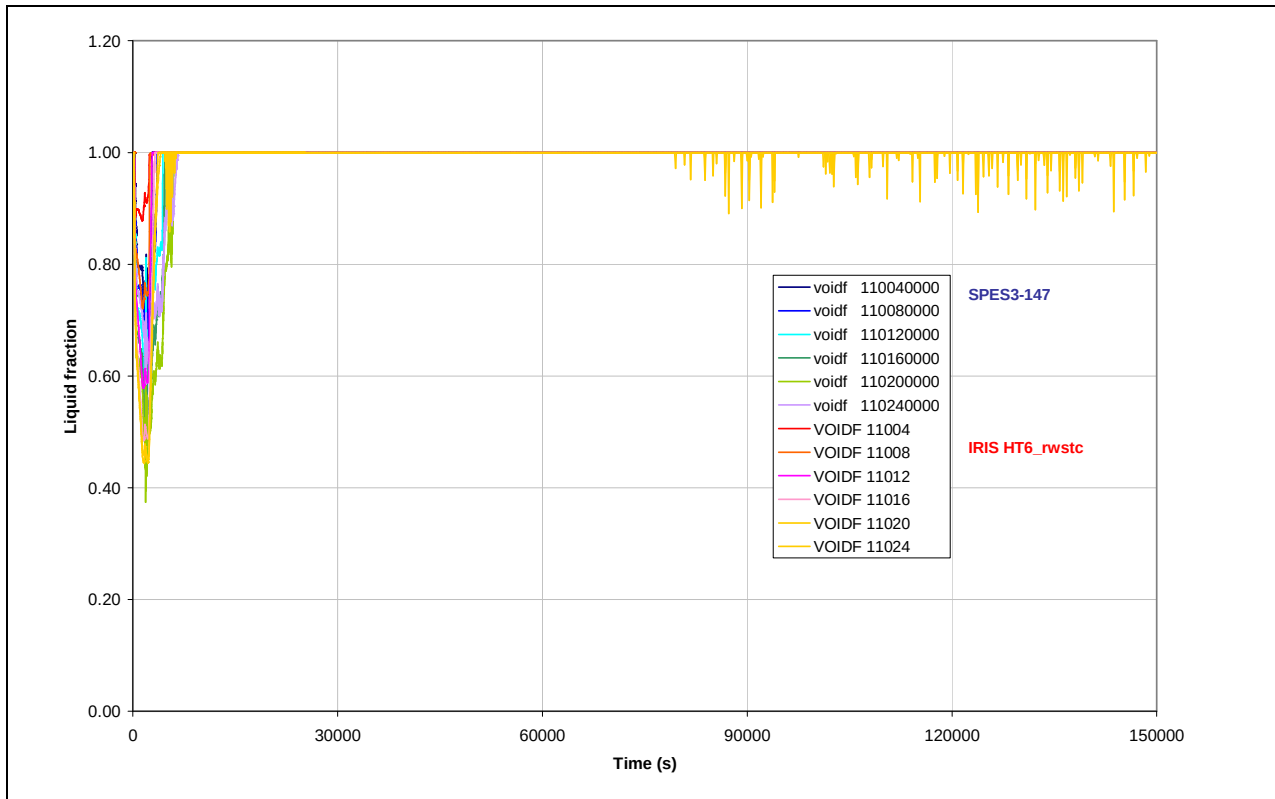


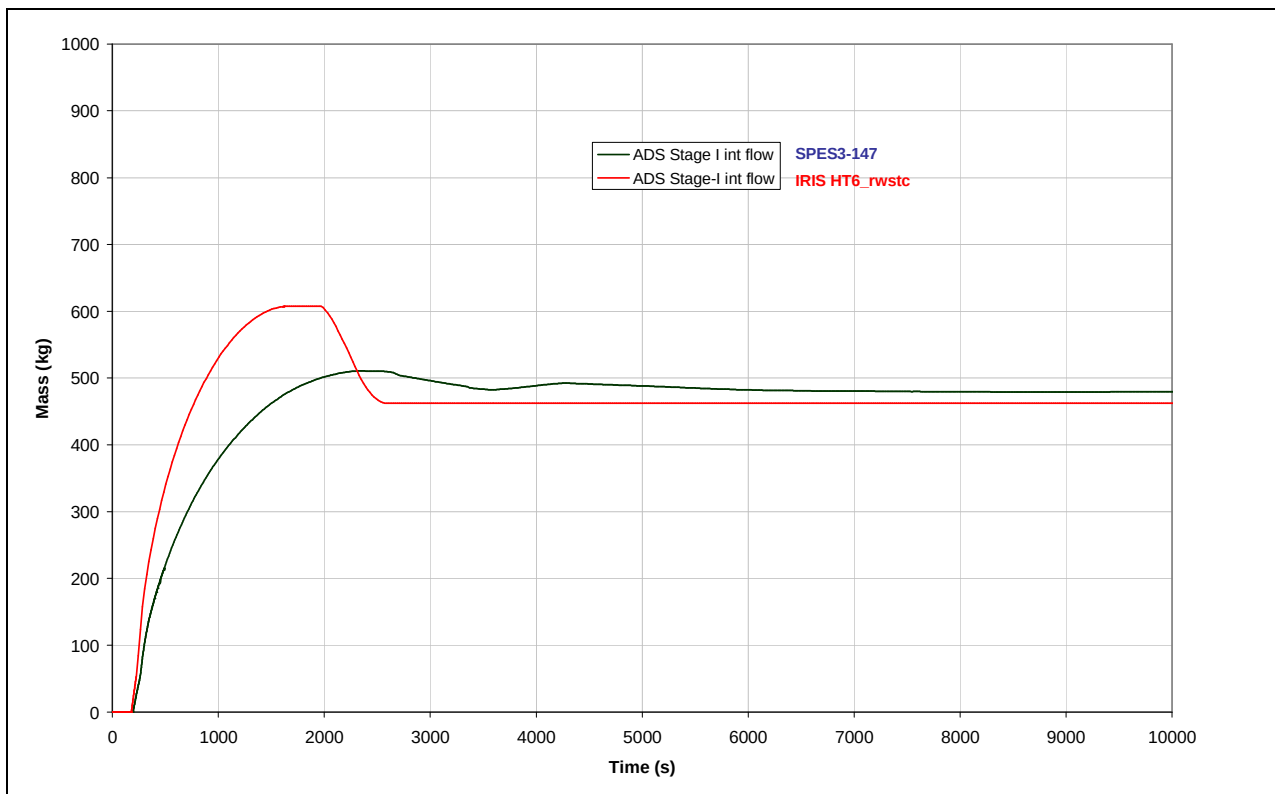
Fig.9. 52 – SPES3-147 and IRIS HT6\_rwstc core liquid void fraction (window)



**Fig.9. 53 – SPES3-147 and IRIS HT6\_rwstc core liquid void fraction**

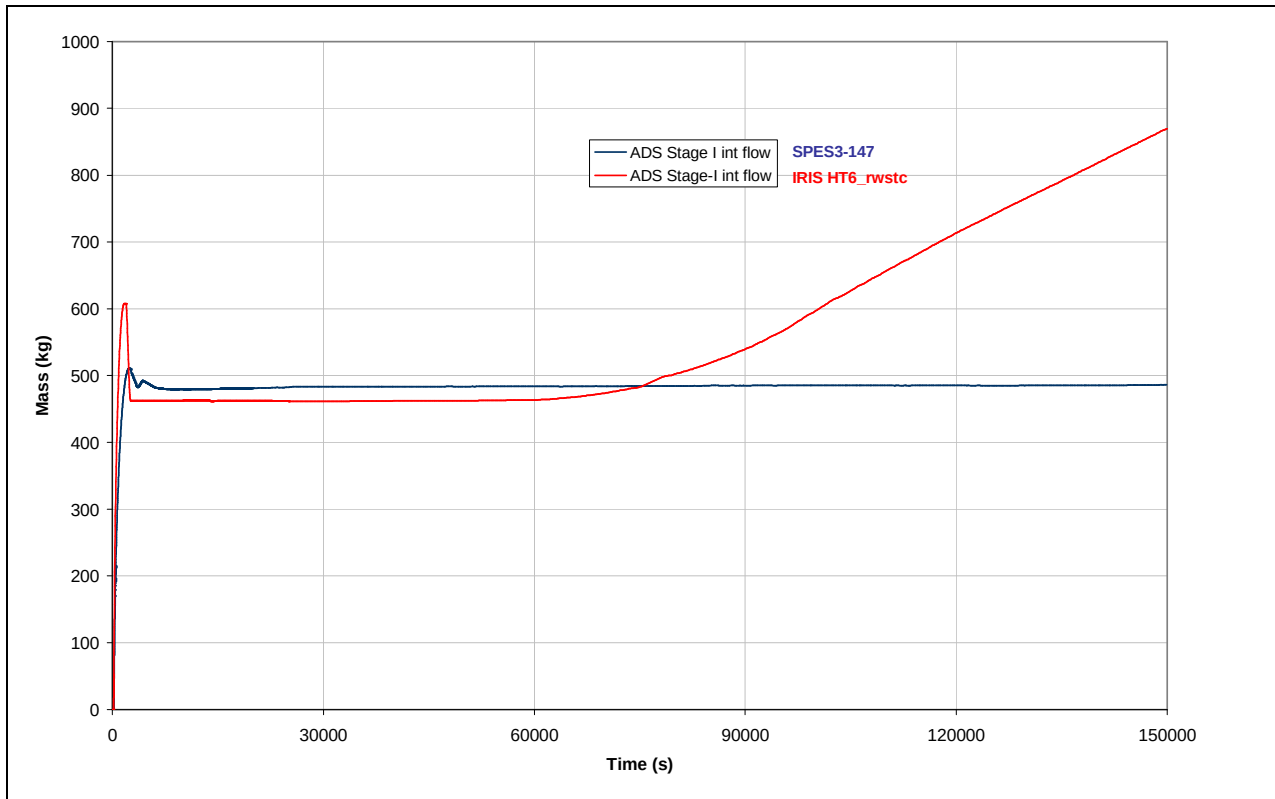


**Fig.9. 54 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-I integral flow (window)**

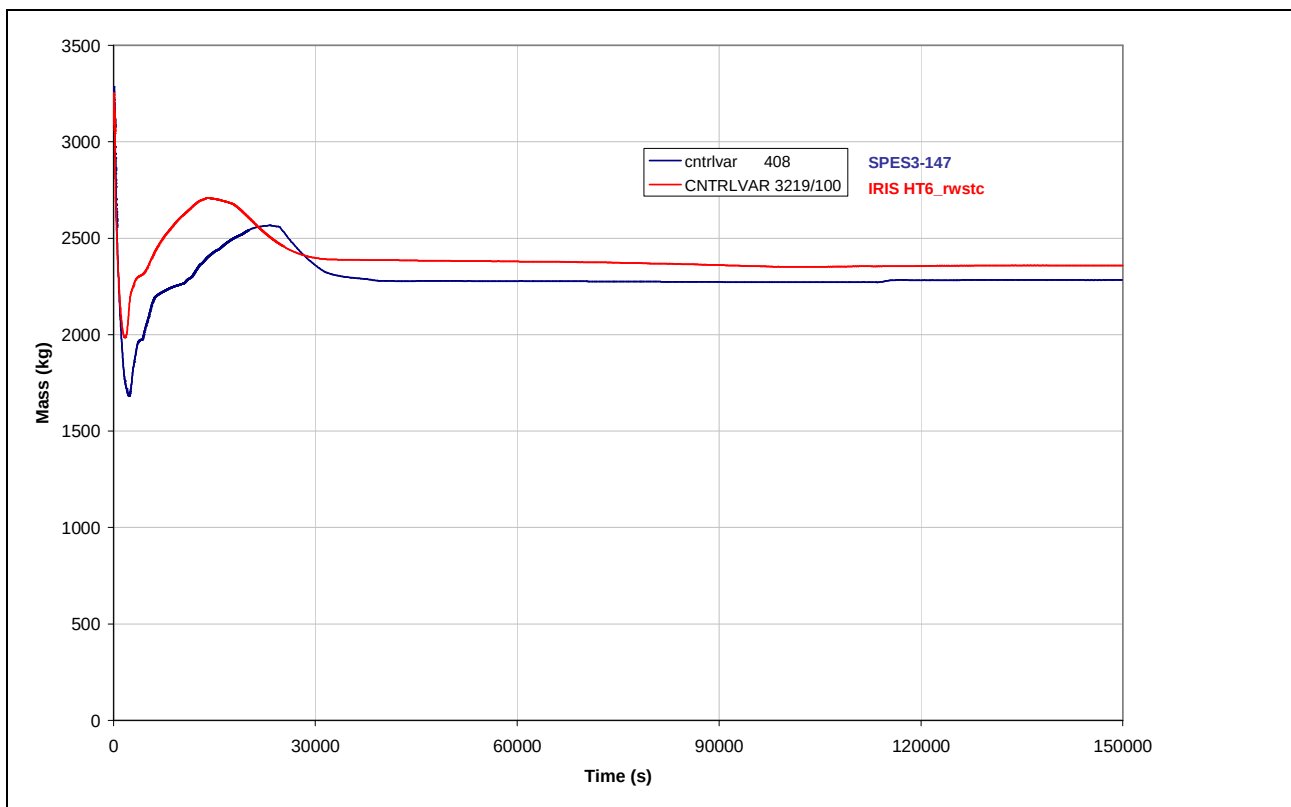




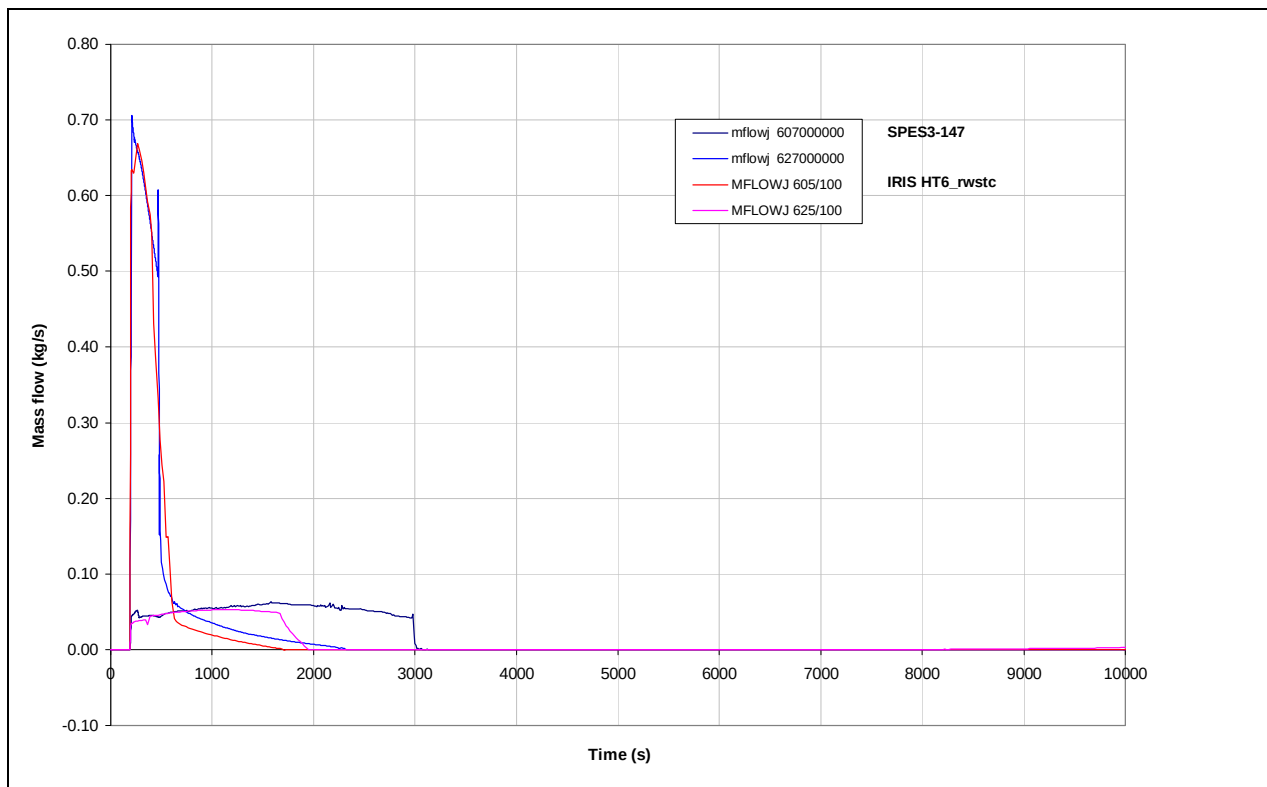
**Fig.9. 55 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-I integral flow**



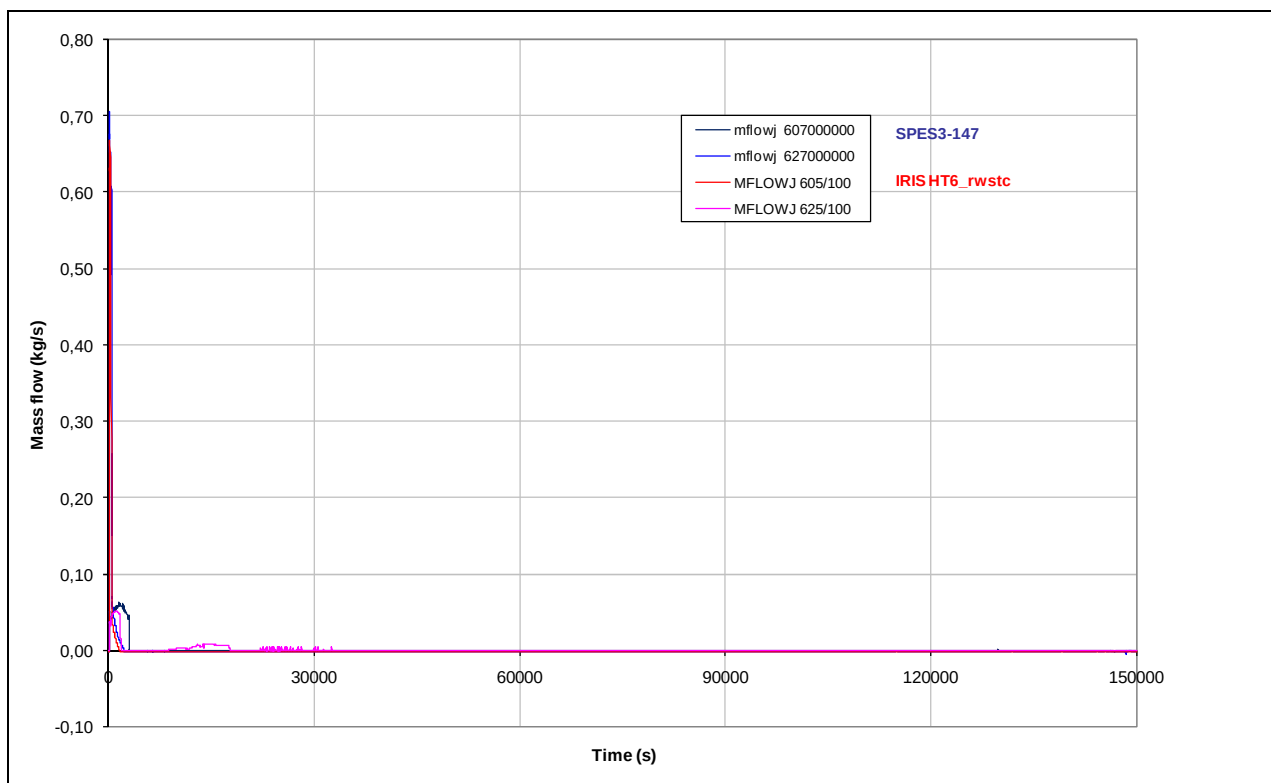
**Fig.9. 56 – SPES3-147 and IRIS HT6\_rwstc RV mass**



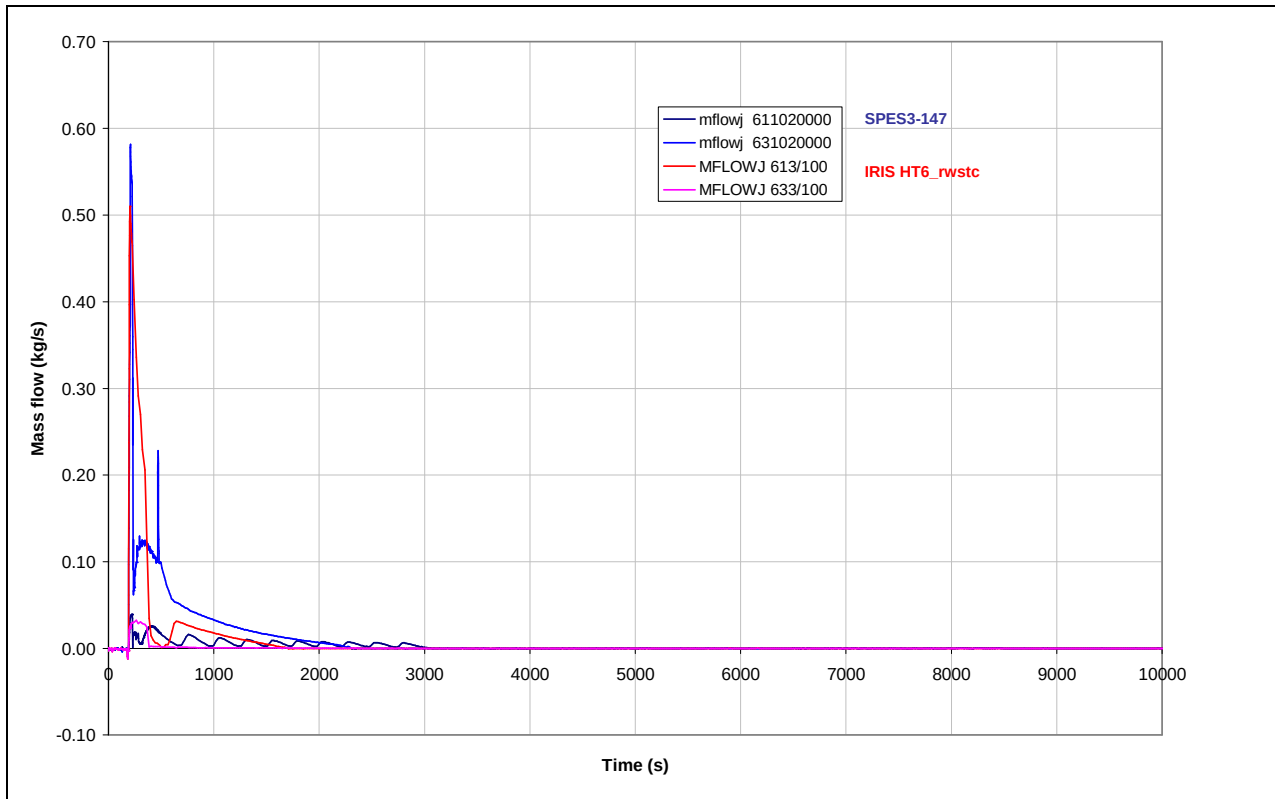
**Fig.9. 57 – SPES3-147 and IRIS HT6\_rwstc EBT injection mass flow (window)**



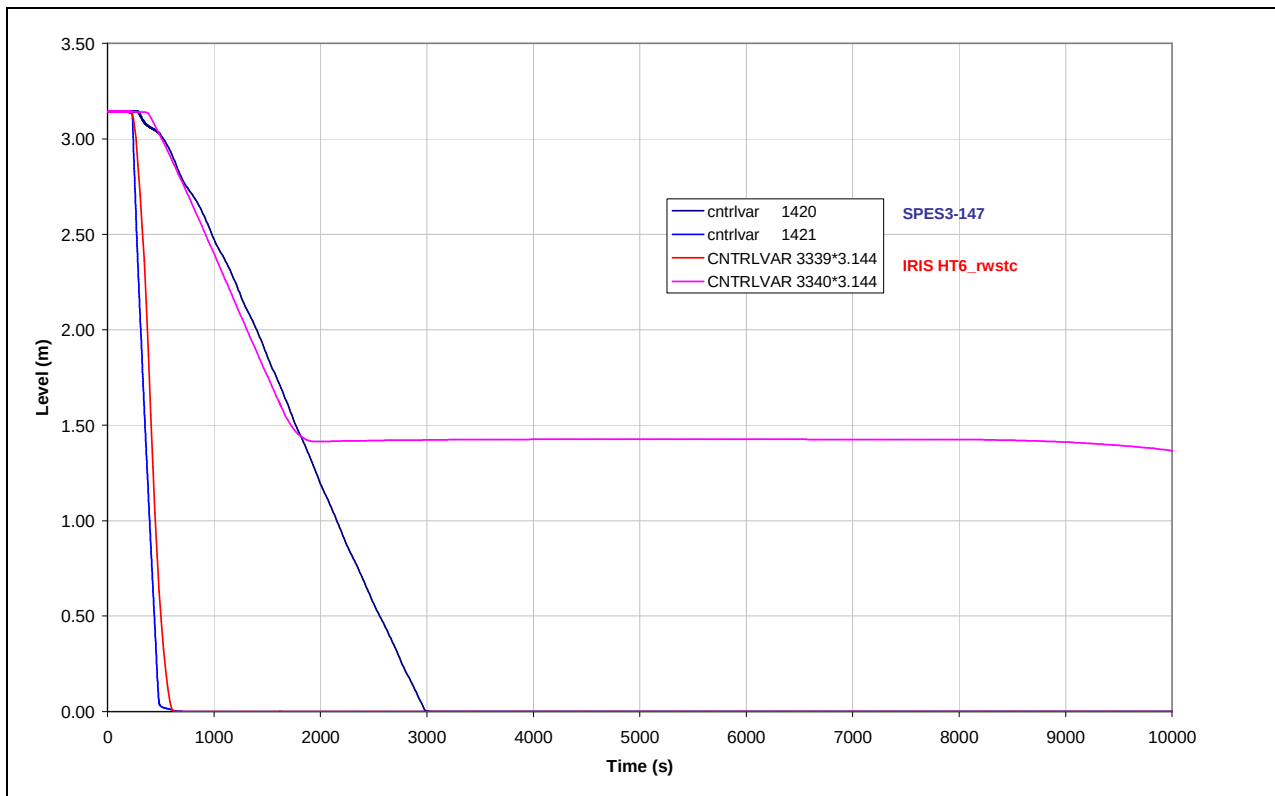
**Fig.9. 58 – SPES3-147 and IRIS HT6\_rwstc EBT injection mass flow etichetta figura**



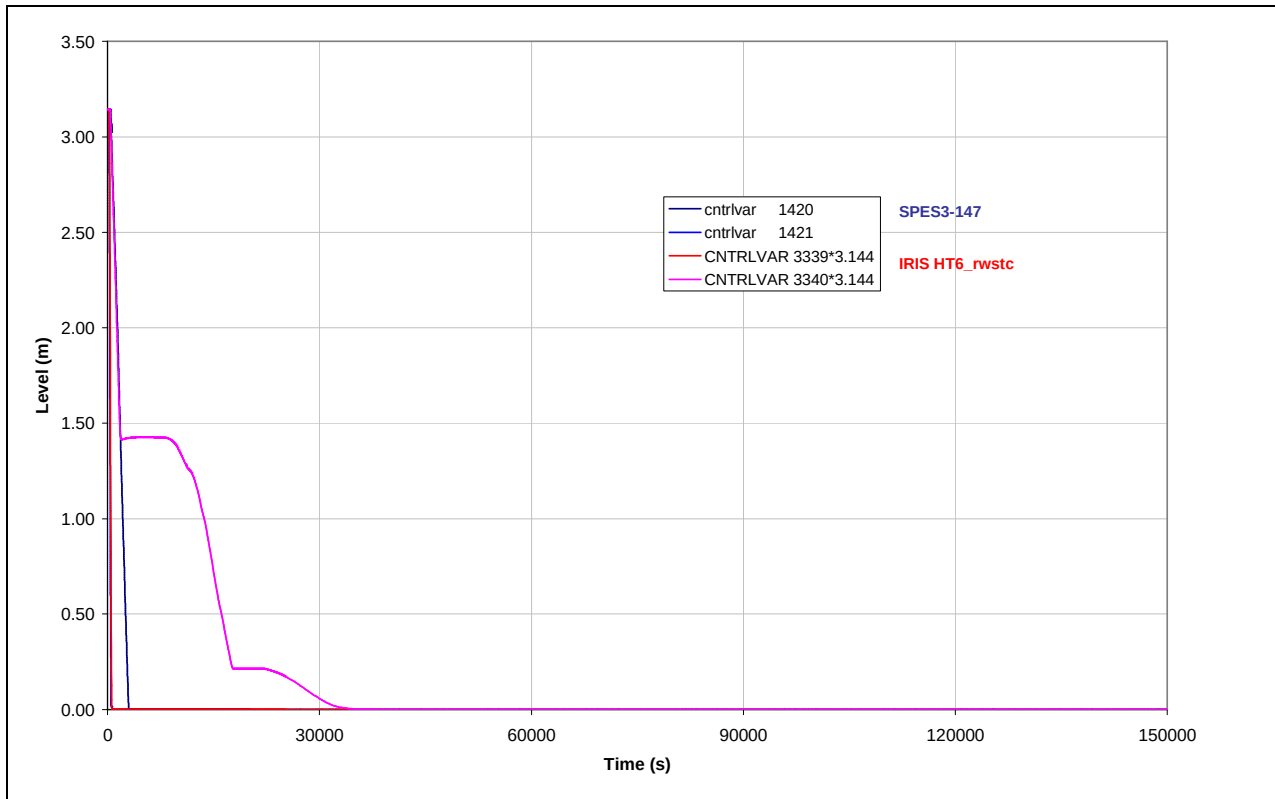
**Fig.9. 59 – SPES3-147 and IRIS HT6\_rwstc EBT balance line to RV mass flow (window)**



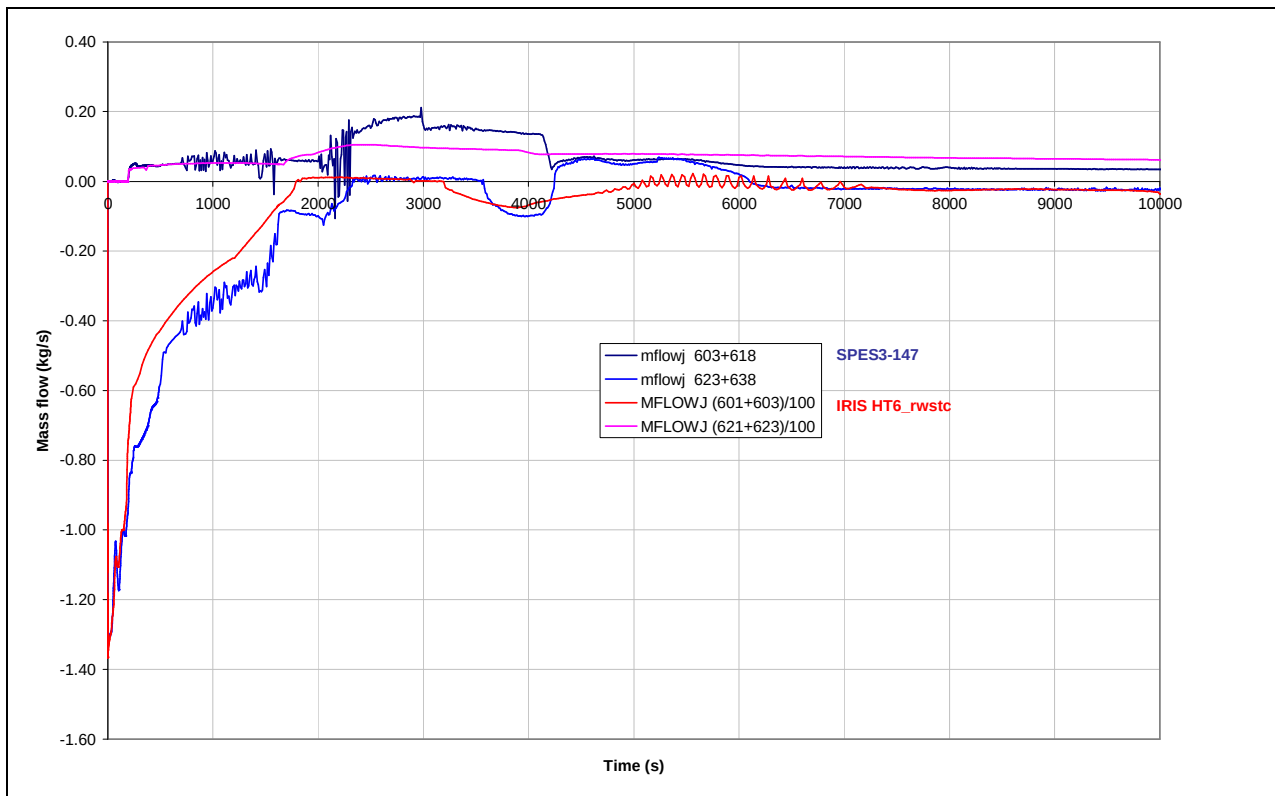
**Fig.9. 60 – SPES3-147 and IRIS HT6\_rwstc EBT level (window)**



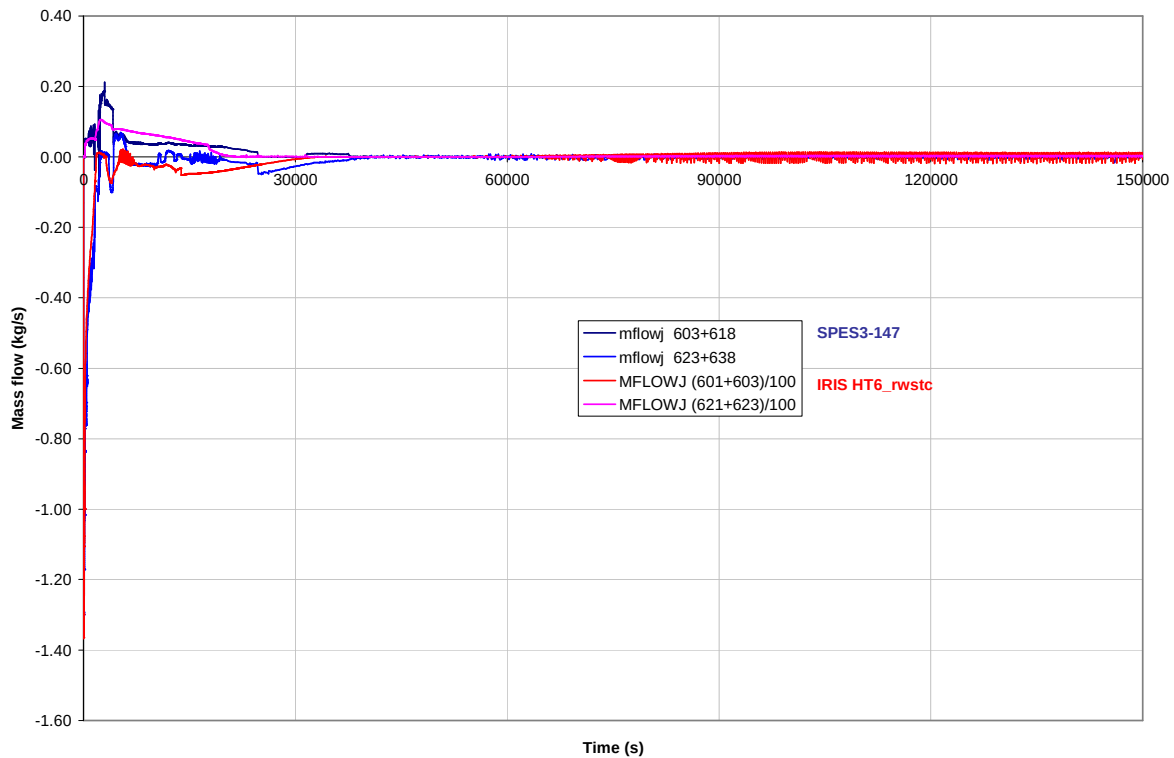
**Fig.9. 61 – SPES3-147 and IRIS HT6\_rwstc EBT level**



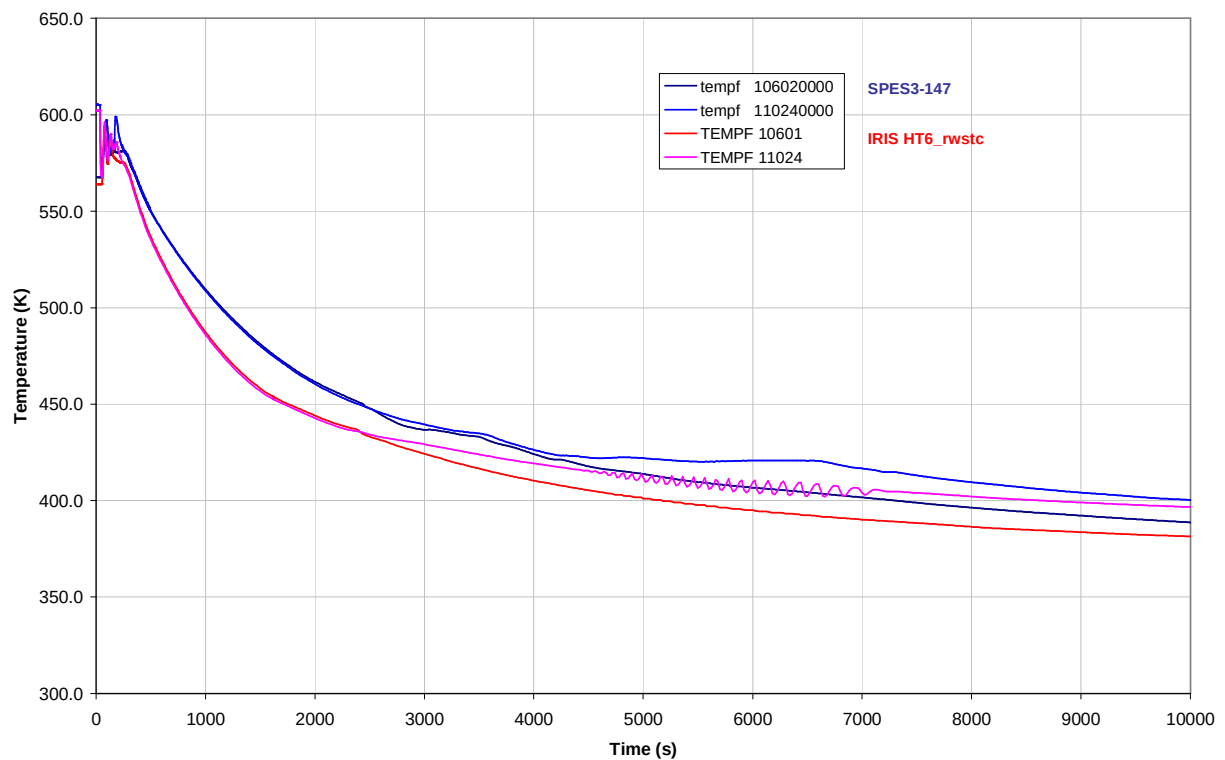
**Fig.9. 62 – SPES3-147 and IRIS HT6\_rwstc DVI mass flow (window)**



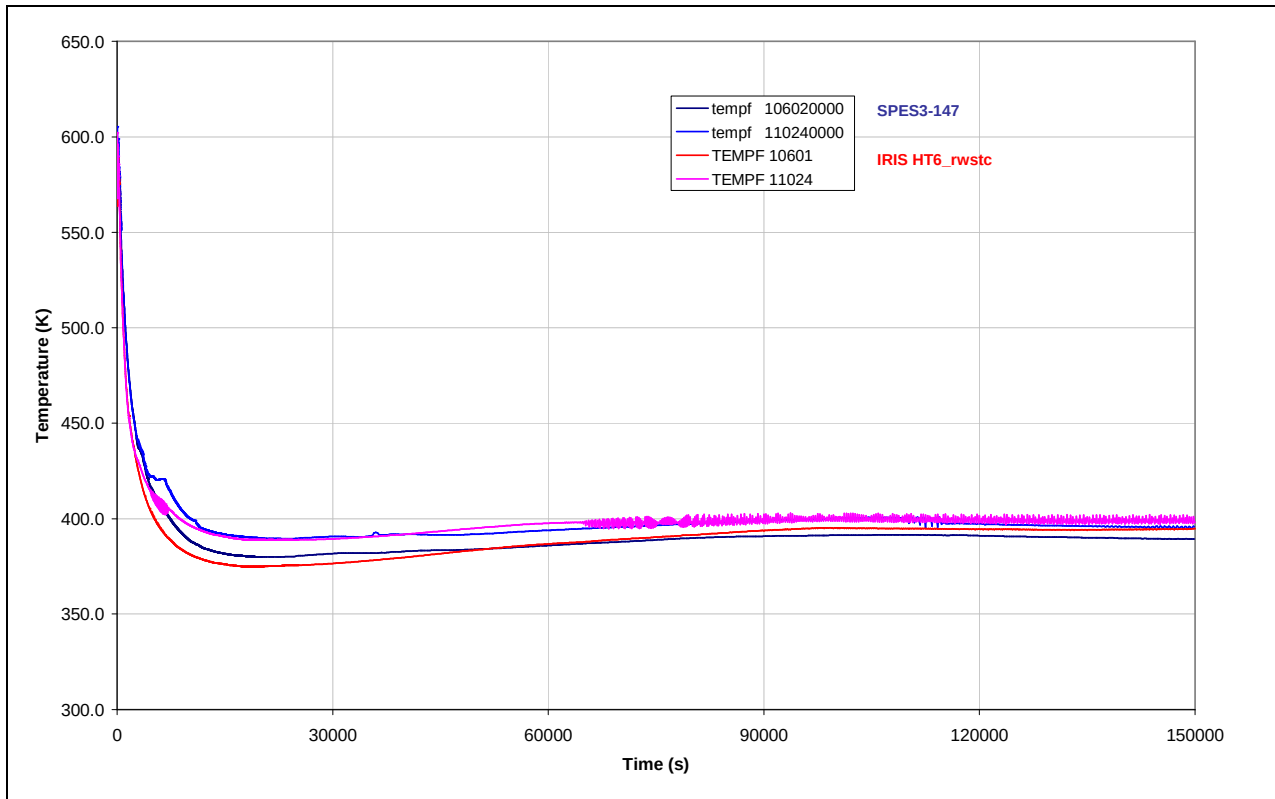
**Fig.9. 63 – SPES3-147 and IRIS HT6\_rwstc DVI mass flow**



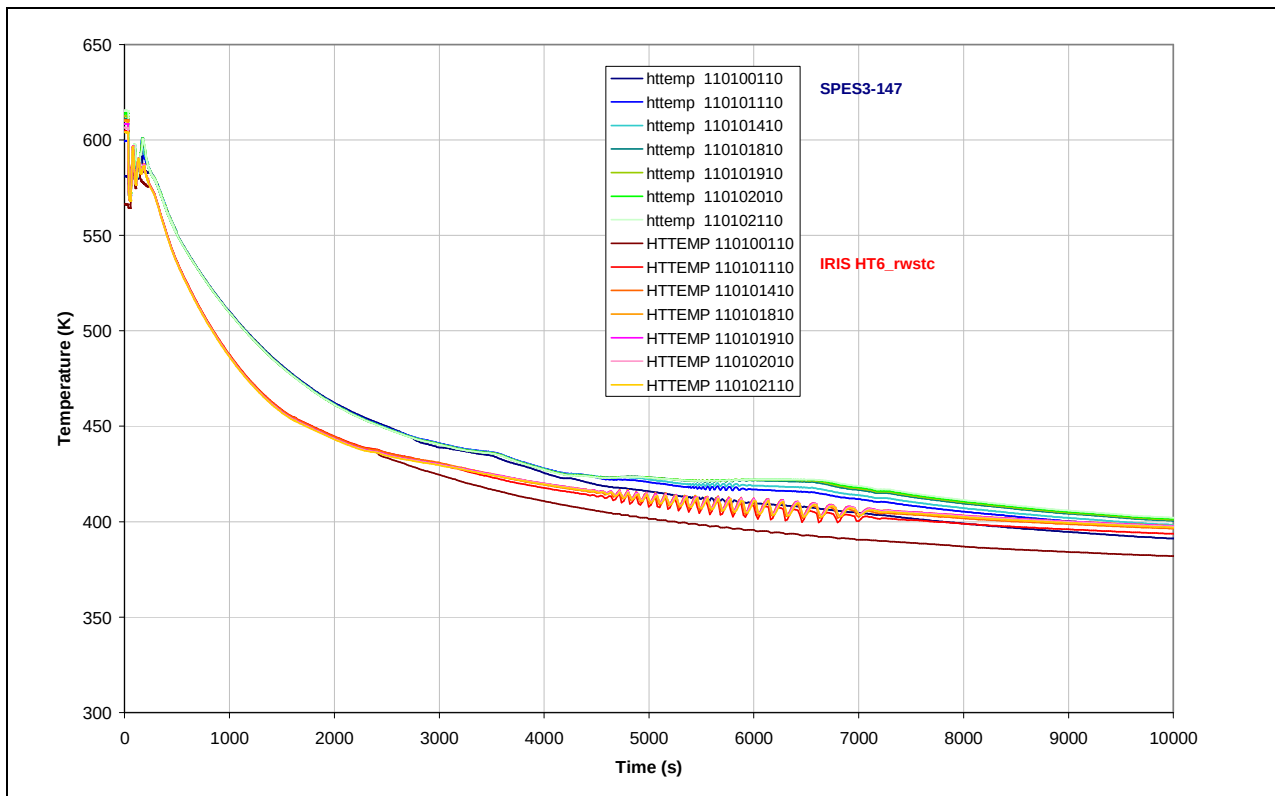
**Fig.9. 64 – SPES3-147 and IRIS HT6\_rwstc Core inlet and outlet temperatures (window)**



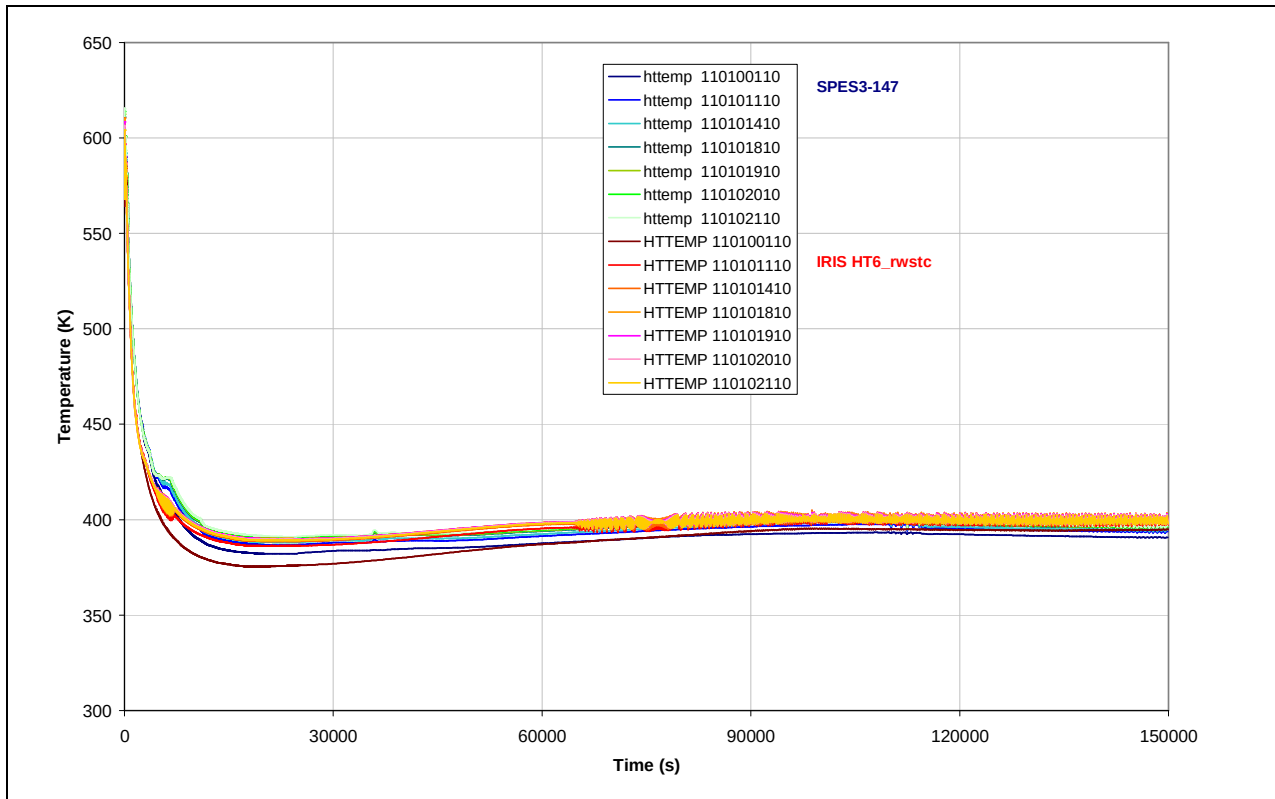
**Fig.9. 65 – SPES3-147 and IRIS HT6\_rwstc Core inlet and outlet temperatures**



**Fig.9. 66 – SPES3-147 and IRIS HT6\_rwstc Core heater rod outer surface temperature (window)**



**Fig.9. 67 – SPES3-147 and IRIS HT6\_rwstc Core heater rod outer surface temperature**



**Fig.9. 68 – SPES3-147 and IRIS HT6\_rwstc LGMS injection mass flow (window)**

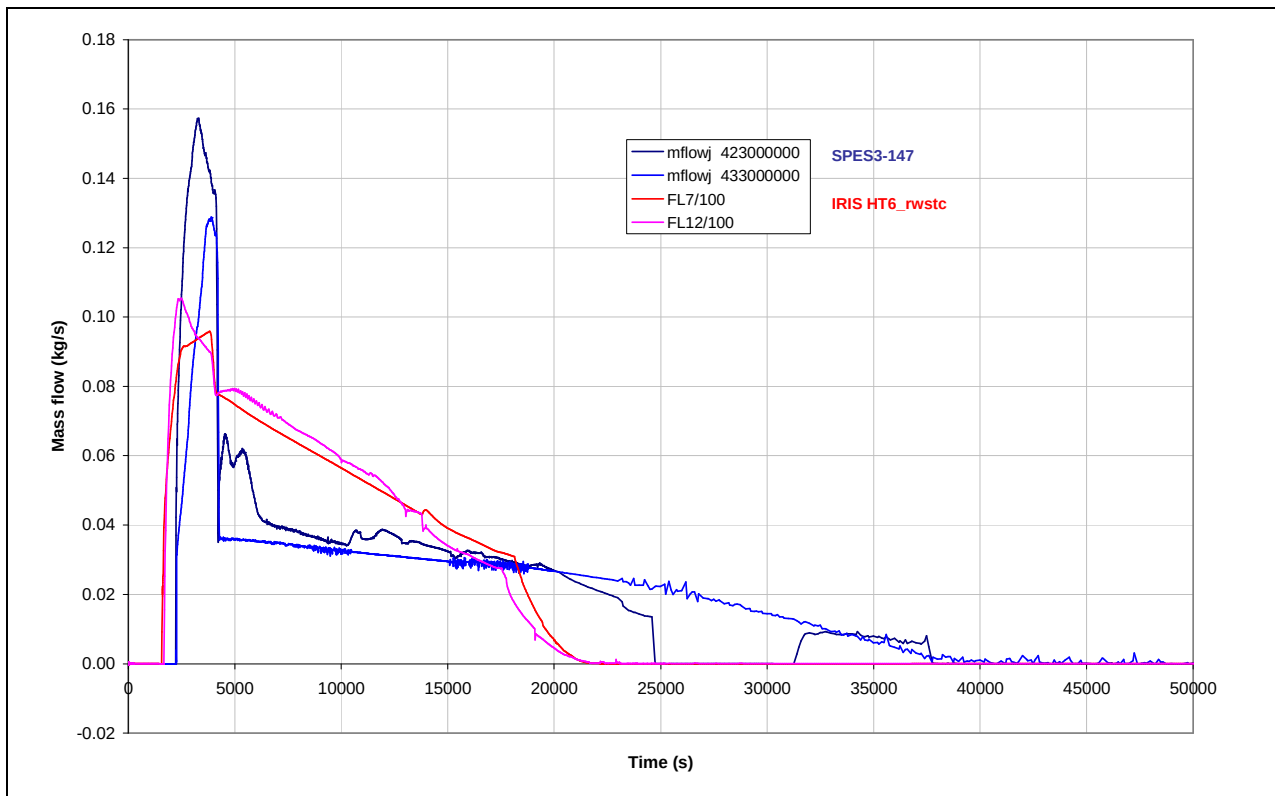


Fig.9. 69 – SPES3-147 and IRIS HT6\_rwstc LGMS mass (window)

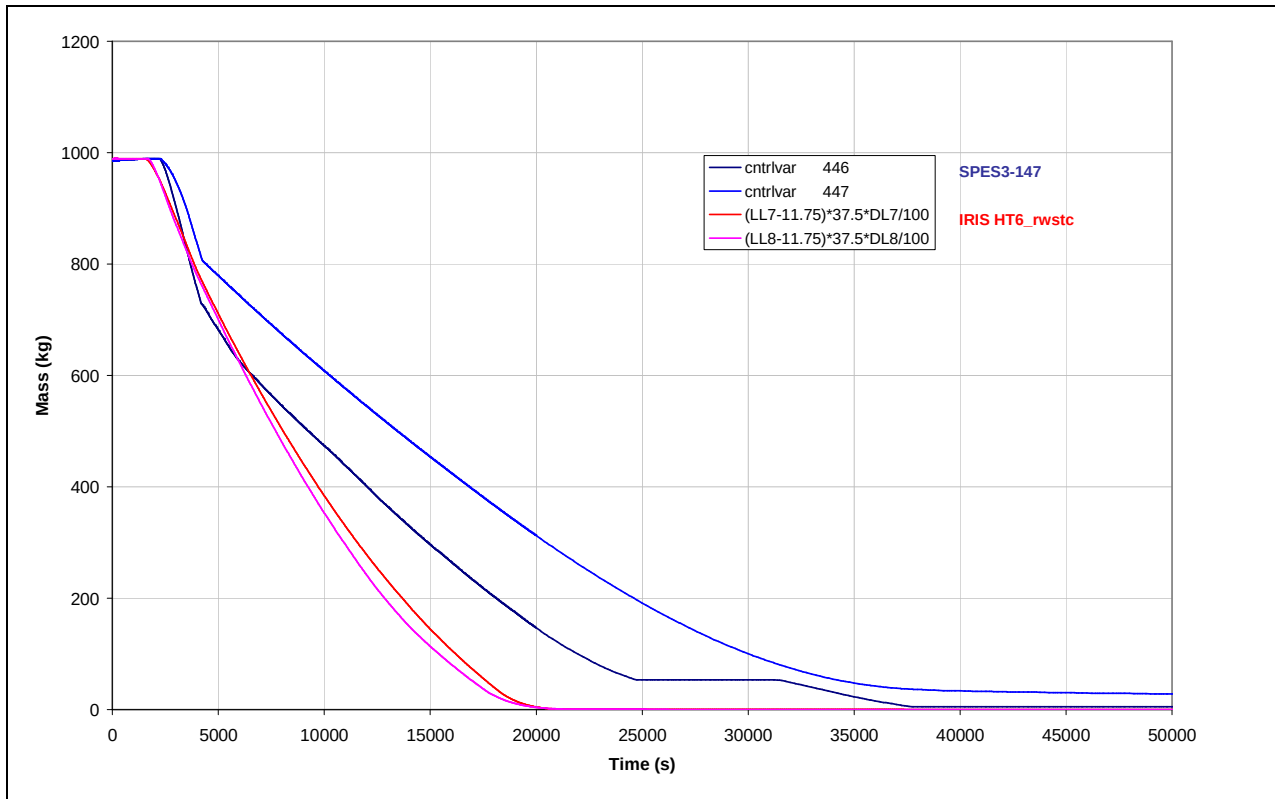


Fig.9. 70 – SPES3-147 and IRIS HT6\_rwstc LGMS and DVI pressure (window)

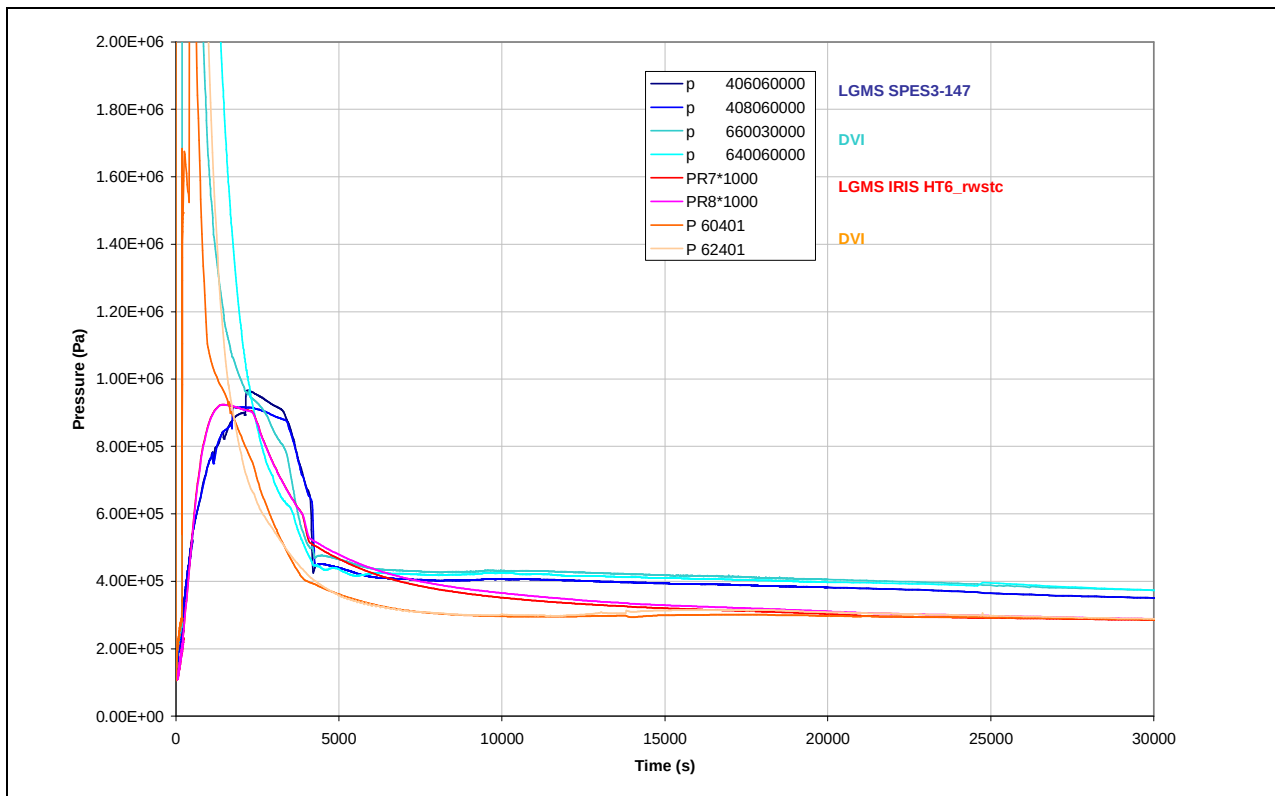




Fig.9. 71 – SPES3-147 and IRIS HT6\_rwstc LGMS and DVI pressure

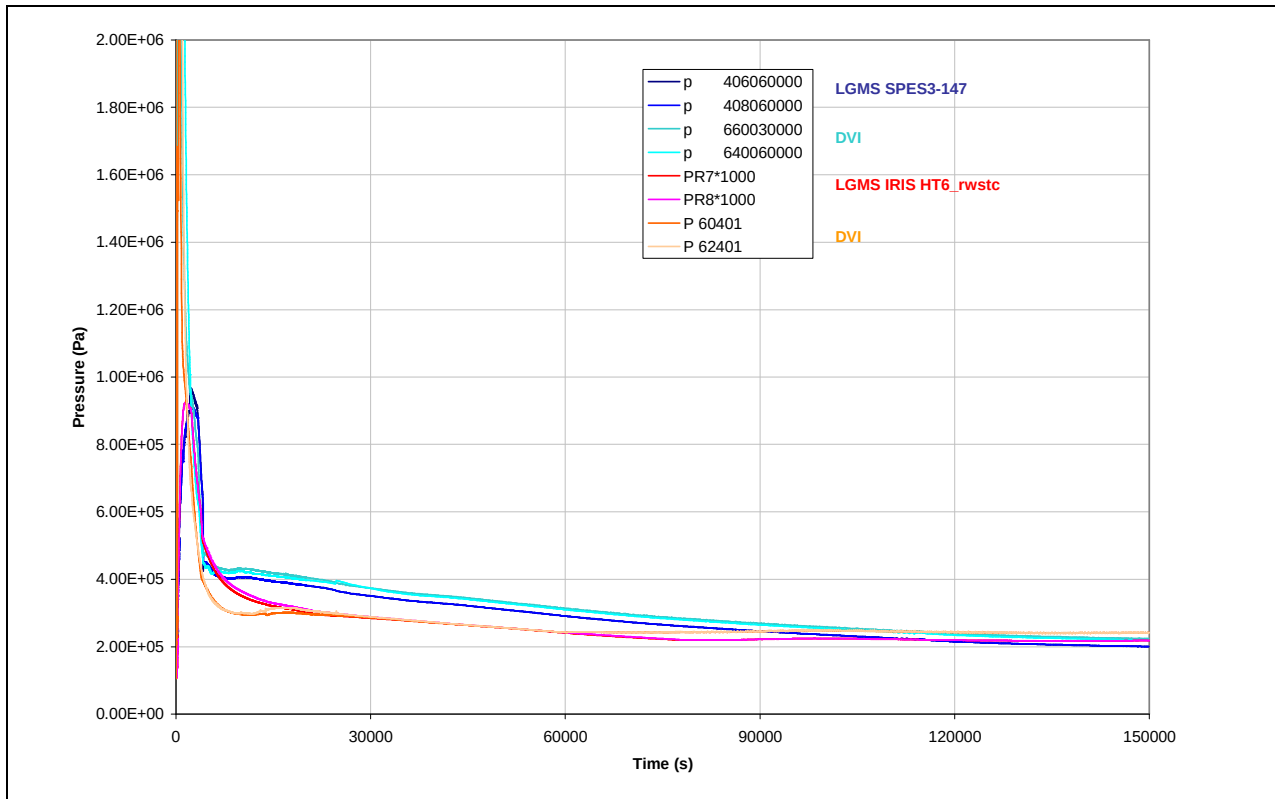


Fig.9. 72 – SPES3-147 and IRIS HT6\_rwstc RC to DVI mass flow (window)

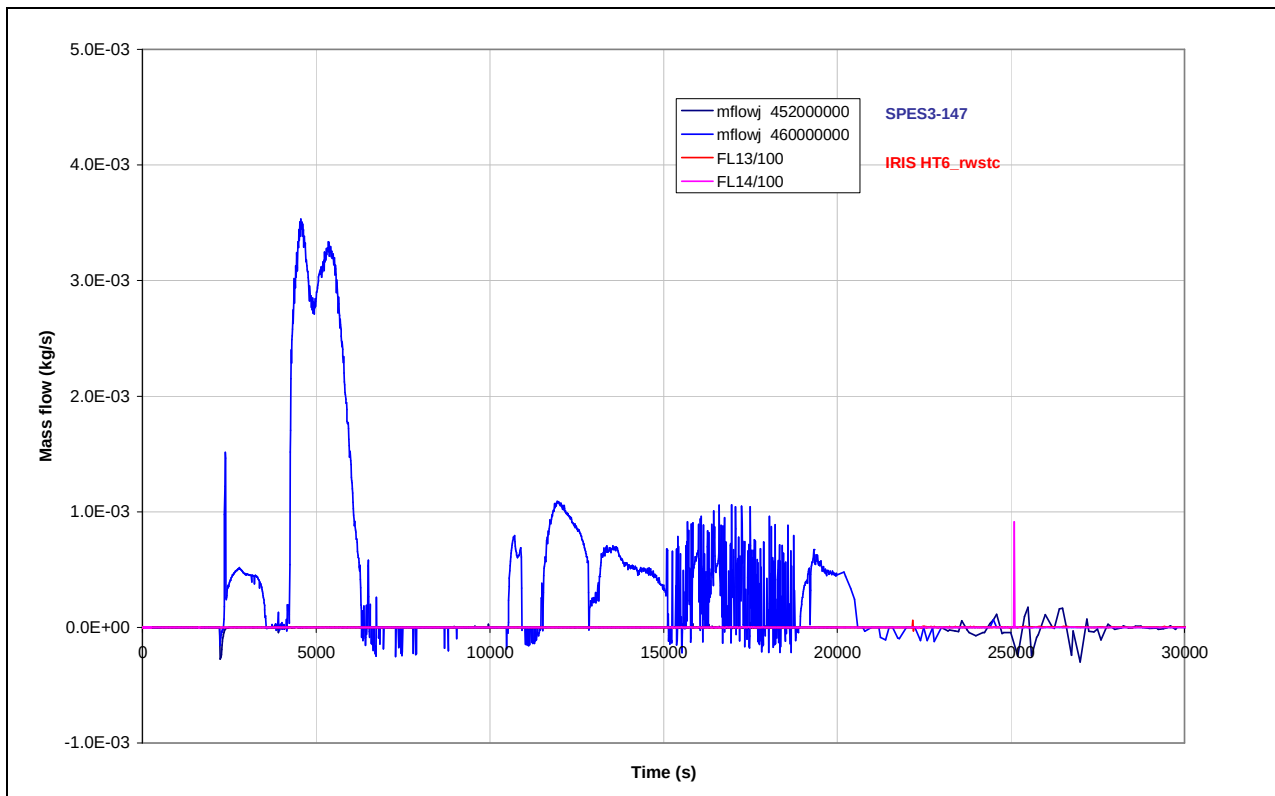


Fig.9. 73 – SPES3-147 and IRIS HT6\_rwstc RC to DVI mass flow

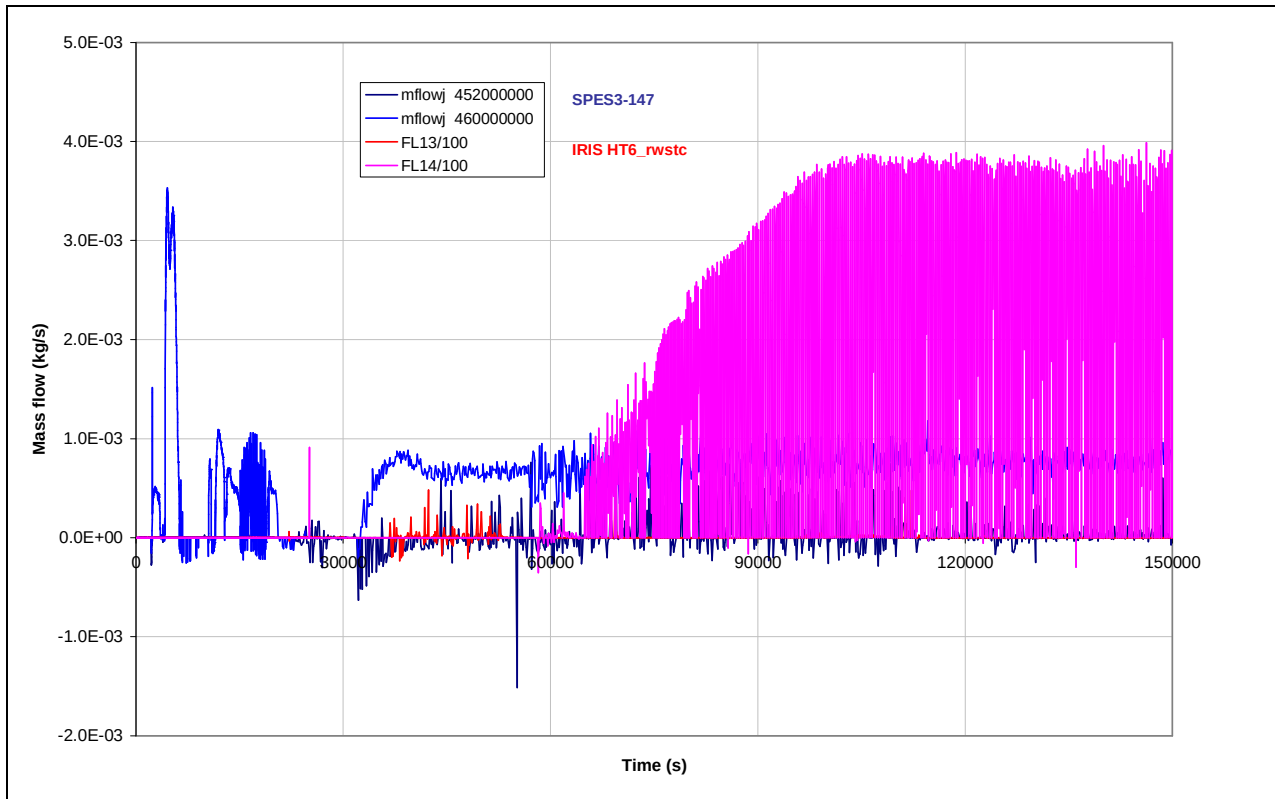
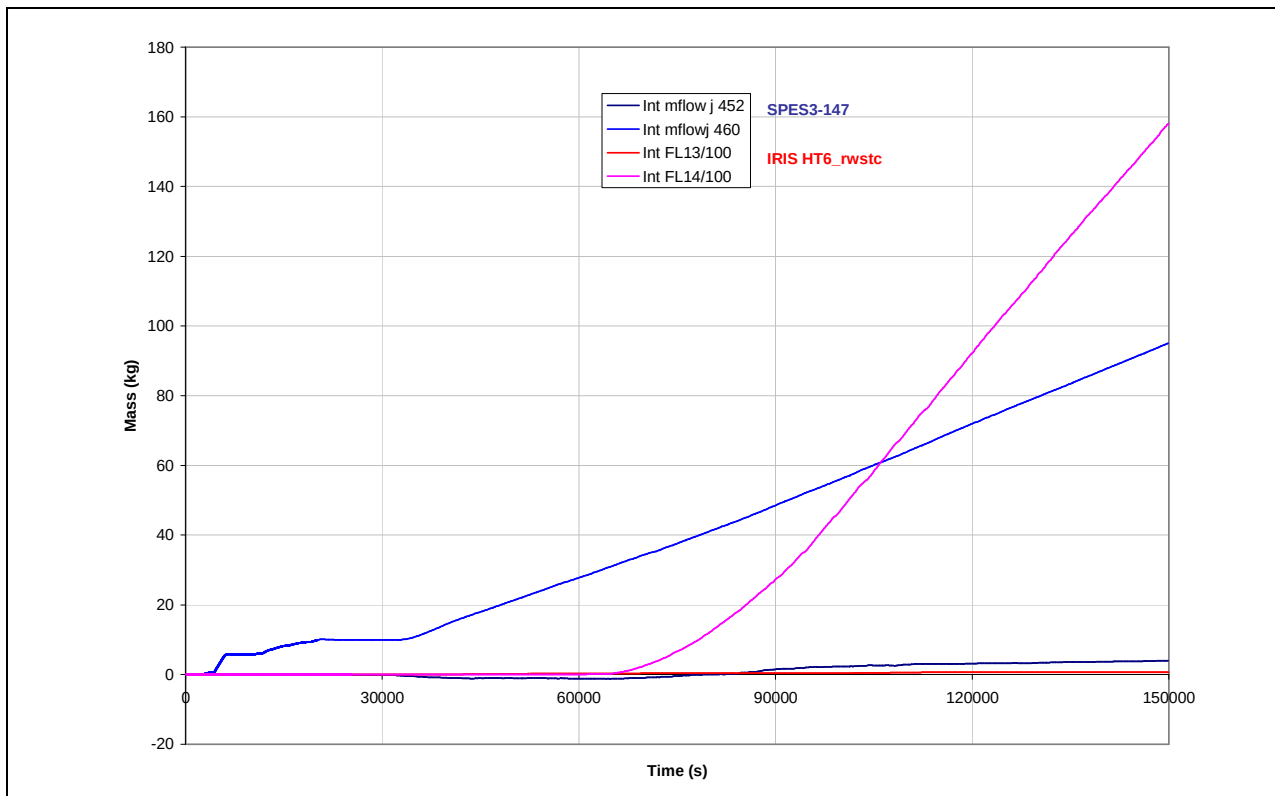
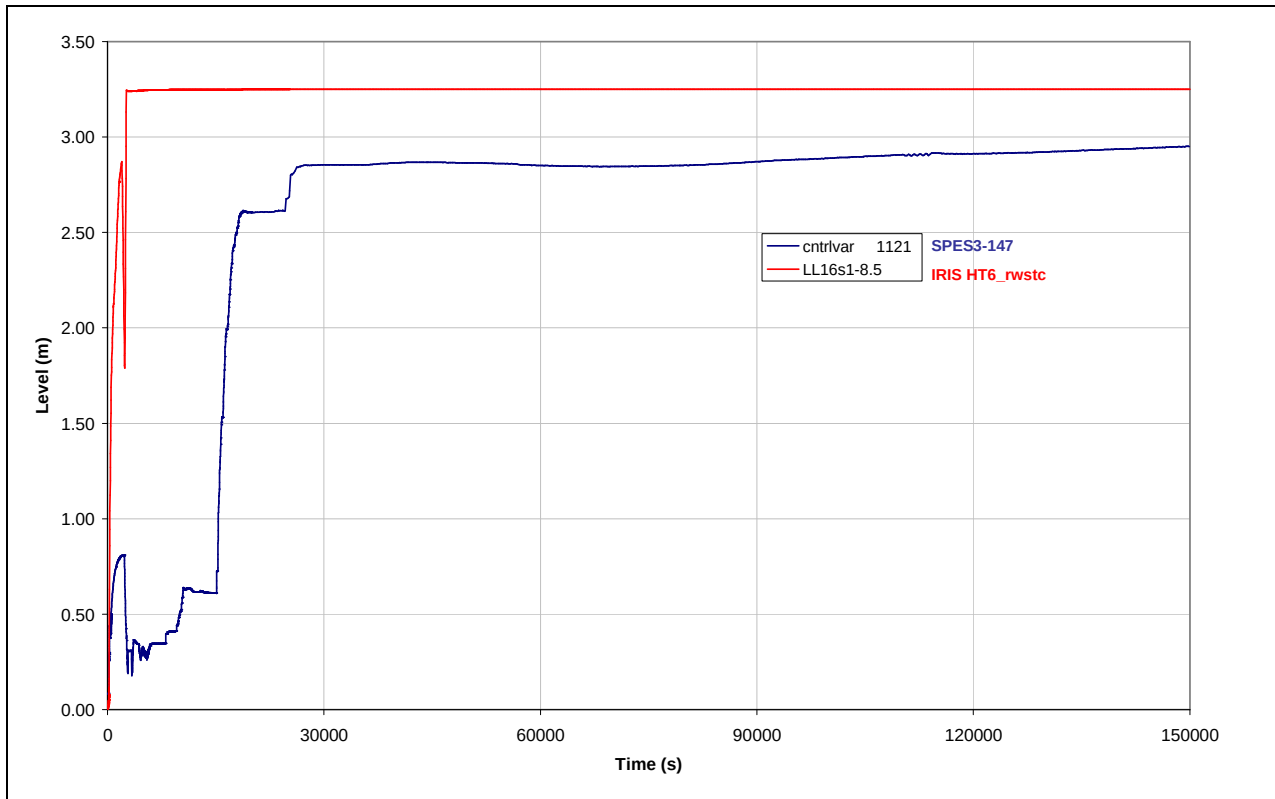


Fig.9. 74 – SPES3-147 and IRIS HT6\_rwstc RC to DVI integral mass flow



**Fig.9. 75 – SPES3-147 and IRIS HT6\_rwstc QT level**



**Fig.9. 76 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-II mass flow (window)**

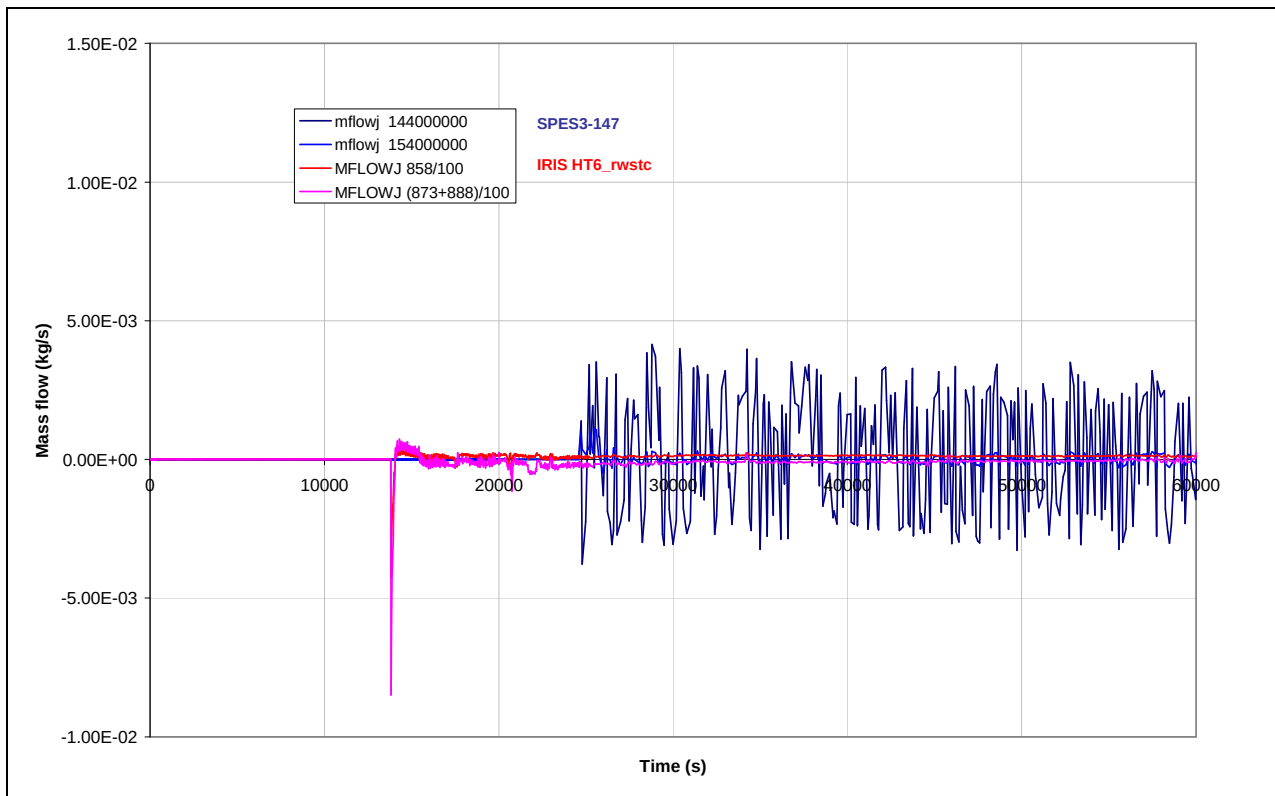


Fig.9. 77 – SPES3-147 and IRIS HT6\_rwstc ADS Stage-II mass flow

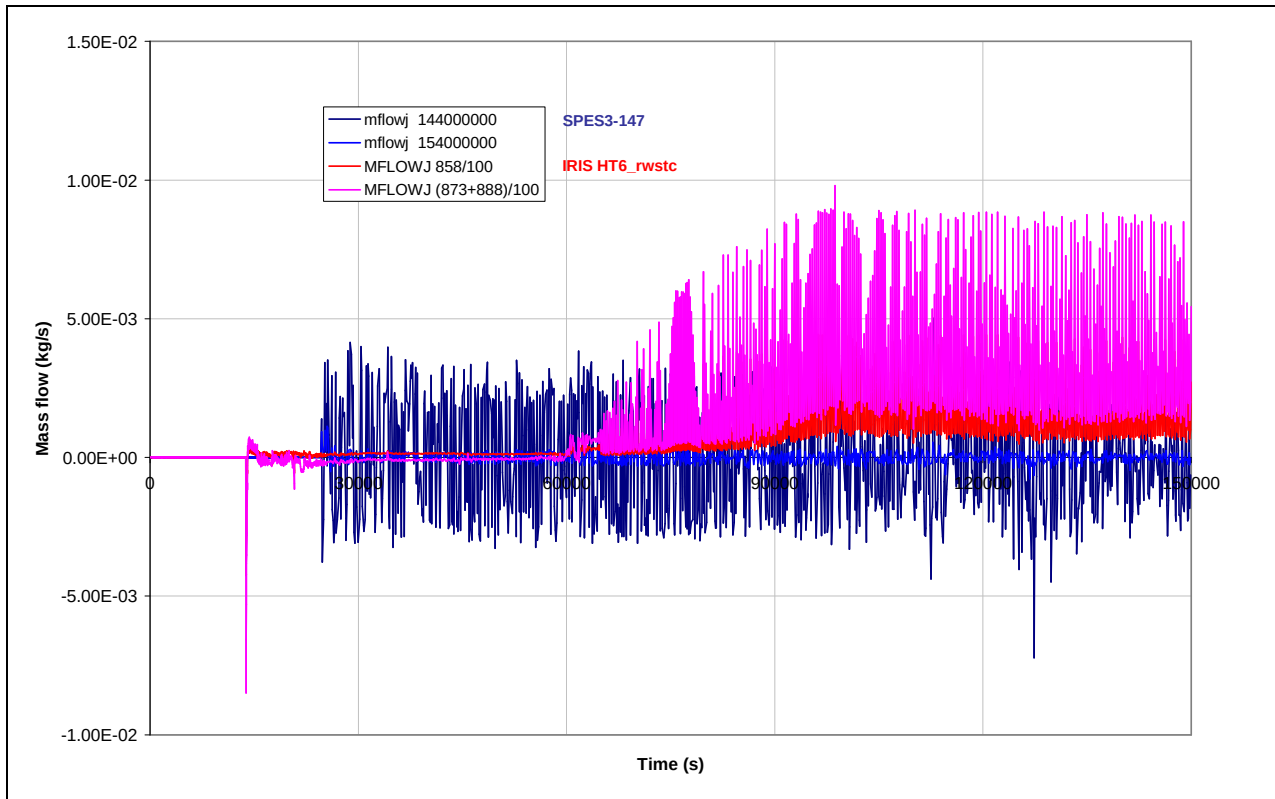
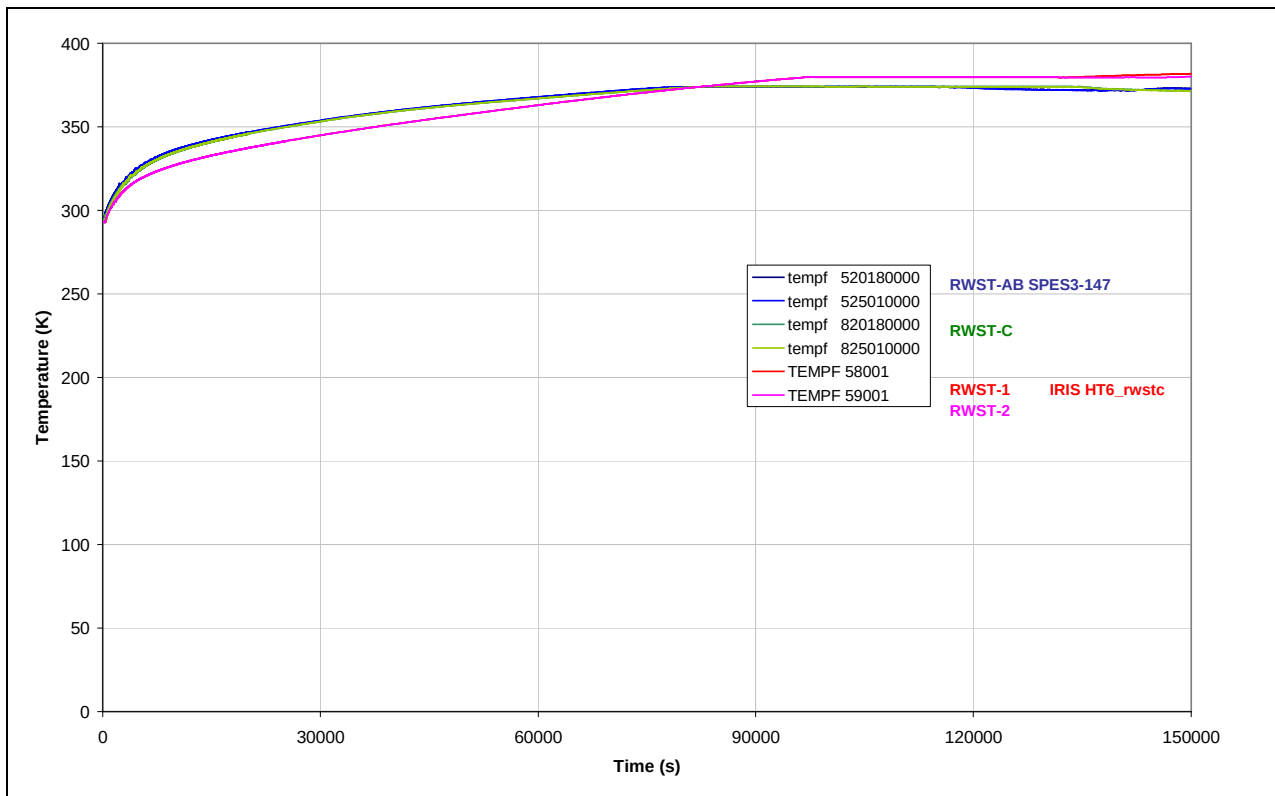
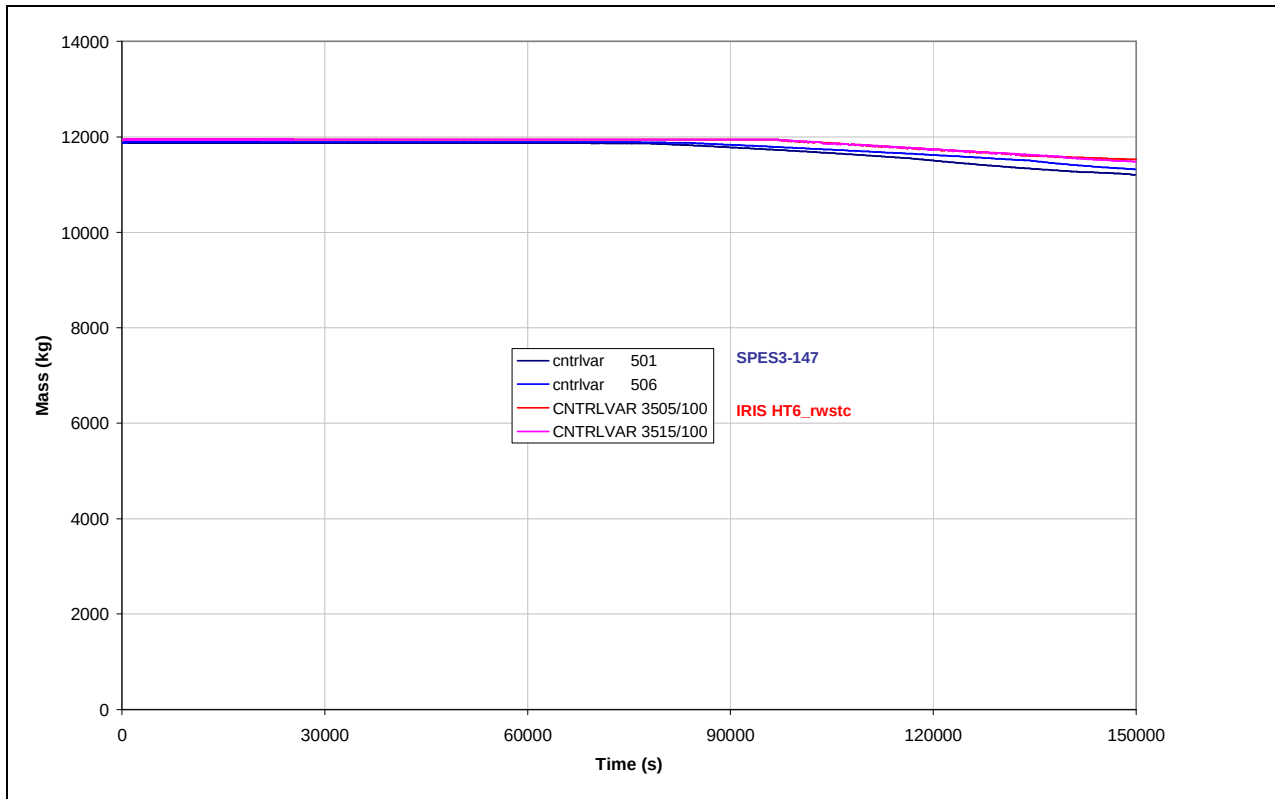


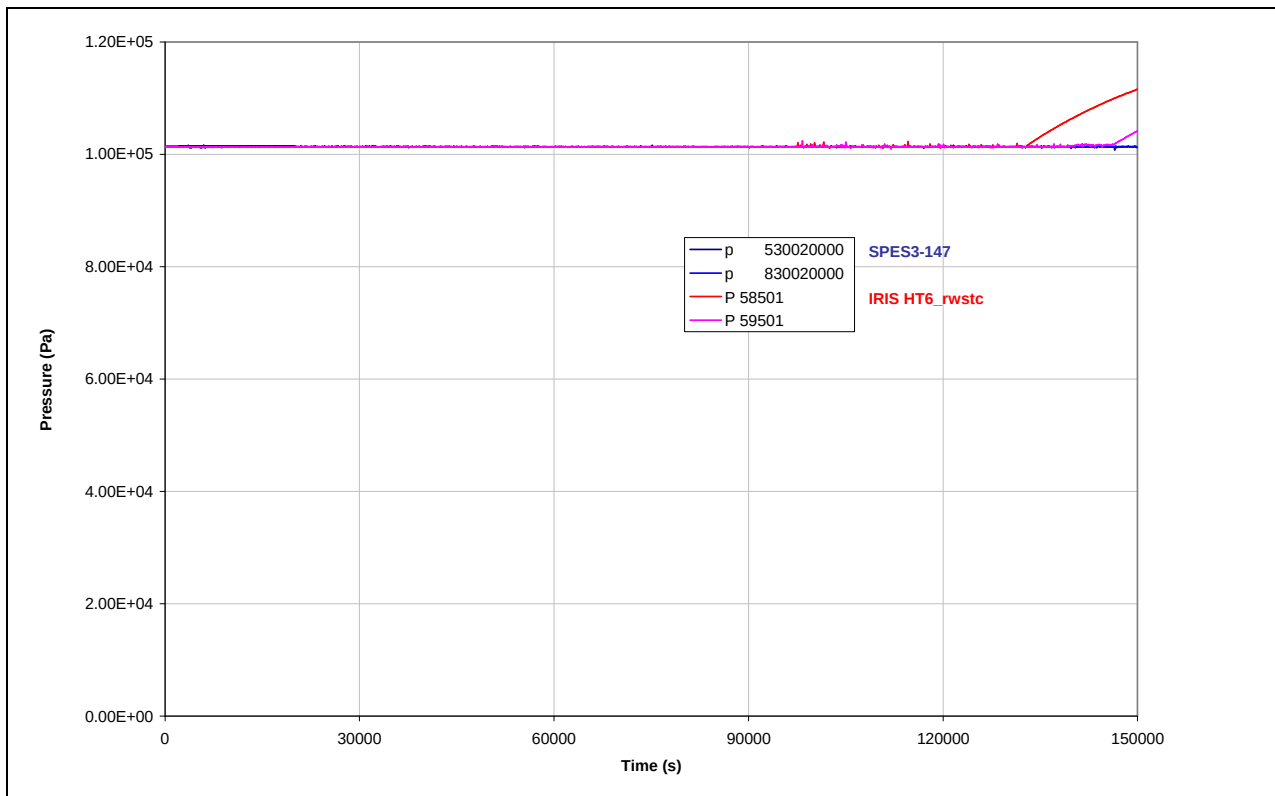
Fig.9. 78 – SPES3-147 and IRIS HT6\_rwstc RWST temperature



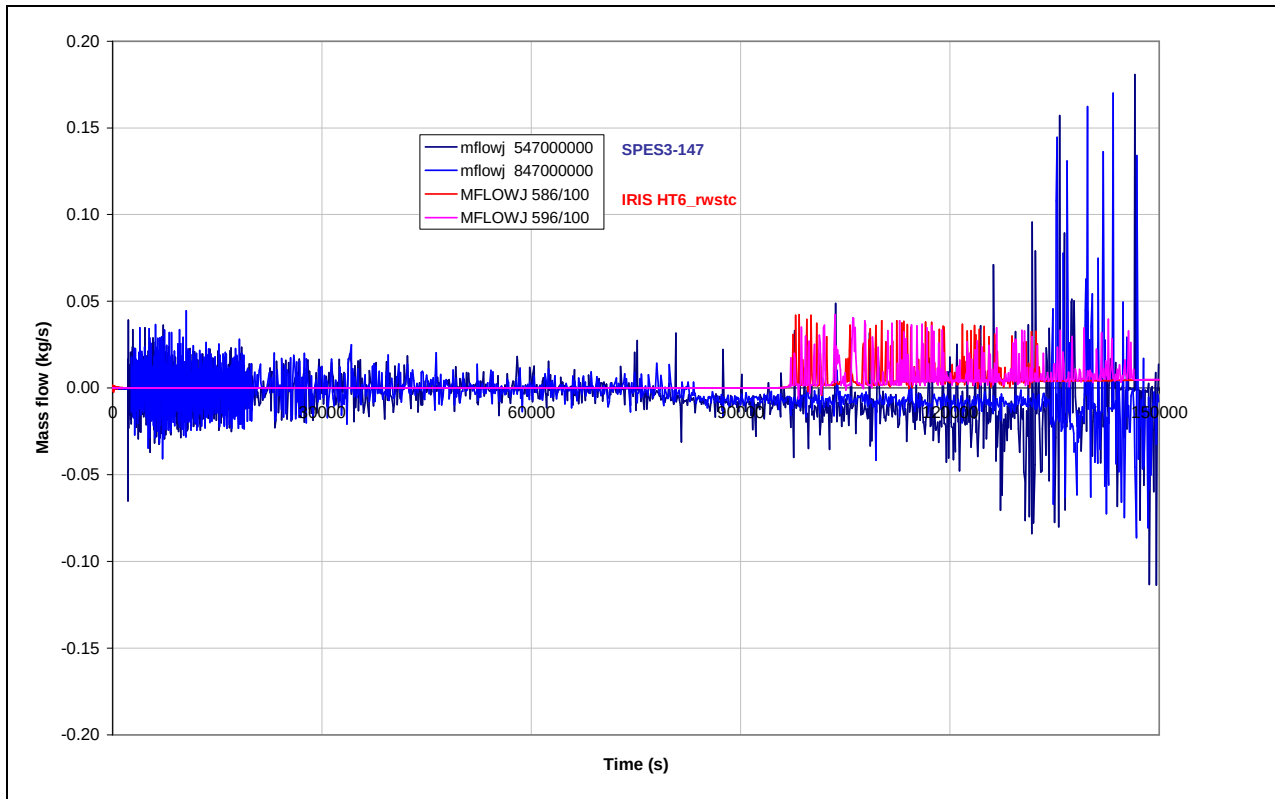
**Fig.9. 79 – SPES3-147 and IRIS HT6\_rwstc RWST mass**



**Fig.9. 80 – SPES3-147 and IRIS HT6\_rwstc RWST pressure**



**Fig.9. 81 – SPES3-147 and IRIS HT6\_rwstc RWST top mass flow**



**Fig.9. 82 – SPES3-147 and IRIS HT6\_rwstc RWST top integral mass flow**

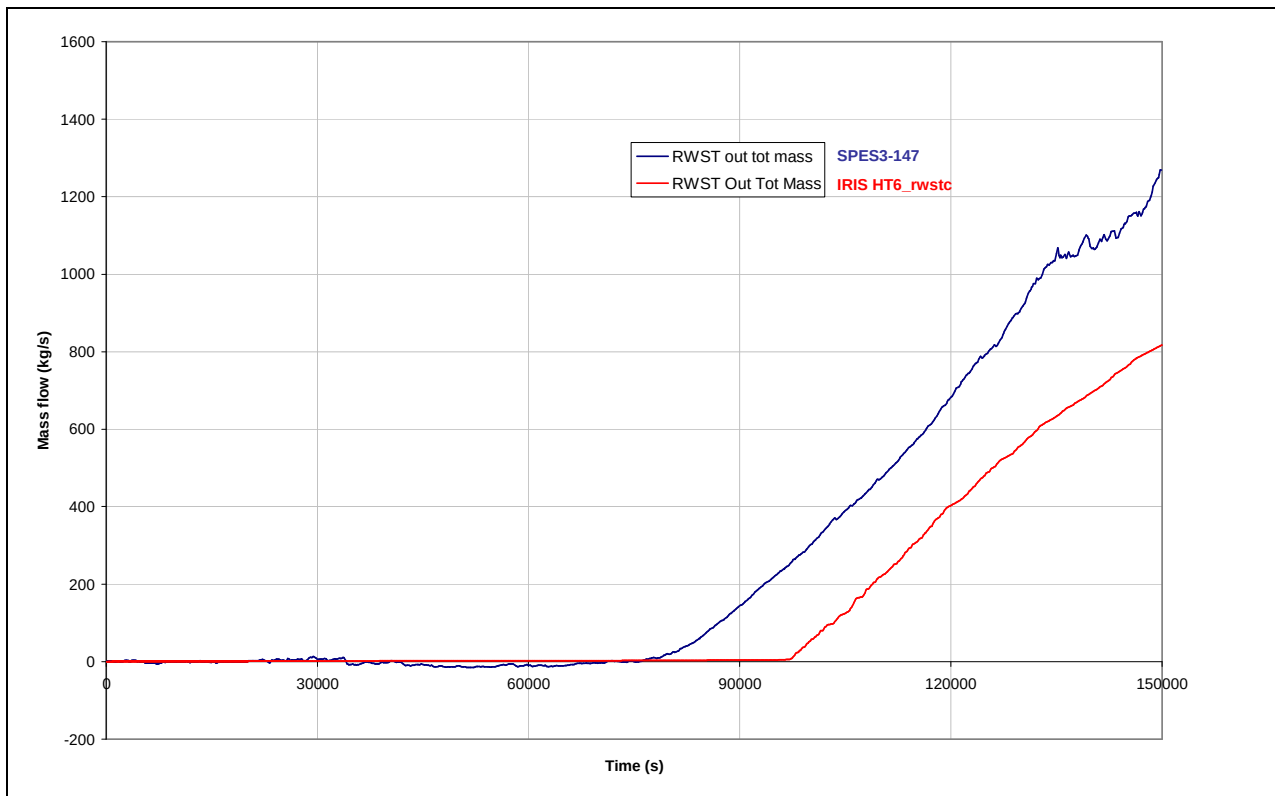


Fig.9. 83 – SPES3-147 and IRIS HT6\_rwstc RWST power (window)

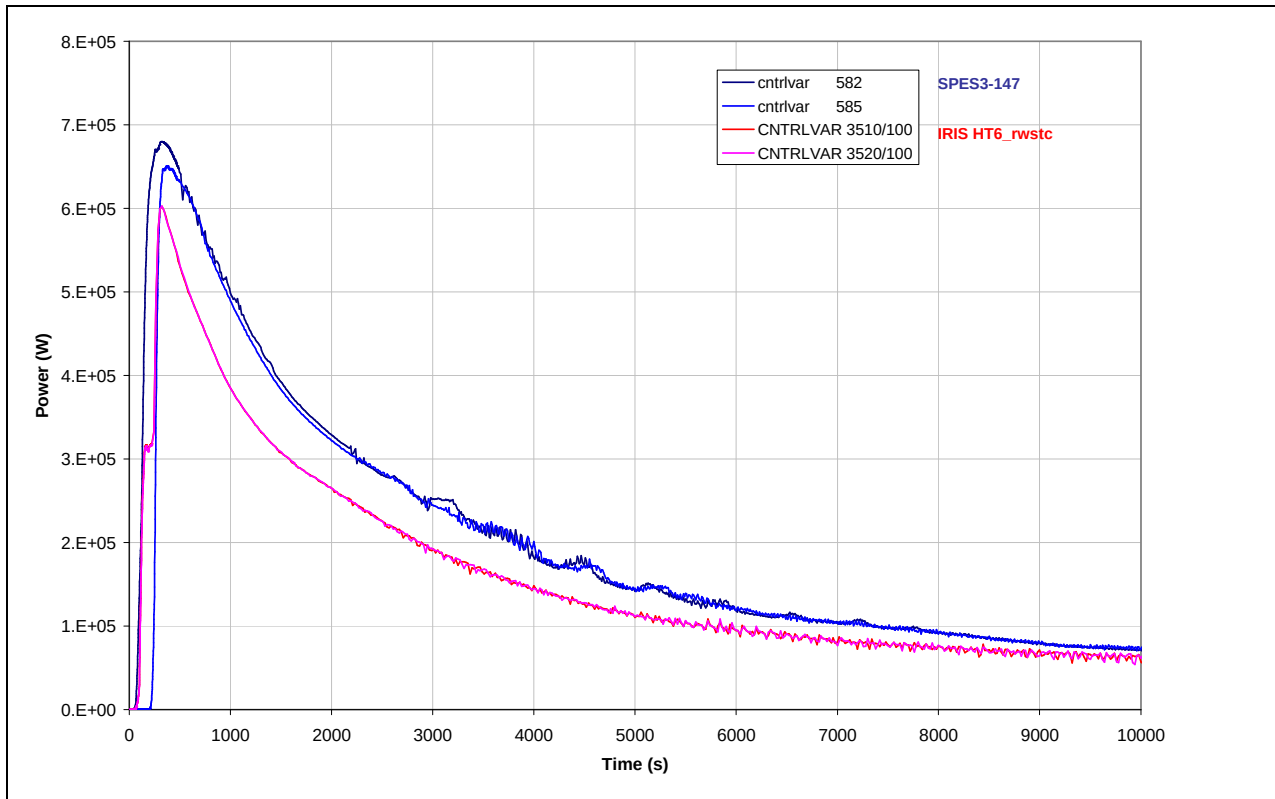


Fig.9. 84 – SPES3-147 and IRIS HT6\_rwstc RWST power

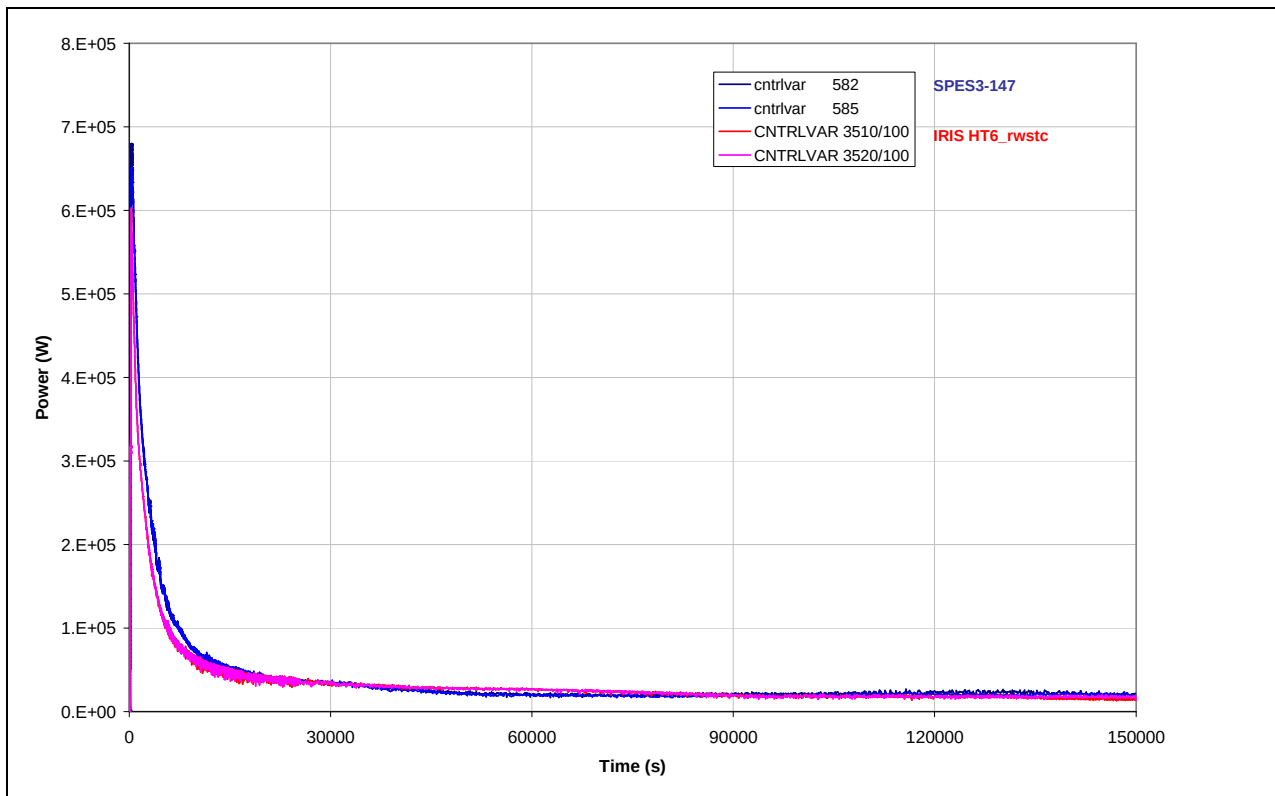


Fig.9. 85 – SPES3-147 and IRIS HT6\_rwstc DW power (window)

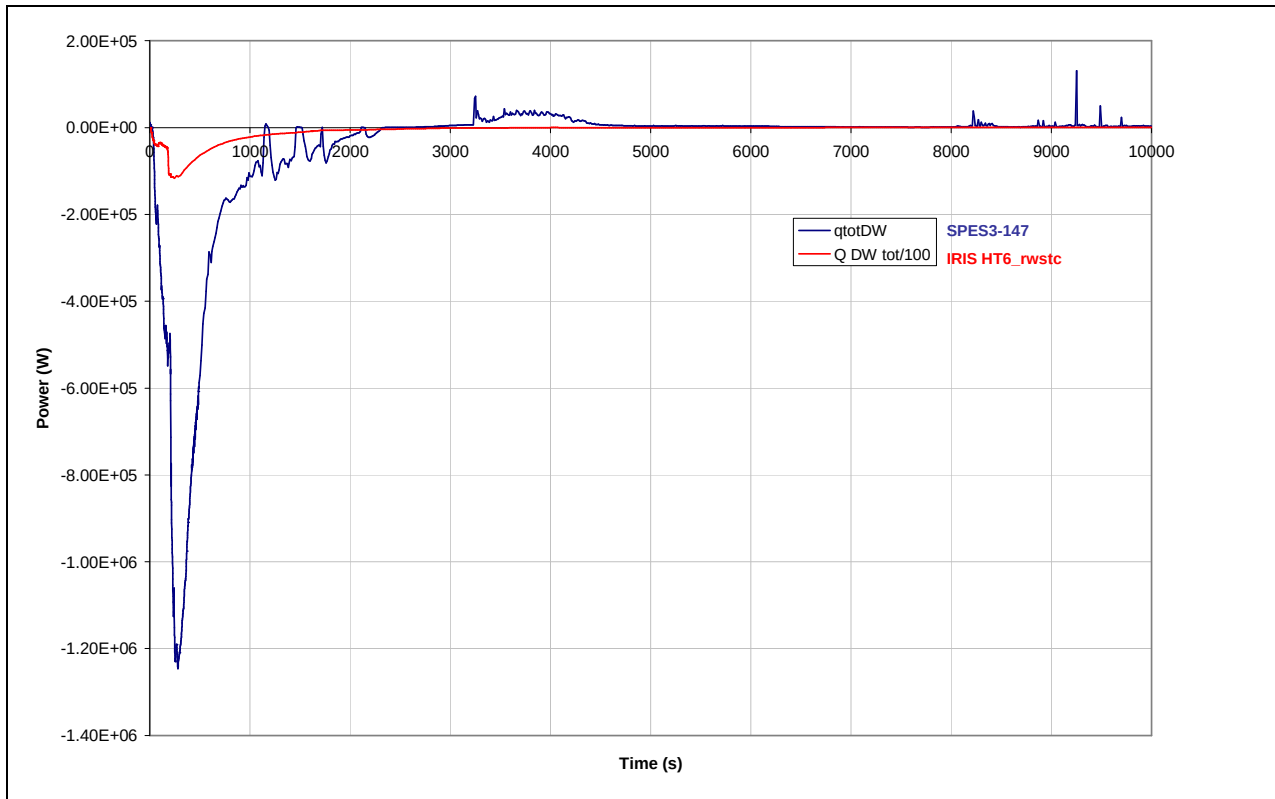


Fig.9. 86 – SPES3-147 and IRIS HT6\_rwstc DW power

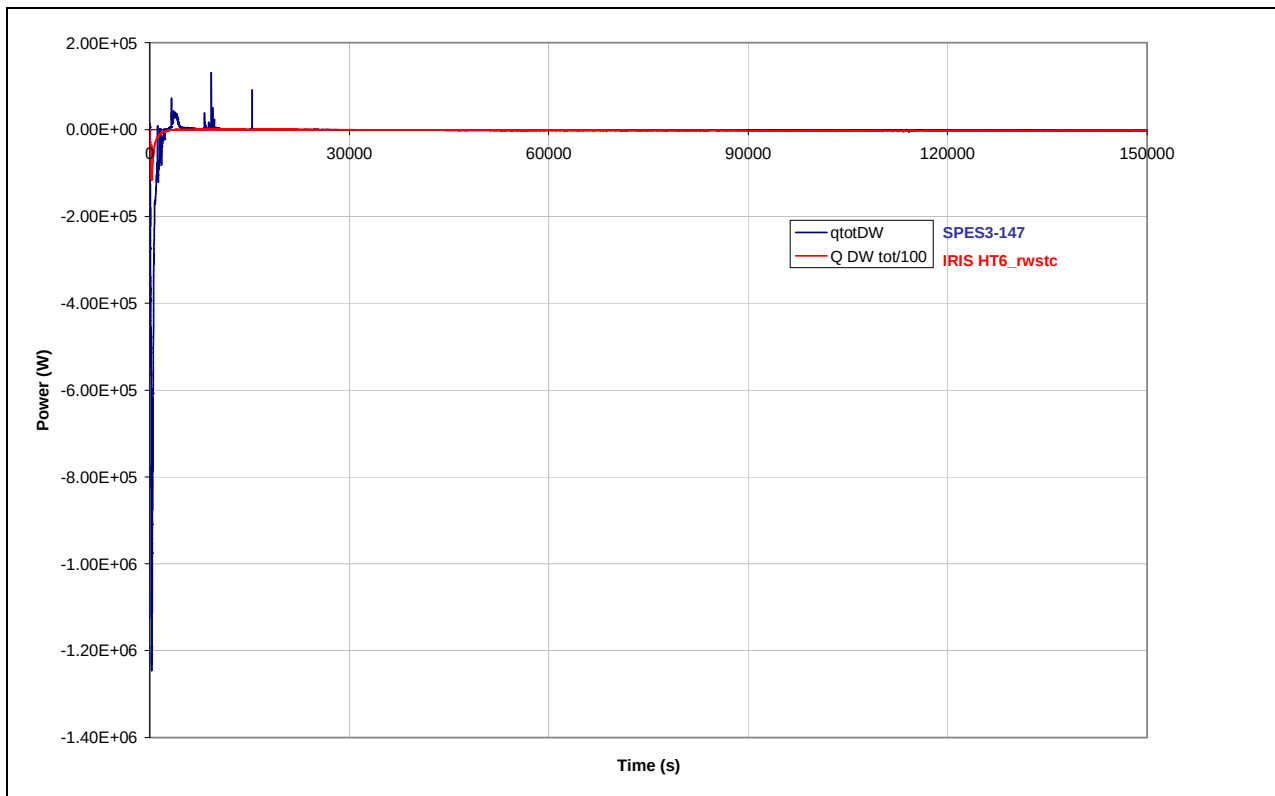




Fig.9. 87 – SPES3-147 and IRIS HT6\_rwstc DW inner and outer wall temperature (window)

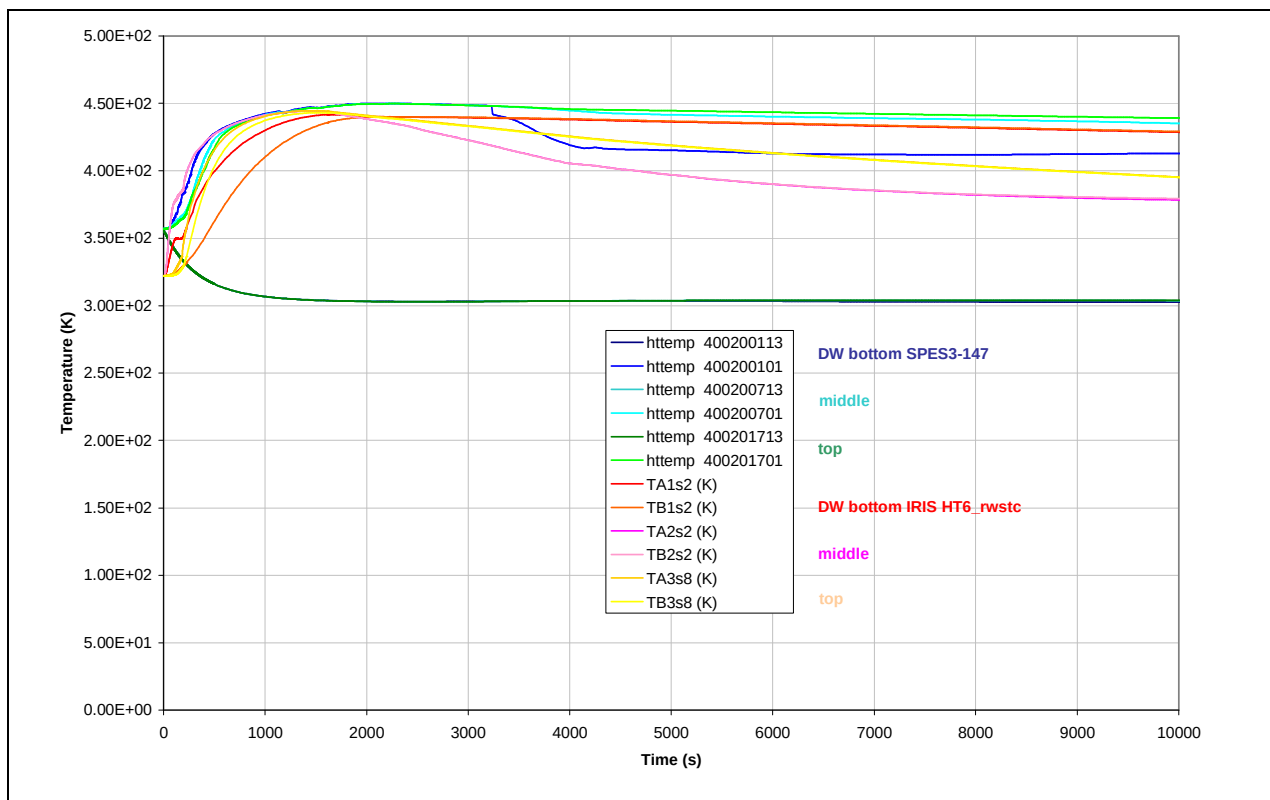


Fig.9. 88 – SPES3-147 and IRIS HT6\_rwstc DW inner and outer wall temperature

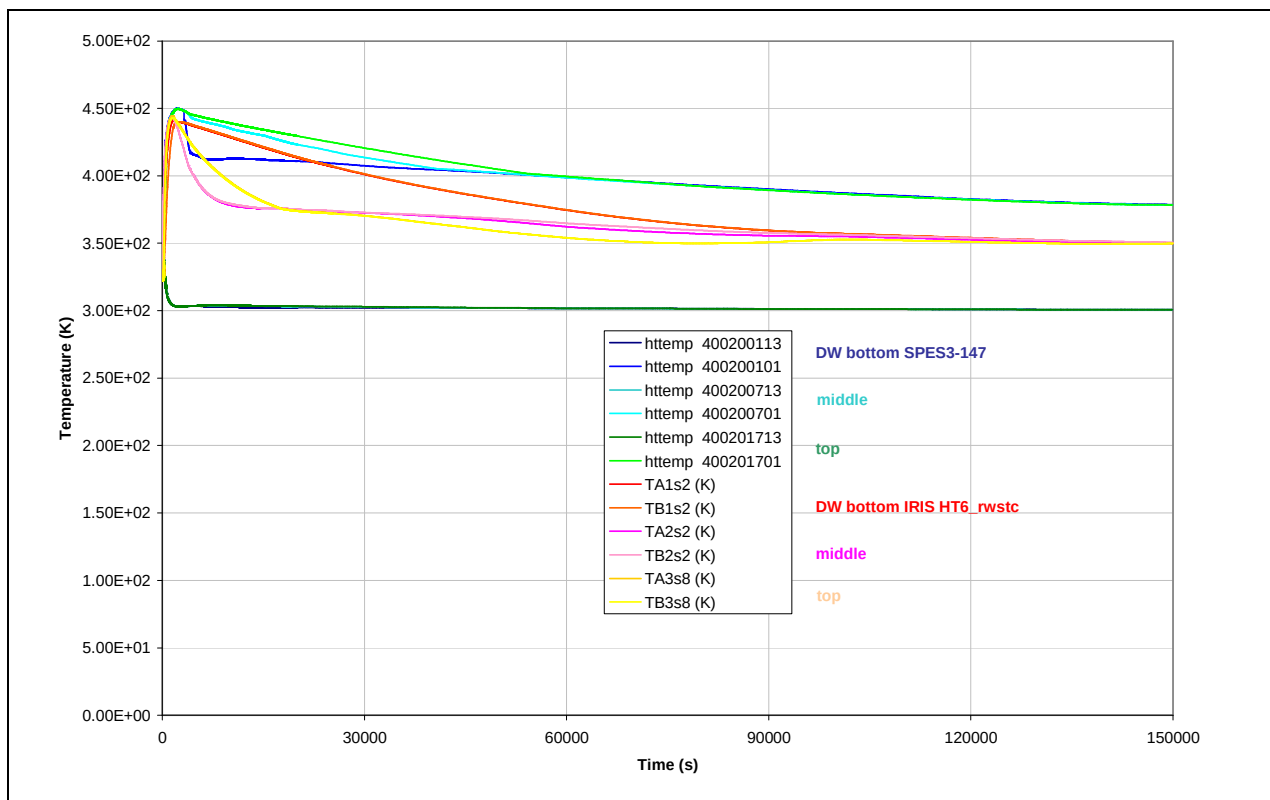


Fig.9. 89 – SPES3-147 and IRIS HT6\_rwstc T (PRZ) – T (SG)

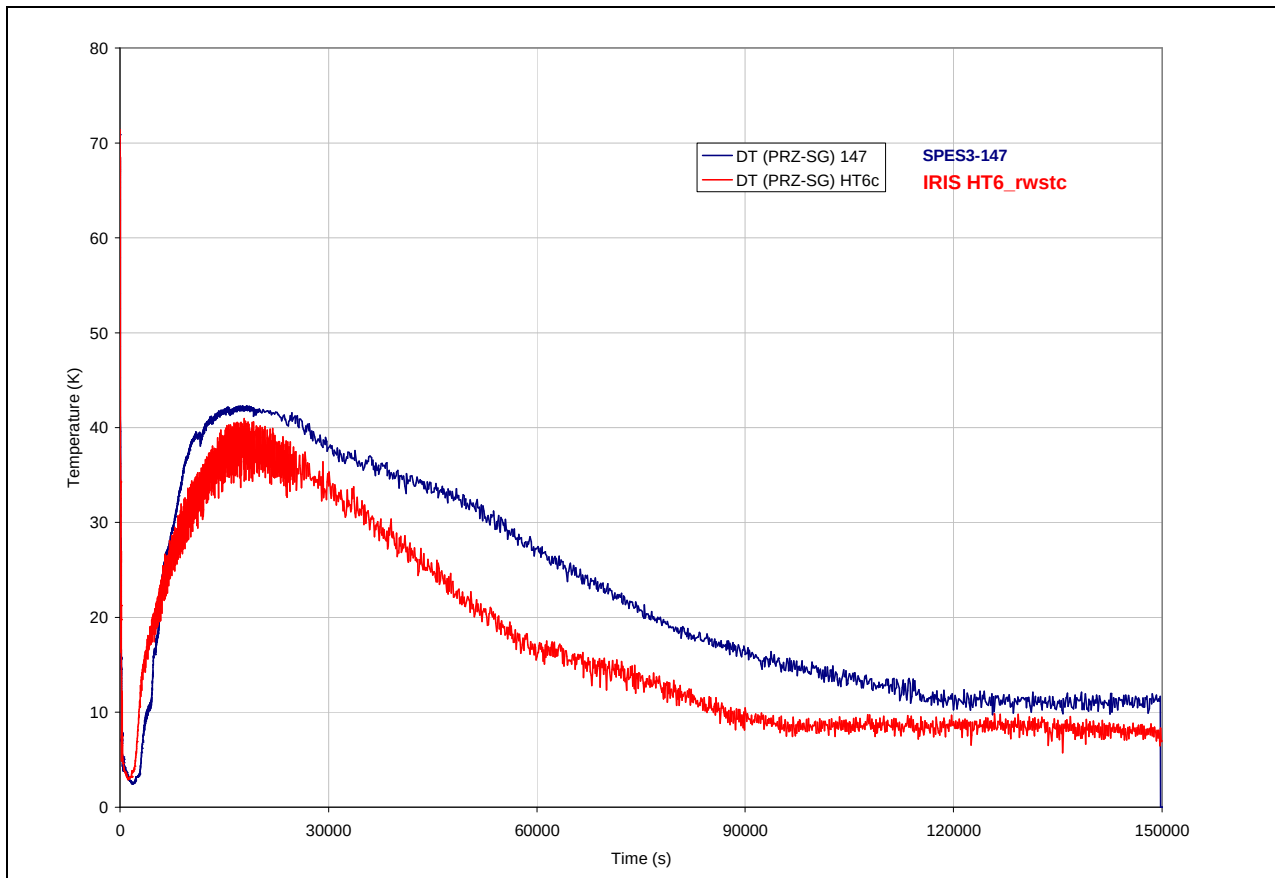
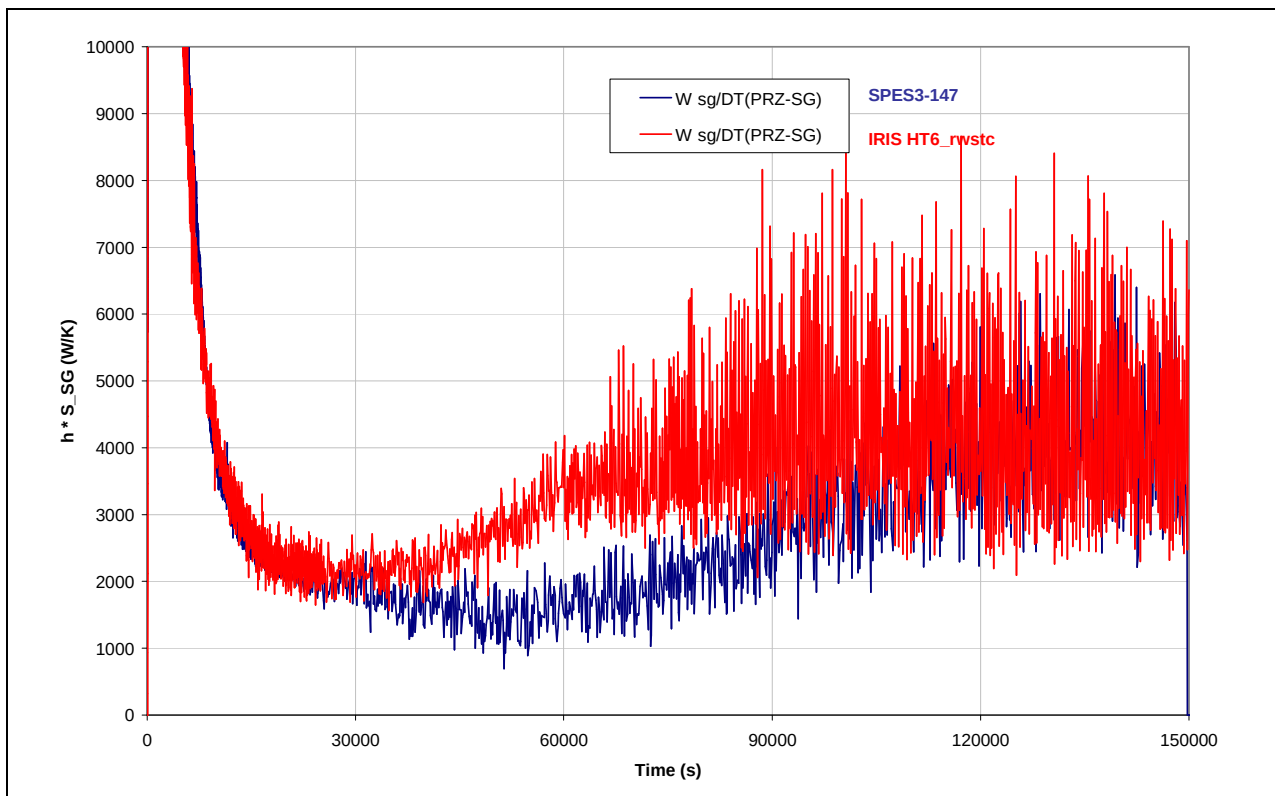
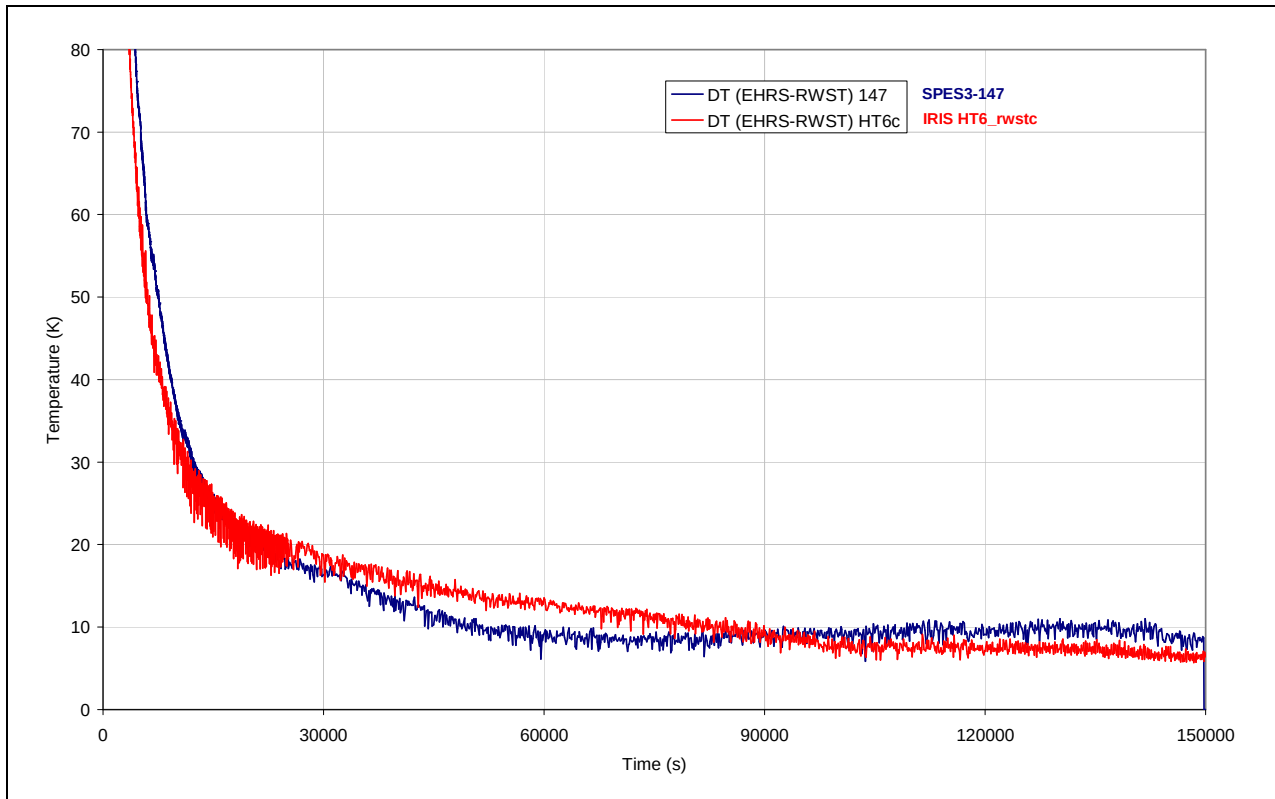


Fig.9. 90 – SPES3-147 and IRIS HT6\_rwstc SG global heat transfer coefficient



**Fig.9. 91 – SPES3-147 and IRIS HT6\_rwstc T (EHRS) – T (RWST)**



**Fig.9. 92 – SPES3-147 and IRIS HT6\_rwstc EHRS global heat transfer coefficient**

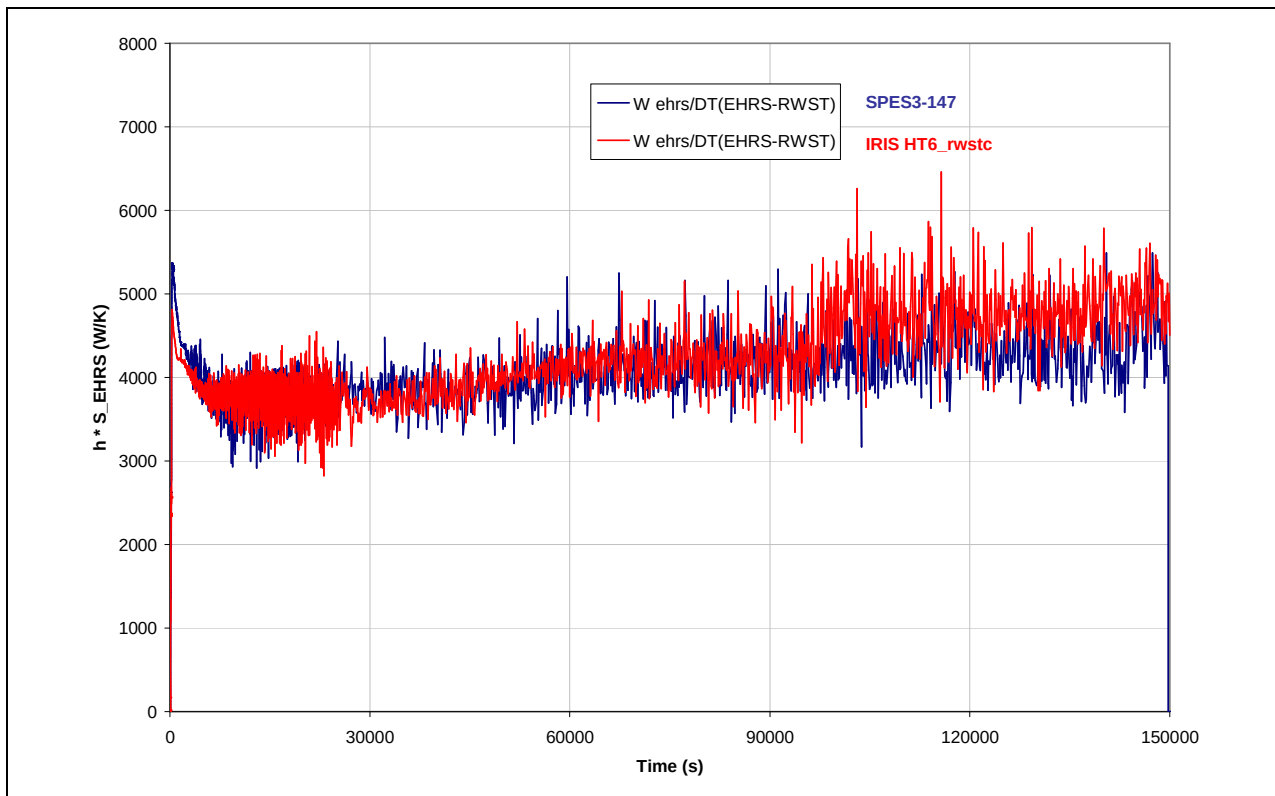


Fig.9. 93 – SPES3-147 and IRIS HT6\_rwstc T (PRZ) – T (RWST)

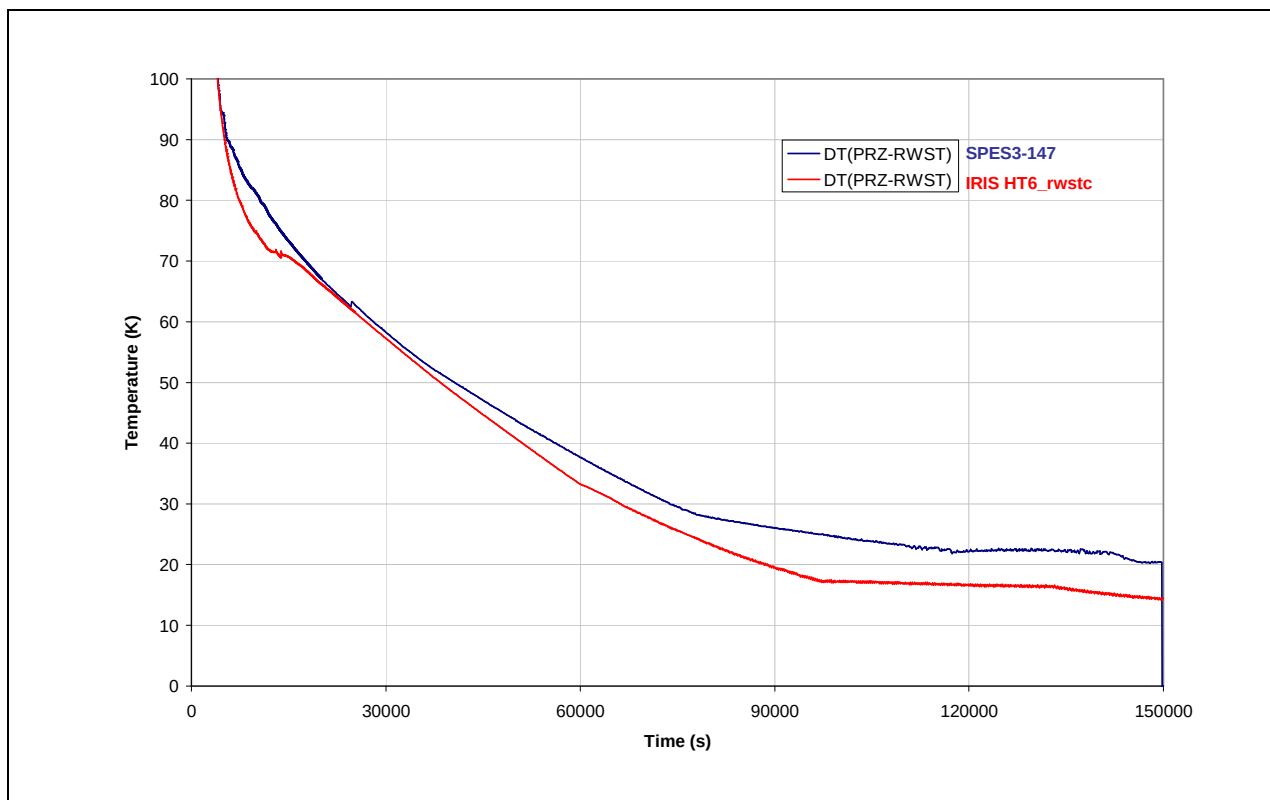
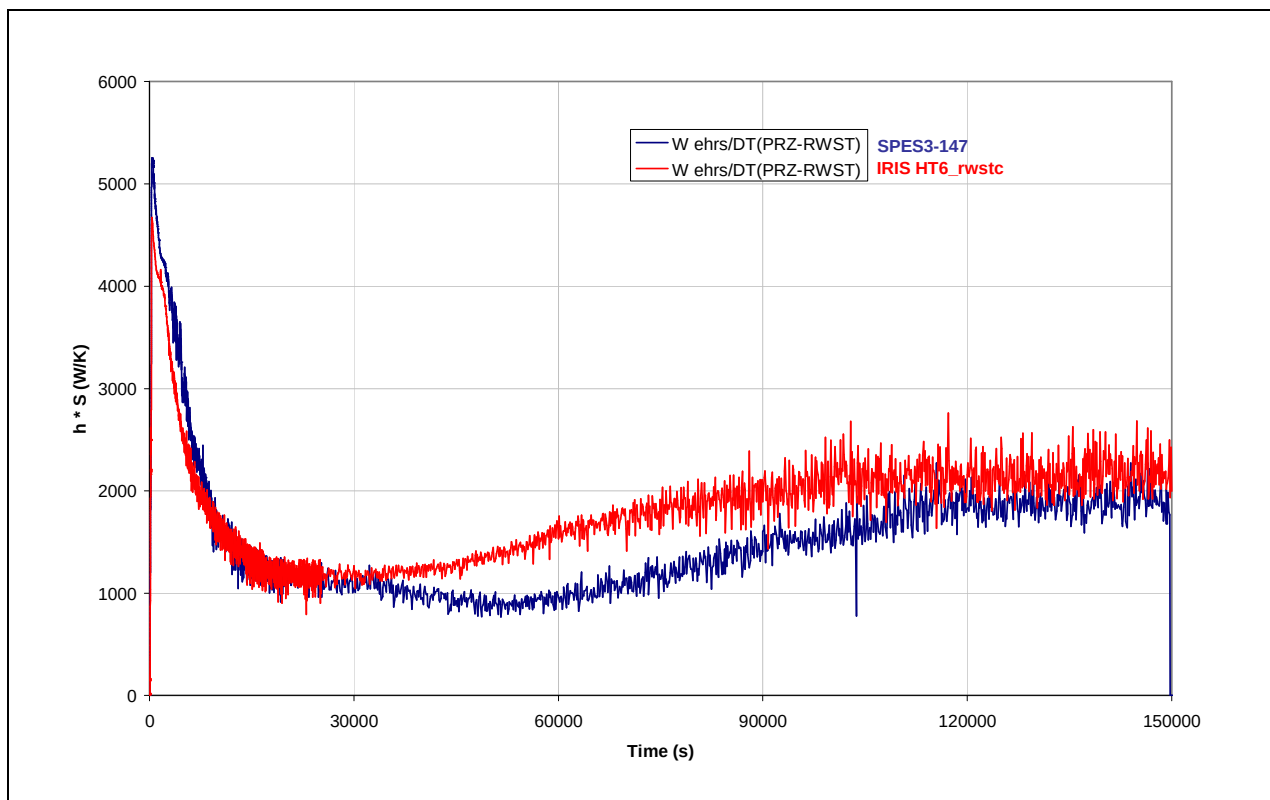


Fig.9. 94 – SPES3-147 and IRIS HT6\_rwstc PRZ-RWST global heat transfer coefficient



## 10. CONCLUSIONS

This document describes in detail all the modifications to the SPES3 containment design required to match the IRIS DVI DEG break transient, assumed as reference for the comparison and investigation of the plant response differences.

Starting from a base case for SPES3 and IRIS, the greatest difference evidenced between SPES3 and IRIS was the Containment Volume (CV) pressure that affects the dynamic coupling between primary and containment systems and consequently the RV mass inventory with possible influence on rod clad temperature.

The identified and investigated parameters that affect the CV pressure are listed in the following:

- a) DW inner surface thermal insulation;
- b) containment tank volumes;
- c) containment tank wall metal masses;
- d) containment metal structure initial temperature;
- e) containment piping pressure drops (PSS to DW, LGMS to DVI, RC to DVI);
- f) EHRS and RWST modeling and heat transfer coefficients.

The DW thermal insulation, simulated with different materials and thickness, aimed at limiting the influence of the 10 times larger surface-to-volume ratio in SPES3 than IRIS, showed a beneficial effect limited to the early phases of the transient, whereas, adding mass to the system, worsens the pressure trend in the long term.

The exact 1:100 scaling of the containment tank volume and the relative water-air space ratio is fundamental to have the correct compartment pressurization when air is transferred from DW to PSS after the break occurrence.

The containment tank metal mass is identified as the most affecting parameter of the CV pressure response, both in SPES3 and IRIS. In SPES3, the metal mass is over scaled with respect to IRIS, due to mechanical reasons, and the solution of metal pre-heating is adopted to compensate for the extra mass. The SPES3 containment metal pre-heating and the correct IRIS containment compartment mass simulation led to have close DW pressure responses and thermalhydraulic parameter similarity in the updated configurations of SPES3 and IRIS

Particular care was set in reproducing IRIS piping pressure drops in SPES3 as mass flow in the PSS to DW lines largely affects the containment depressurization after the pressure peak as well as mass flows from LGMS and RC to DVI affects the RV mass make-up.

The EHRS and RWST modeling and heat transfer coefficient optimization, according to experimental data on an in-pool heat exchanger in similar conditions, together with the piping pressure drop similarity, led to improve the pressure response in the long term.

The SPES3 design-simulation feedback process has led to an optimization of the facility design suitable to reproduce the IRIS phenomena. On the basis of the achievements of this document, Westinghouse has issued a revision of the IRIS test technical specification, which includes the SPES3 and IRIS design updates, [20]. Moreover, SIET is reviewing the piping size, layout and verifying mechanical stresses.

The updated numerical simulations of the two plants provide a data base for the FSA methodology application to obtain a quantitative evaluation of discrepancies of thermo-fluid dynamic parameters, based on the PIRT specified Figures of Merit [21].

## 11. REFERENCES

- [1] G. D. Storricks: IRIS integral system test specification. Westinghouse Electric Company STD-AR-08-01 Rev.1, November 2008.
- [2] R. Ferri, C. Congiu: Conceptual design of the SPES3-IRIS facility. SIET 01 334 RT 07 Rev.1. Piacenza (I), September 5<sup>th</sup>, 2008
- [3] RELAP5 code manual. NUREG/CR-5535/Rev1. Idaho National Engineering Laboratory (USA), May 2001.
- [4] R. Ferri, C. Congiu: SPES3-IRIS facility nodalization for RELAP5 Mod.3.3 code and steady state qualification. SIET 01 423 RT 08 Rev.0. Piacenza (I), January 30<sup>th</sup>, 2009.
- [5] R. Ferri, C. Congiu: SPES3-IRIS facility RELAP5 base case transient analyses for design support. SIET 01 489 RT 09 Rev.0. Piacenza (I), April 7<sup>th</sup>, 2009.
- [6] G. Tortora, M. Ricotti: Application of Fractional Scaling Analysis for IRIS and SPES3 Containment Vessel pressure response during DVI-SBLOCA event. CIRTEN, Politecnico di Milano, ENEA XCIRTEN – P9LU-035 June 16<sup>th</sup>, 2009.
- [7] D. Lioce: IRIS & SPES3 Reactor and Containment vessels pressure response after pressure equalization. DIMNP Pisa University and Westinghouse, Pittsburg February 4<sup>th</sup>, 2009.
- [8] R. Ferri, C. Congiu: SPES3-IRIS facility RELAP5 sensitivity analyses of the Lower Break transient for design support. SIET 01 499 RT 09 Rev.0. Piacenza (I), June 11<sup>th</sup>, 2009.
- [9] R. Ferri: Impianto SPES3 – Progetto esecutivo: Elenco elaborati. SIET 01 488 ST 09 Rev.0. Piacenza (I), 25 Marzo 2009.
- [10] A. Achilli: Impianto SPES3 – Progetto esecutivo: Dimensionamento e caratteristiche delle tubazioni. SIET 01 487 ST 09 Rev.0. Piacenza (I), 25 Marzo 2009.
- [11] S. Botti: Impianto SPES3 – Progetto esecutivo: Specifica tecnica dei serbatoi. SIET 01 338 ST 07 Rev.0. Piacenza (I), 19 Marzo 2009.
- [12] L. Oriani, D. Grgic, T. Bajis, V. Segon, F. Berra: IRIS base input deck and steady state qualification for RELAP5 Mod.3.3. WEC STD-ES-04-19 Rev. 2.4, August 2004.
- [13] D. Grgic: Influence of Containment Modeling on IRIS Long Term Behaviour during Lower Break SBLOCA Reference Case. FER-ZVNE/SA/DA-TR05/09-0 (DRAFT).
- [14] e-mail April 24<sup>th</sup>, 2009 from D. Grgic to R. Ferri, etc. Subject: containment HS. IRIS DW heat structures.
- [15] e-mail April 17<sup>th</sup>, 2009 from M. Dzodzo to G. Storricks, etc. Subject: RE: We will have our next IRIS SPES3 conference call on Friday, April 17<sup>th</sup>. Insulating material properties.
- [16] e-mail April 1<sup>st</sup>, 2009 from F. S. Nitti to R. Ferri, etc. Subject: Condenser System.
- [17] P- Meloni, F. S. Nitti, F. Bianchi: Analysis of thermal-hydraulic performance of IRIS/SPES3 EHRS condenser with an appropriate RELAP5 model. ENEA FPN-P9LU-020\_rev.0. March 25<sup>th</sup>, 2009.
- [18] R. Ferri: PERSEO project: Post-test calculations with the Relap5 Mod. 3.3 beta code. SIET 01 061 RA 03 Rev.0. Piacenza (I), July 7<sup>th</sup>, 2003.
- [19] e-mail January 19<sup>th</sup>, 2010 from D. Grgic to R. Ferri. Subject: Re: Sensitivity cases on SPES3 EHRS/RWST stand alone model.
- [20] G. D. Storricks: IRIS integral system test specification. Westinghouse Electric Company STD-AR-08-01 Rev.2, June 2010.
- [21] Larson et al.: IRIS small break LOCA phenomena identification and ranking table (PIRT). Nuclear Engineering and Design 237 (2007) 618-626.

## 12. ATTACHMENTS

The two attached files contain the SPES3-146 nodalization description flowsheets and the local pressure drop calculation flowsheets:

File: SPES3 nodalization\_merge\_BN rev12.xls

File: pressure drop coefficients Rev5.xls