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Numerical analysis of the thermal-hydraulic behaviour of the ICE test section by the coupling of a system code and a CFD code

N. Forgione, D. Martelli

CIRTEN - CONSORZIO INTERUNIVERSITARIO PER LA RICERCA TECNOLOGICA NUCLEARE

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NUMERICAL ANALYSIS OF THE THERMAL-HYDRAULIC BEHAVIOUR OF THE ICE TEST SECTION BY THE COUPLING OF A SYSTEM CODE AND A CFD CODE

N. Forgione, D. Martelli – CIRTEN Università di Pisa

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Sommario

In this report the thermal fluid-dynamics results of the DHR (Decay Heat Removal) pre-test analysis of the test foreseen at ENEA by the ICE (Integral Circulation Eutectic) test section of CIRCE (CIRCulation Eutectic) facility are presented. The aim of this work is the study of the PLOHS (Protective Loss Of Heat Source) + LOF (Loss Of Flow) accident that in a LFR (Lead Fast Reactor) consists in the loss of all primary pumps and secondary circuits, with consequent reactor scram and decay heat removed in natural circulation by emergency systems (DHR-HXs).
In order to better represent the boundary conditions a one way coupled model between the RELAP5 system code and the CFD Fluent code was developed. In particular, the boundary conditions implemented in the Fluent code as the HX (Heat eXchanger) removed power and the LBE (Lead-Bismuth Eutectic) flow rate at the entrance of the HS (Heater System) were set-up by previous RELAP5 stand alone simulations. The CFD (Computational Fluid Dynamic) analysis was performed adopting an axial-symmetric domain and assuming adiabatic the external walls. The natural circulation in the HLM (Heavy Liquid Metal) pool and the cooling capability of air circulating in the secondary side of the DHR were also investigated in transient conditions. Twenty hours of transient analysis were performed and at the end of that time the system had not yet reached complete steady state conditions. At $t = 20$ h, the temperature results show a stratified temperature field in the pool region, reaching a distribution in which the upper region is characterized by a temperature of about 316°C and a lower region in which the LB) reaches an approximately uniform value of about 283°C. The LBE mass flow rate in the DHR annular region reaches a value of about 7.5 kg/s (i.e. about 94% of the total LBE mass flow rate entering at the inlet section); under these conditions the DHR system is able to remove about 39 kW of heat power from the vessel, which represents 5% of the nominal power generated before the accident.

Note

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Autori: N. Forgione ,D. Martelli (UNIPI)

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Numerical analysis of the thermal-hydraulic behavior of the ICE test section by the coupling of a system code and a CFD code (Analisi numerica del comportamento termoidraulico della sezione di prova ICE mediante accoppiamento di un codice di sistema e di fluidodinamica computazionale)

Authors:

N. Forgione

D. Martelli

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Abstract

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1 Introduction

In the design of cooling systems for LMFBR (Liquid Metal Fast Breeder Reactor) increasing attention is being given to the use of passive safety systems for the mitigation of severe accidents [1]. In this context, natural circulation plays an important role in passive decay heat removal from reactor core; this justifies the special attention given to such phenomenon using both experimental and computational analyses. Thermal stratification is also considered one of the most important topics in the study of the cooling of Generation IV reactors.

In literature there are many works on natural circulation phenomena in the nuclear field, but these deal with water or sodium only as working fluids (see e.g. Ref [2-3]) and generally neglect thermal stratification.

In the frame of THINS (Thermal Hydraulic of Innovative Nuclear System) Large Scale Collaborative Project (7th Framework Program EU), several experimental works are addressed to investigate thermal-hydraulic aspects relevant to mixed convection phenomena in HLM reactors cooled by lead or lead-bismuth alloy [4].

At the Brasimone ENEA Research Centre a large scale integral test named CIRCE experiment was built and employed with LBE as a working fluid. The objective of the CIRCE experiment is to characterize the phenomena of mixed convection and stratification in a heavy liquid metal pool in the relevant safety situation, that is during the transition from nominal flow conditions to the natural circulation typical of DHR conditions. To achieve this goal the large scale CIRCE facility already representative of a HLM pool-type reactor will be fitted with a DHR system and suitable instrumentation [5].

In this work the results of the WA-DHR thermal fluid-dynamic pre-test analysis, performed developing a one way off-line coupling model between the REPAL5 system code and the CFD Ansys Fluent code, are illustrated. Practically, codes run separately and some of the variables, computed by the system code that simulate the complete test section, were set in the CFD code as boundary conditions by means of an UDF, while no exchanged variables were considered in the opposite direction, i.e. from the CFD code to the system code.

2 CFD Simulations

2.1 Computational domain and numerical model

For a detailed description of the CIRCE facility and the ICE test section refer to previous documents [6-7]. The calculation domain was modeled as a 2D axial-symmetric geometry, assuming the DHR's axis as axis of symmetry for the domain (see Figure1.1). Gravity acts along the *x* axis (coincident with the symmetry axis).

The cross section of the geometrical domain is equal to the cross section of LBE pool of ICE at the same vertical position (the diameter of DHR was included in a cylindrical tank with a inner diameter equal to the equivalent diameter of the cross section of LBE pool); also the total mass of LBE considered in the domain is the same of that contained into the ICE pool and into the other components of ICE test section (HS, riser, gas separator and main HX).

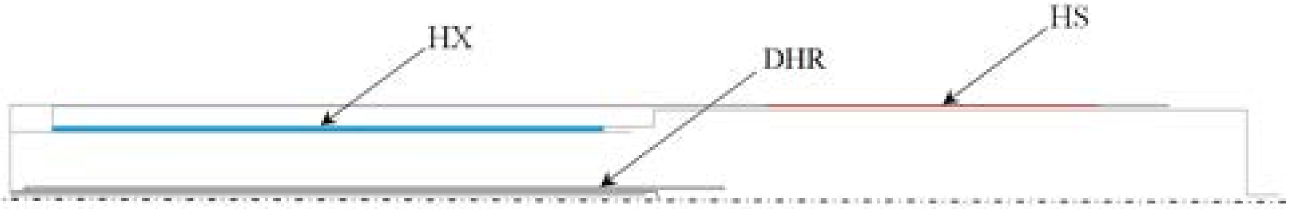

Figure 1.1: 2D axial symmetric computational domain.

The domain was discretized using hexahedral mesh with the exception of the rounded bottom side of the air pipe [6]; special refinements near the wall boundaries of the domain were adopted according to requirement $y^+ = 1$ for enhanced wall treatment model used in the CFD code, the total amount of cells was about 927300. The adopted turbulence model was the *k-ε* Renormalized Group (RNG) model with the "enhanced wall treatment" option for near-wall turbulence modeling. The working fluid was Lead Bismuth Eutectic alloy (LBE) for the primary circuit and air for the secondary circuit of the DHR-HX. The thermodynamic and thermo-physical properties of the LBE alloy such as density, molecular viscosity, thermal conductivity and specific heat were chosen according to the "Handbook on Lead-bismuth Eutectic alloy and Lead properties, material compatibility, thermal-hydraulics and technologies" [8]. Air, properties were considered as a function of temperature and implemented into the FLUENT code as polynomial functions.

The DHR was entirely reproduced in the model, while other components of ICE test section as HS, riser, gas separator and main HX were schematically represented whilst maintaining the same transit time of the real geometry and the same heat flux in the HS and in the HX. A transient analysis assuming a time step of 1 s was performed and a total of twenty hours of transient was investigated. Temperature, velocity and turbulence kinetic energy fields assigned as initial conditions for the transient simulation were obtained from a preliminary CFD steady state calculation. This steady state calculation was performed assuming nominal operative conditions for the facility, i.e. the HS thermal power was imposed to a value of 800 kW with an equal power removed by the main HX, the LBE mass flow rate at the entrance of the HS was assumed equal to 54.8 kg/s and a temperature of about 300°C was set in the LBE pool. All the walls separating the facility from the external environment were considered adiabatic, i.e. no heat losses were considered.

During the transient, due to the PLOHS+LOF accident, the HS main effect was simulated imposing a total heat power of about 40 kW (about 5% of the ICE nominal power). The heat flux removed by the HX, during the accidental scenario simulated by RELSAP5, decreases from an initial value of about 800 kW to zero in about half an hour. The decrease trend was set at the HX peripheral walls by means of an User

Defined Function (UDF) imposing an heat flux time trends obtained from the previous RELAP5 calculation [4] and reported in Figure 1.2. The cutoff of the HX results in a decrease in the heat removal trend as showed in Figure 1.2, mainly due to the heat removed by the evaporation process of the water contained in the HX in the initial phase of the simulated transient.

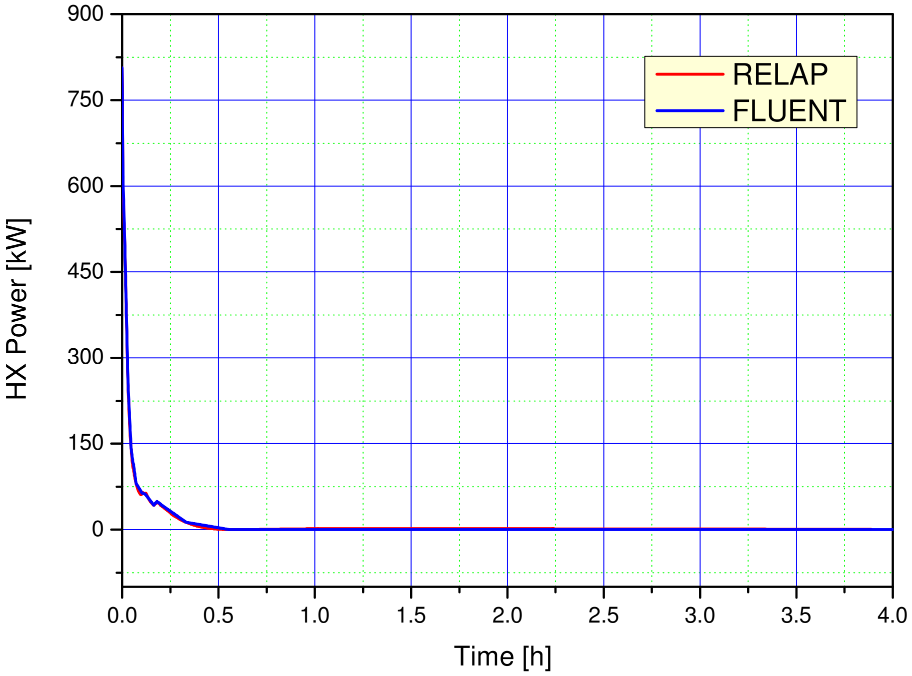

Figure 1.2: HX thermal power time trend.

Also the mass flow rate at the entrance of the computational domain (corresponding to the entrance section of the HS) was imposed in agreement with the results obtained in the previous RELAP5 calculation [4]. Figure 1.3 shows the comparison of the LBE mass flow rate as evaluated from the RELAP5 code and as imposed in the FLUENT code.

As shown in Figure 1.3, as the PLOH+LOS transient is started at *t* = 0 s, the mass flow rate in the primary system quickly decreases, because of the stopped argon injection into the riser, to a value of about 8 kg/s predicted by the RELAP5 code for the stable natural circulation. The temperature value imposed as the boundary condition at the inlet section of the domain (entrance of the HS) was assumed equal to the average value of the temperature at the outlet section of the domain, by means of an appropriate UDF.

For the secondary circuit (air) an inlet mass flow rate of 0.3 kg/s and an inlet temperature of 20°C were imposed as boundary conditions.

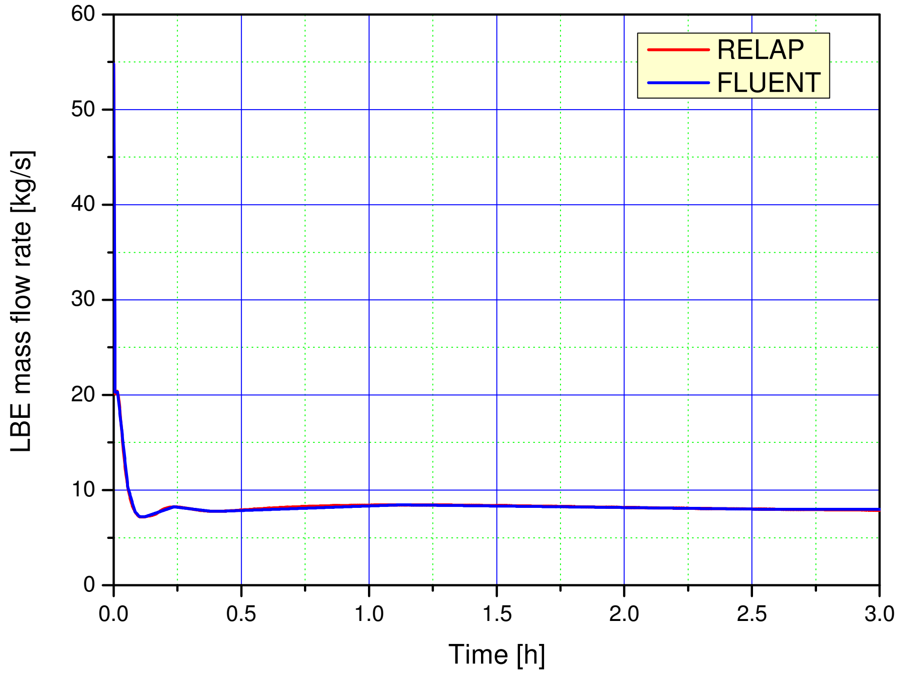

Figure 1.3: LBE mass flow rate in the primary circuit.

2.2 Obtained results

During the analysed transient, the LBE mass flow rate in the DHR annular region was monitored (see Figure 1.4). In particular, after 20 hours from the start of the accident the LBE mass flow rate through the primary side of the DHR reaches a value of about 7.5 kg/s, i.e. 94% of the LBE mass flow rate flowing through the HS.

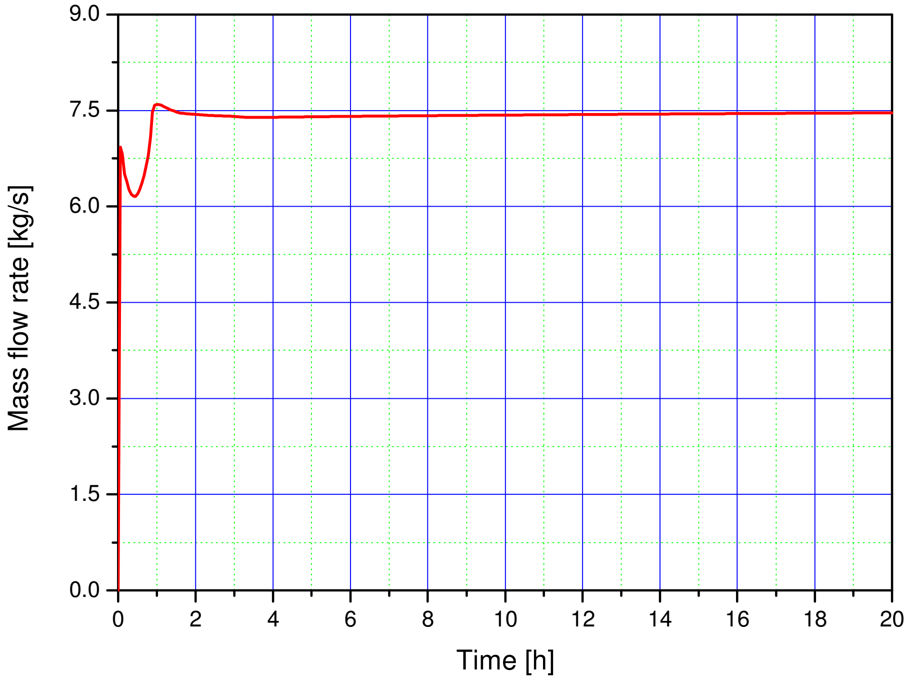

Figure 1.4 :LBE mass flow rate at the inlet section of the DHR cooling annular channel.

Figure 1.5 shows the LBE temperature distribution at initial steady state condition and at 1, 4, 8 and 20 hours of transient. As can be seen, at the beginning of the transient the LBE temperature assumes a constant value of 300°C. After an initial decrease in temperature (during about the first 2 h of transient), due to the sharp reduction in the XS thermal power and to a non instantaneous reduction in the thermal power removed by the HX, the LBE temperature in the upper vessel zone starts to increase. This is due to the hot LBE mass entering the domain (no longer cooled by the main HX), while in the lower part of the vessel region it decreases because of the cooling action of the DHR. After about 8 hours, thermal stratification phenomenon is clearly evident in the entire pool (see Figure 1.5). The LBE temperature in the upper and lower plenum stabilizes at two different levels, respectively of 316°C and 283°C, with a transition zone shown in the region between the elevation of the exit from the HX and of the exit from the DHR.

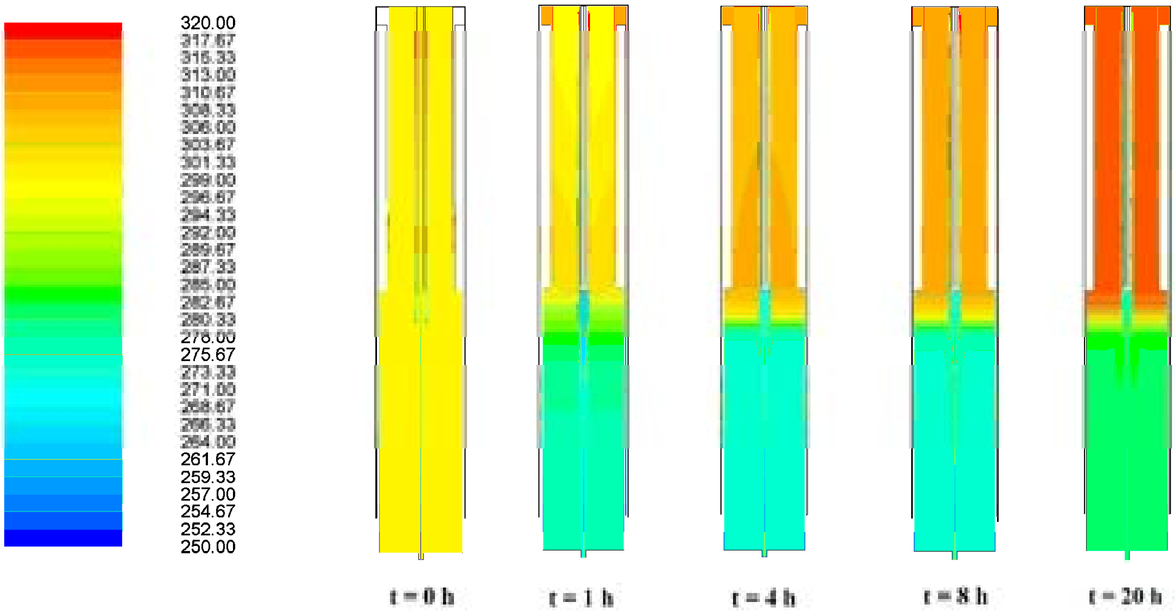

Figure 1.5: LBE temperature contour plot [°C] at five different times during the transient.

A vertical control reference line placed at $y = 0.3$ m (see Figure 1.6) was used to check the trend of LBE temperature inside the pool region along the *x*-axis direction. As can be observed from Figure 1.7 the temperature distribution is quite constant from the top of the pool up to the bottom of the air channel of the DHR; it gradually decreases until the DHR skirt exit and then remains roughly constant from this elevation until the bottom of the pool (see Figure 1.7).

Figure 1.6: Control line at $y = 0.3$ m in the LBE pool region.

At $t = 1$ h the temperature in the upper part of the vessel is about three degree celsius lower than the initial temperature value because when the accidental scenario starts, the HS power is reduced to zero instantaneously while the cutoff of the HX results in a non instantaneous decrease in the heat removal trend (see Figure 1.2).

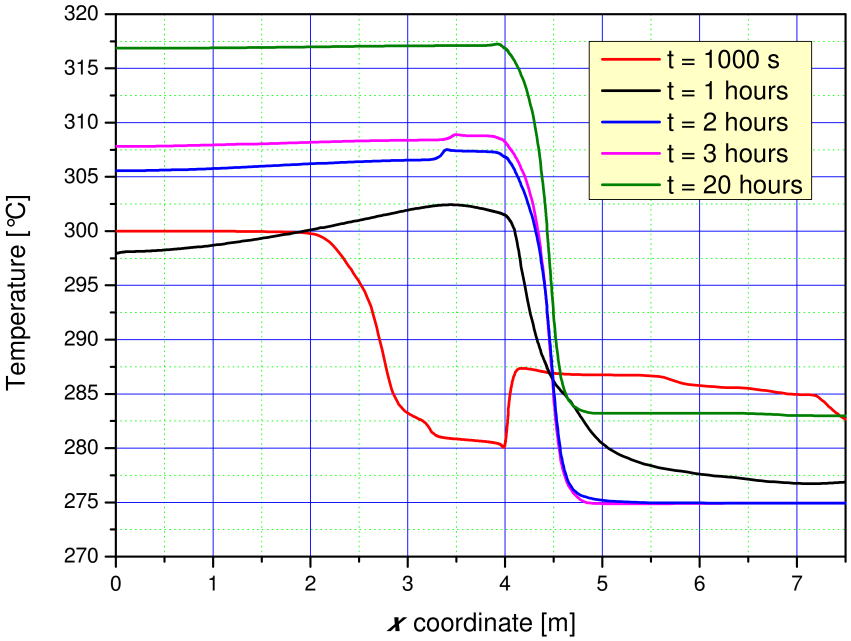

Figure 1.7: Temperature trend along the control line at y = 0.3 m inside the LBE pool region for five different simulation times.

In the DHR secondary circuit, two control lines are used to monitor the temperature trend along the *x* direction into the internal and the external pipe of the air flow path (see Figure 1.8): the first line matches the axis of the domain, while the second line is placed in the middle of the external annular pipe (at *y* = 0.04455 m) where the air flows upward. Air temperature increases along the air flow path, especially in the external annular pipe because of heat received from LBE.

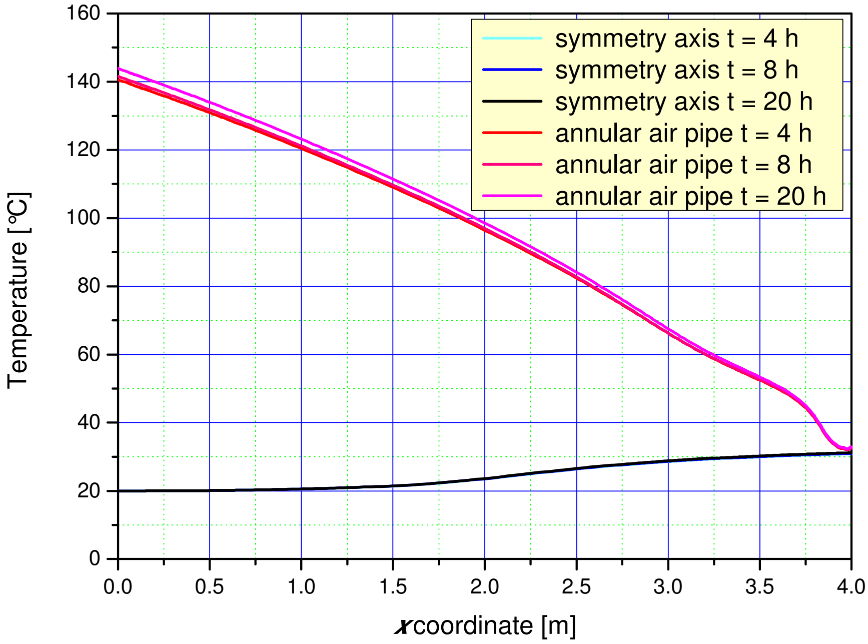

Figure 1.8: Air temperature distribution along two vertical control lines (*y* = 0 m and *y* = 0.04455 m) after 4, 8 and 20 hours.

The time trend of the thermal power removed by the DHR is reported in Figure 1.9. For steady state condition the DHR must be able to remove the 40 kW produced by the HS and representing the heat decay; Figure 1.9 shows how suddenly the DHR reacts to its activation, after 2 hours it is able to remove about the 92% of the total power supplied by the HS. At *t* = 20 h the removed thermal power is about 39 kW, i.e. the 97.5 % of the heating power.

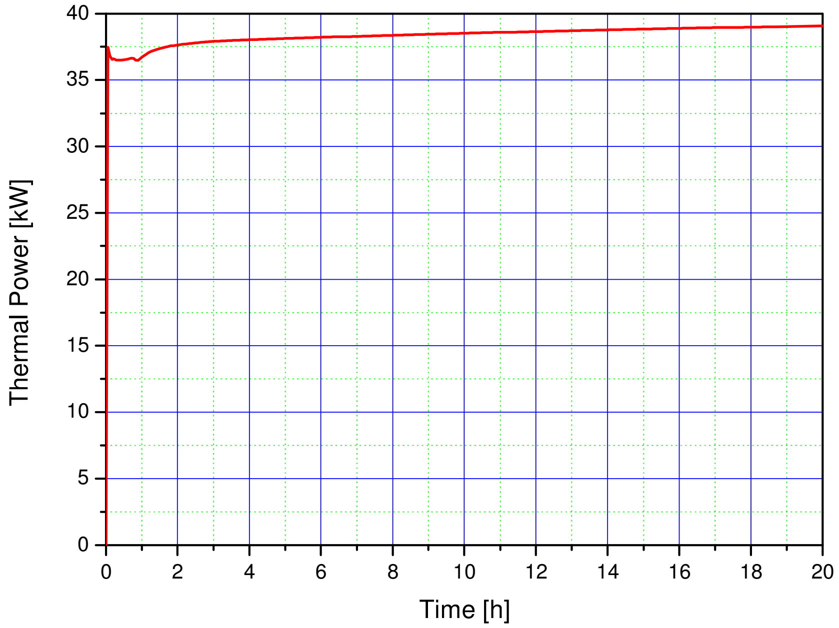

Figure 1.9: Thermal power removed by the DHR as function of time.

Figure 1.10 shows the time trends of the LBE temperature at the inlet section of the HS and at the outlet section of the HX: after 20 hours the LBE temperature difference assumes a value of about 34°C; this value is a result of the heat power imposed at the HS and of the heat removed by the DHR.

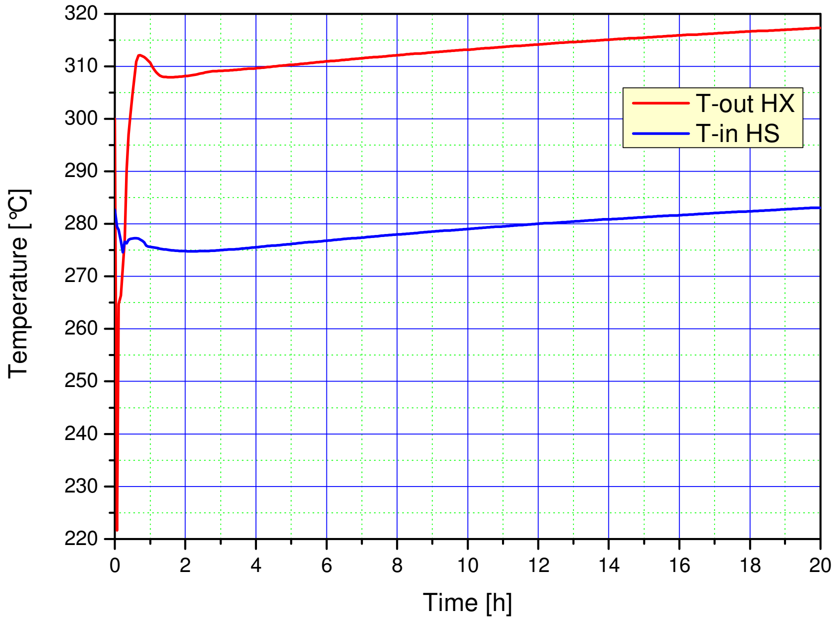

Figure 1.10: Temperature time trends at the outlet section of the HX and at the inlet section of the HS.

Figure 1.11 shows the temperature time trend of points located respectively at the center of the outlet section and at the center of inlet section of the DHR LBE cooling channel. At *t* = 20 h, the difference in temperature is about 30°C. This difference is lower than what was found in Figure 1.10, because the temperature in the inlet section of the LBE cooling channel is monitored a few centimeters below the entrance.

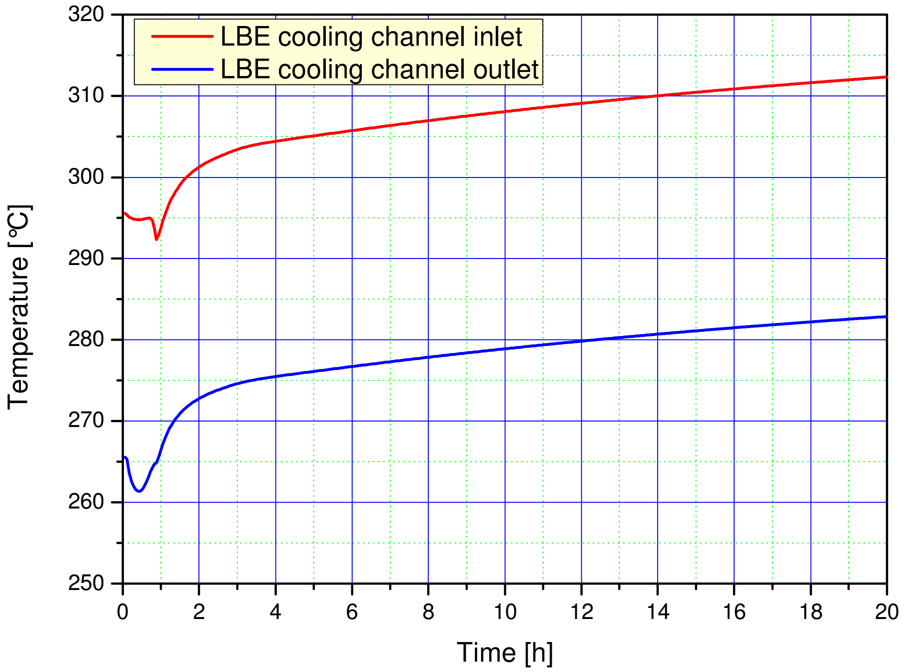

Figure 1.11: Temperature time trend of points at the LBE cooling channel inlet and outlet.

Two points were used to monitor the temperature time trend of LBE in the upper and lower plenum regions (see Figure 1.12). The hot LBE mass entering the domain influences the temperature trend of the whole pool increasing the average temperature both in the upper and lower zone; it is clear from Figure 1.12 that steady state conditions have not yet been reached after the simulated 20 hours.

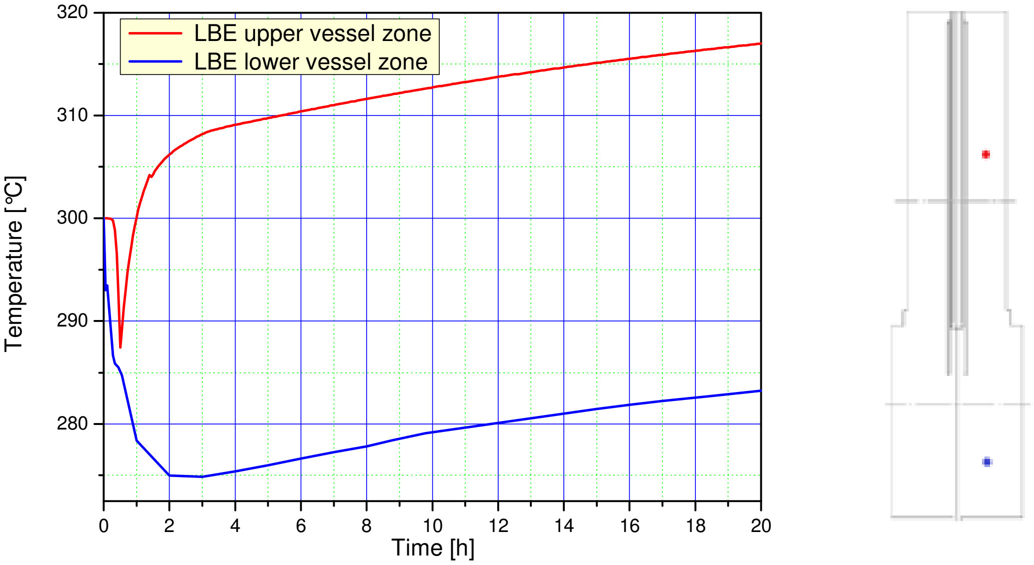

Figure 1.12: LBE temperature time trend evaluated in points
placed in the LBE upper and lower vessel zone.

In Figure 1.13 the flow path of the LBE exiting the HX section is visualized. At *t* = 0 when the main heat exchanger is still working and the DHR has not yet been activated, the LBE leaves the HX cooled and flows down due to its higher density. When the HX is stopped, the LBE exits at a temperature higher than the LBE pool temperature and rises the upper zone of the vessel reaching the entrance of the DHR brushing the external wall of the HX. After the first hour the path lines tend to move toward the external wall of the DHR while rising to its entrance (see Figure 1.13).

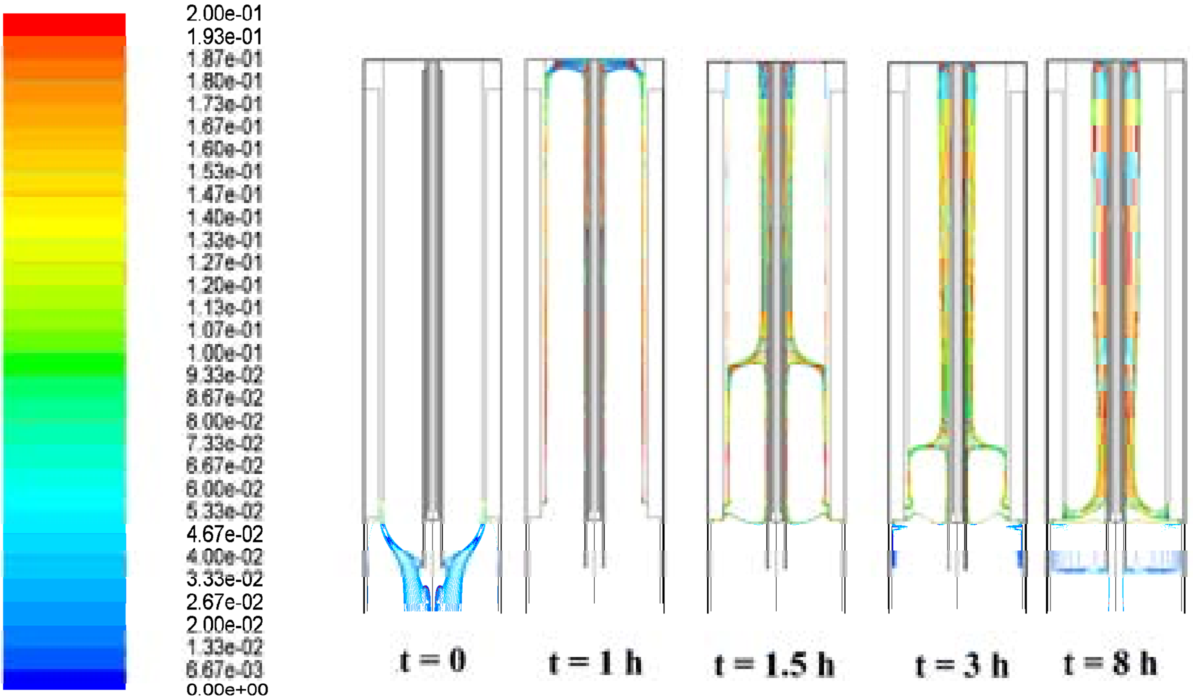

Figure 1.13: Path lines coloured by velocity magnitude [m/s].

In Figure 1.14 an enlargement of the DHR entrance region is shown. At *t* = 1 h, not all the LBE moved up enters into the DHR cooling annular channel, but a certain amount of LBE decreases in temperature due to mixing with the LBE in the upper vessel zone at a lower temperature. It therefore, increases in density and flows downward to the lower vessel zone brushing the outer wall of the DHR. This behaviour seems to move downward as the LBE temperature in the upper vessel zone became more homogeneous and when thermal stratification became more clearly marked. After 3 hours of transient all the LBE moved up enters in the DHR system. As regarding the LBE domain, the maximum in the velocity magnitude is about 0.25 m/s in the proximity of the LBE inlet (see 1.14).

Looking at the HX exit region, not all the LBE that exits the HX moves towards the DHR but a small amount seems to mix with the LBE at a lower temperature near the HX exit and then is dragged downwards and cooled by the LBE plume that exits the DHR (see Figure 1.15).

Finally, in Figure 1.16 the contour of velocity magnitude in the region between the elevation of the HX exit section and the exit from the DHR is shown. This put in evidence that the two stratified regions with different temperatures (see Figure 1.5) are separated by a transition zone where the velocity magnitude is practically zero. Inside this transition region, that has a height of about 0.5 m, the heat is exchanged mainly by heat conduction.

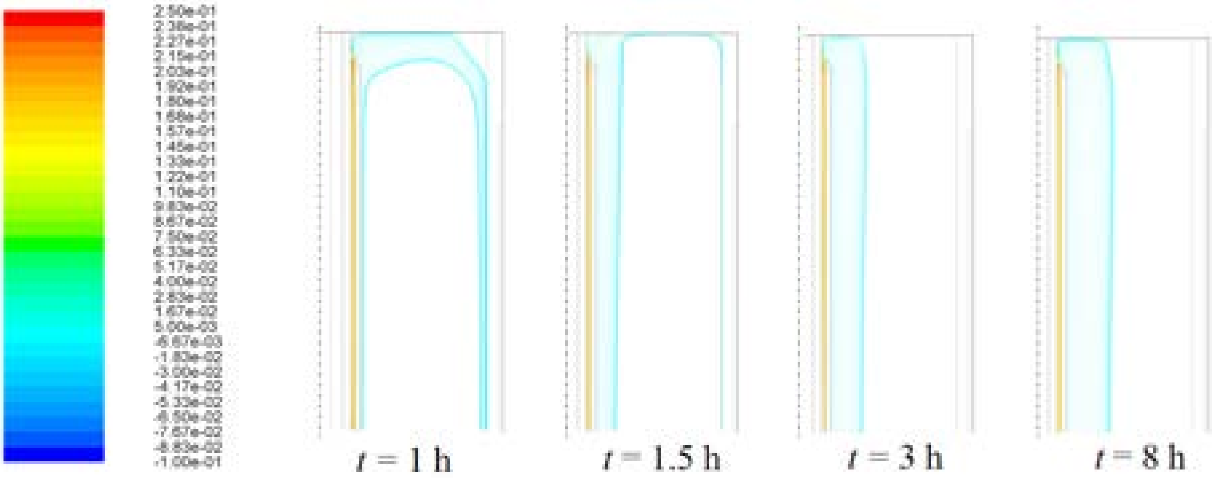

Figure 1.14: Path lines coloured by axial velocity [m/s] (enlargements at the DHR entrance).

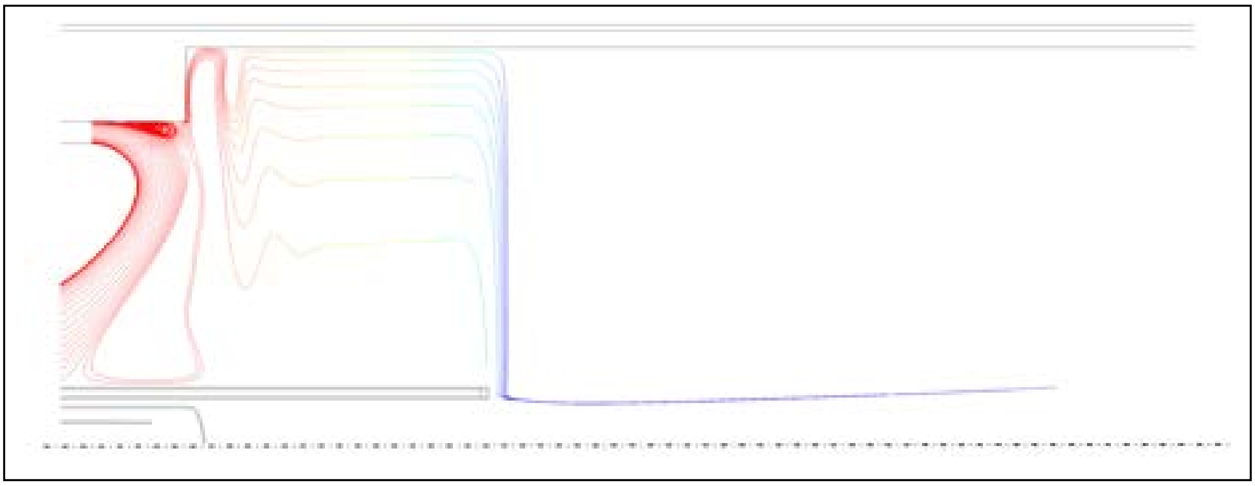

Figure 1.15: Path lines enlargements at the exit of the HX at *t* = 20 h.

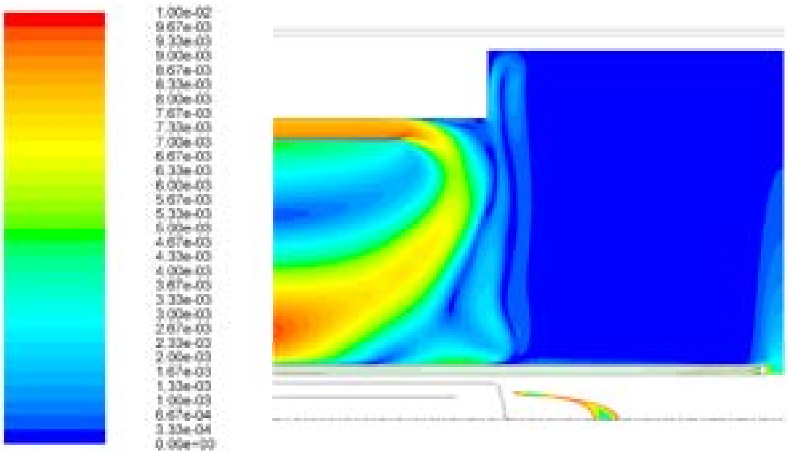

Figure 1.16: Contour plot of velocity magnitude [m/s].

3 Conclusions

The aim of this work is to give useful information about the phenomena of natural circulation and thermal stratification foreseen in the ICE test section equipped with DHR HX in a heavy liquid metal pool configuration.

The analysis was performed developing a one way off-line coupled model between the RELAP5 system code and the CFD Fluent code. In particular, codes run separately and the boundary conditions implemented in the Fluent code, as the HX removed power and the LBE flow rate at the entrance of the HS, were calculated by a previous RELAP5 stand alone simulation. A simplified 2D axial-symmetric domain was implemented in order to reproduce the test section, adopting the RNG (Renormalized group) *k-ε* model to take into account turbulence phenomena inside both air and LBE fluids and neglecting the heat losses through the external walls.

Even if complete steady-state conditions were not yet completely reached after 20 hours of transient analysis, the obtained results gave significant information about mixed convection and thermal stratification in heavy liquid metal cooled by lead-bismuth alloy. LBE temperature contours show thermal stratification phenomena in the entire pool: the upper region is characterized by a uniform temperature of about 316°C while the lower region temperature is about 283°C. The lead-bismuth eutectic moves upwards and enters the cooling channel where it exchanges heat with air, decreasing in its temperature and increasing density. The LBE is hence driven downwards by gravity at the end of the DHR annular channel.

At the end of the analyzed transient (20 h) the LBE mass flow rate in the annulus between outer DHR pipe and the thermal insulator gap is about 7.5 kg/s (~94% of the total LBE mass flow rate imposed at the HS inlet section), with a thermal power value removed by the DHR of about 39 kW, i.e. about the 97.5% of the total thermal power supplied by the HS.

As already mentioned, the numerical results obtained in this work are based on simplified assumptions and they may be affected by inaccuracies connected to the three-dimensional effects and to the heat exchanged with the external environment. The weight of these simplifications will be evaluated comparing the numerical results with the future experimental data and, eventually, will be taken into account for improving the model in post-test analysis.

Future work is planned to develop a two-way coupling model between the RELAP5 system code and the Fluent CFD code of the ICE-DHR configuration, in order to better reproduce the analyzed accidental scenario and apply this new model for post-test analysis.

Reference

[1] Generation IV International Forum, “*A Technology Roadmap for Generation IV Nuclear Energy Systems*”, Report GIF-002-00 (2002).

[2] O. Watanabe, Y. Motomiya, H. Takeda, T. Koga "*An application of higher order finite difference method to a natural convection experiment in the hot plenum of an LMFBR*", *Nuclear Engineering and Design*, Vol 146, pp. 25-34, 1994.

[3] T. Ishitori, K. Ogura, K. Sato, I. Oshima, H. Nei, M. Uotani, T. Fukada, T. Akimoto "*Experimental study of sodium natural convection heat transfer in the intermediate plenum for pool-type LMFBRs*", *Nuclear Engineering and Design*, Vol 99, pp. 431-440, 1987.

[4] G. Bandini, P. Meloni, M. Polidori, P. Gaggini, M. Tarantino, and A. Ciampichetti "*Analysis of integral circulation and decay heat removal experiment in the Lead-Bismuth Circe Facility with Relap5*", Nureth14, Toronto, Canada, September 2011.

[5] G. Bandini, I. Di Piazza, P. Gaggini, A. Del Nevo, M. Tarantino "*CIRCE Experimental set-up design and test matrix definition*", ENEA Brasimone research Center, Internal report, 2011.

[6] N. Forgione, M. De Rosa, D. Martelli, G. Bandini, M. Tarantino "*Thermal-Hydraulic pre-test analysis of ICE test section with DHR system*", XXX UIT Heat Transfer Conference, Bologna Italy, June 25-27, 2012

[7] N. Forgione, M. De Rosa, D. Martelli, F. Oriolo "*Thermal-Hydraulic pre-test analysis of ICE test section with WA-DHR*", Report RdS/2011/47, Accordo di Programma Ministero dello Sviluppo Economico – ENEA, Settembre 2011.

[8] AA. VV., “*Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Material Compatibility, Thermal-hydraulics and Technologies*”, OECD/NEA, 2007

[9] Ansys Fluent 14 User’s Guide Documentation, Ansys Inc, 2011.

Nomenclature

Abbreviations and acronyms

CFD	Computational Fluid Dynamics
CIRCE	CIRCulation Experiment
ENEA	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile
DHR	Decay Heat Removal
DIMNP	Dipartimento di Ingegneria Meccanica Nucleare e della Produzione
HLM	Heavy Liquid Metal
HX	Heat eXchanger
HS	Heat Source
ICE	Integral Circulation Experiment
LBE	Lead-Bismuth Eutectic
LFR	Lead-cooled Fast Reactor
LOF	Loss Of Flow
PLOHS	Protective Loss Of Heat Source
RNG	Renormalized Group
THINS	Thermal Hydraulic of Innovative Nuclear System
UDF	User Defined Function
WA-DHR	Water Air -Decay Heat Removal

Breve CV del gruppo di lavoro

Nicola Forgione

Ricercatore in Impianti Nucleari presso il Dipartimento di Ingegneria Meccanica, Nucleare e della Produzione (DIMNP) dell’Università di Pisa dal 20 dicembre 2007. Laureato in Ingegneria Nucleare nel 1996 presso l’Università di Pisa ed in possesso del titolo di Dottore di Ricerca in Sicurezza degli Impianti Nucleari conseguito all’Università di Pisa nel 2000. La sua attività di ricerca è incentrata principalmente sulla termofluidodinamica degli impianti nucleari innovativi, con particolare riguardo ai reattori nucleari di quarta generazione. Autore di oltre 20 articoli su rivista internazionale e di numerosi articoli a conferenze internazionali.

Daniele Martelli

Ha conseguito la laurea in Ingegneria Aerospaziale presso l'Università di Pisa nel 2009. A partire dallo stesso anno ha iniziato a collaborare, attraverso la società spin-off ACTA, con il DIMNP per analisi di fluidodinamica computazionale nell’ambito dell’ingegneria nucleare. Nel biennio 2010-2011 ha usufruito di una borsa di ricerca presso il DIMNP riguardante l’analisi del comportamento termoidraulico dei sistemi di refrigerazione dei reattori nucleari refrigerati a metallo liquido. Da gennaio 2012 è inscritto al corso di dottorato in “Ingegneria Nucleare e Sicurezza Industriale” in svolgimento presso il DIMNP dell'Università di Pisa. La sua attività di ricerca è principalmente incentrata sullo studio dei fenomeni di scambio termico in regime di convezione naturale e mista per reattori nucleari refrigerati a metallo liquido pesante.