https://doi.org/10.52676/1729-7885-2023-2-49-57
УДК 621.039.587

# MODELING OF THE CORIUM AND METALS – COOLERS INTERACTION IN A CORE CATCHER OF A LIGHT WATER REACTOR

**M. K. Skakov[1], V. V. Baklanov[2], K. O. Toleubekov[2,3*], A. S. Akaev[2], M. K. Bekmuldin[2,3], A. V. Gradoboev[4]**

*[1] National Nuclear Center of the Republic of Kazakhstan, Kurchatov. Kazakhstan*
*[2] Branch "Institute of Atomic Energy" RSE NNC RK, Kurchatov. Kazakhstan*
*[3] Shakarim University, Semey, Kazakhstan*
*[4] Tomsk Polytechnic University, Tomsk, Russia*

** E-mail for contacts: toleubekov@nnc.kz*

The core catcher is one of the mandatory elements of the reactor safety system, which prevents the release of reactor core materials in a severe accident. The core catcher is steel vessel filled with sacrificial materials (SM) and forming a tank where a corium melt coming from the core is formed. The trap is a steel body filled with sacrificial materials (LM) and forming a vessel where a corium bath is formed coming from the core. The melt formed in the core catcher is cooled by heat removal to the cooling water through the shell of the steel vessel, as well as by water supplied directly to the surface of the melt after the dissolution process of the SM in corium (gravitational inversion). The delay in the water supply to the melt is associated with the features of the component structure of corium and its interaction with water (the formation of explosive hydrogen and the possibility of its detonation, as well as the threat of a steam explosion).
However, a certain amount of time is spent on the implementation of gravitational inversion, and it is desirable to start the water supply to the melt immediately at the moment when the corium enters the core catcher due to the danger of the system going beyond the permissible limits (the beginning of boiling of uranium dioxide) due to decay heat in the corium. In this regard, the authors have an idea – to use a fusible metal for additional cooling of the surface of the corium in order to organize heat removal and reduce the temperature of the corium in the period before the end of the gravitational inversion process.
The article presents the results of modeling the interaction of corium with candidate low-melting metals – coolers. The modeling was conducted using the ANSYS software package. As a result of the conducted work, the time for which each of the considered cooling metals will reach the points of phase transitions of melting and boiling is determined. The analysis of the results allowed us to draw appropriate conclusions about the possible practical implementation of the proposed method of cooling corium.

***Keywords:*** *light-water reactor, corium, severe accident, core catcher, modeling, ANSYS, unsteady calculation, hydrogen formation, steam explosion.*

## INTRODUCTION

As is known, the formation of corium occurs during the development of a severe accident at a nuclear power plant with the melting of the core. The core catcher is one of the main barriers preventing the release of corium into the environment. The mail goal of a core catcher is to accept and cool corium in localization volumes as soon as possible in order to prevent its heating, release of non-volatile fission products and prevent the formation of repeated criticality [1].

Currently, there are several options of a core catcher design [2], among which the most well-known are the so-called "crucible" versions of a core catcher for trapping molten materials from the core [3].

The crucible core catcher is steel forming a tank where a corium melt coming from the core is formed. The melt formed in the core catcher is cooled by heat removal to the cooling water through the shell of the steel vessel, as well as by water supplied directly to the surface of the melt after the dissolution process of the gravitational inversion.

The gravitational inversion is a feature of the crucible core catcher used due to corium, according to some data, is system of two immiscible liquid phases – oxide and metal [4]. Due to the density difference between the two systems, the metal part of the corium is above the oxide part. This means that water is supplied directly to the metal part of corium. In that regard, it can be supposed that with the active interaction of water with the metal part of the corium, there is a possibility of the formation of a critical concentration of hydrogen and its detonation in the end. This means that the conditions of hydrogen safety and integrity of the containment cannot be reached.

Additional difficulties are created by the fact that, according to some scenarios, the output of corium from the reactor vessel is carried out not in a single mass, but in portions for some time [5]. In this regard, it is assumed that when water for cooling the corium is supplied immediately after the first portion of the corium enters the trap, this leads to the fact that at outflowing of the second portion of the corium (approximately 0.5–1 hour after the outflow of the first portion), a water pool is formed on the surface of the melt. In this case, when a high-energy melt falls into a container filled with water, there is a possibility of a steam explosion, as a result of which not only the device for trapping the molten materials of the core, but also the concrete burden with a sealed zone can be destroyed [6].

The main element of the concept of gravitational inversion is sacrificial materials. Sacrificial materials are used to dilute the heat-generating oxide part of the corium in order to create conditions for the gravitational inversion of parts of the corium and reduce its high temperature [7]. The experiments showed that the mutual dissolution of the sacrificial material and the melt occurs at a rate sufficient to implement the inversion of the oxide and metal layers in <1 h [8]. Thus, the possibility of implementing the concept of gravitational inversion was experimentally confirmed, and after its implementation, water is supplied to the melt to cool it [9]. After the inversion of the corium components, water is supplied to the surface of the melt bath.

The operability of the described concept has been confirmed by various numerical and experimental studies, however, its implementation takes a certain amount of time. Thus, during the melt is localized in the core catcher, there is a small period of time when the cooling of the corium surface is not organized. In this regard, there is a possibility that the system will go beyond the permissible limits (the beginning of boiling of uranium dioxide) due to decay heat in corium [10].

On the basis of the foregoing, methods of melt cooling become very relevant, excluding the direct supply of water to the surface during the period of portioned release of the corium and until the completion of the gravitational inversion of the corium parts. In this regard, the idea is proposed – to use a non-water cooler until the end of the gravitational inversion process to organize additional cooling of the corium surface in order to increase the efficiency of corium localization during a severe accident.

In the article [11], the authors propose to consider low-melting metals as a non-water cooler (*in the following text as metals-coolers*) during the period when water does not enter the surface of the corium. At the end of the process of dissolution of sacrificial materials in corium and the completion of the gravitational inversion process, complete evaporation of the cooling metal – cooler is assumed. In this regard, there will be no reactions of metals – coolers and water vapors with the formation of hydrogen in the core catcher. The choice of metals is primarily due to their thermophysical properties. It's necessary to conduct computational-theoretical justification for confirmation the operability of the proposed concept of corium cooling.

Thus, in this article, in order to estimate the implementation of the proposed concept of corium cooling, the interaction of corium with selected metals-coolers is considered by computer modeling.

## OBJECT STATEMENT OF COMPUTER MODELING

The objective of this work is the time determination during which metal – cooler reaches the points of phase conversions (melting and boiling) and the nature of its interaction with corium under severe accident condition.

In [11], requirements were set for cooling metals and a literary analysis of the physicochemical properties of known metals, which theoretically can be used for cooling corium, was conducted. Table 1 shows the metals selected as cooling metals and their thermophysical properties.

The chemical activity of magnesium is significantly lower compared to other alkaline earth metals. This is due to the fact that magnesium has some chemical properties common to alkaline earth metals, but otherwise differs markedly from them. Nevertheless, magnesium remains a sufficiently active metal, so its candidacy should not be considered for use in a core catcher, however, in this paper magnesium is considered as an example and comparison with other candidate materials in terms of their thermal interaction with corium.

To achieve this goal, in this article, a situation is simulated when the reactor's vessel is melted by corium interaction and corium pours into a core catcher. Development and calculations of the thermal state of the thermophysical model were performed using the ANSYS software [12].

The scheme of the core catcher according to [13] was used as a basis of thermophysical model design and with a small change in the model which takes into account the presence of metal – cooler in the vessel of the core catcher. The computer model considers only thermo-physical interaction between its elements. According to the reference, the mass of outcoming corium from reactor vessel is roughly 200 tons, which occupies about 27 $m^3$ of the core catcher volume. At the same time, the total mass of sacrificial materials in the core catcher is 140 tons, which occupy approximately 25 $m^3$. The total volume of the core catcher basket is 56 $m^3$. Thus, the free volume of the core catcher is ~4 $m^3$. The amount of cooling metal used was determined based on the fact that it should not occupy more than 30% (1.2 $m^3$) of the free volume of the core catcher. In this regard, in thermo-physical models, the volumes of metal coolers are equal, and the masses differ due to different density values.

*Table 1. Thermophysical properties of candidate materials*

| Name | Density $\rho$, kg/m³ | Melt temperature $T_{melt}$, K | Boiling temperature $T_{boil}$, K | Specific heat of melting $\lambda$, kJ/mol | Specific heat of boiling L, kJ/mol |
|---|---|---|---|---|---|
| Antimony | 6691 | 904 | 1908 | 20.08 | 195.2 |
| Zinc | 7133 | 693 | 1179 | 7.28 | 114.8 |
| Manganese | 7210 | 1516 | 2234 | 13.4 | 221 |
| Magnesium | 1738 | 923 | 1363 | 9.2 | 131.8 |

A two-dimensional computational domain was chosen to modeling of heat transfer in the core catcher due to symmetry of the melt trap relative to the central axis. Figure 1 shows the computational domain of the core catcher.

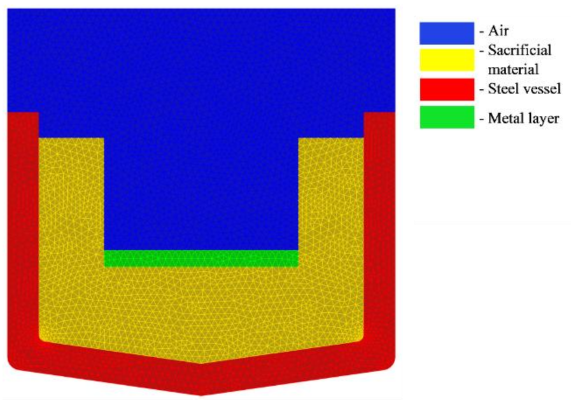


*Figure 1. The computational model of corium interaction with metals – coolers in the core catcher*

The thermophysical properties of the core catcher elements and their temperature dependence used in the calculations according to [14]. The thermophysical properties of the corium melt, such as specific heat capacity, thermal conductivity, viscosity, density according to [15–16].

## RESULTS OF COMPUTER MODELING AND THEIR DISCUSSION

Figure 2 shows the change in the calculated maximum and minimum temperature of the zinc volume the core catcher. Observation of the boundary values of temperatures allows us to estimate time intervals of phase transition of zinc during its interaction with corium in the core catcher.

The graph shows that melting process of zinc start almost instantly after beginning of its interaction with corium and start approximately in ~0.25 s. At the same time, the zinc melting process in the core catcher will occur in parallel its boiling process since according the graph, the start of zinc boiling process is recorded at ~0.75 s. The time of complete zinc melting is estimated at ~1.6 s.

The computer modeling of corium interaction with manganese, antimony and magnesium was conducted in the similar way. Figure 3 shows the change in the calculated maximum and minimum temperature of the antimony volume in the core catcher.

According the graph, the time of complete melting of antimony in the core catcher is estimated at ~3.4 s. As with zinc, the melting of antimony will occur in parallel with its boiling process (antimony will reach the point of boiling in ~1.6 s). However, according the calculation, there are some doubts about the complete boiling of antimony from the core catcher due to sufficiently high boiling point ($T_{boil}$ = 1908 K).

Figure 4 shows the change in the calculated maximum and minimum temperature of the manganese volume in the core catcher.

According the graph, the melting of entire volume of manganese will start in approximately ~0.6 s. The time of complete melting of manganese in the core catcher is estimated at ~5.5 s. Considering the high boiling point of manganese ($T_{boil}$ = 2234 K) and the growth rate of maximum temperature values on the graph, it's more likely that the manganese boiling process won't occur in the process of further interaction with corium in the core catcher.

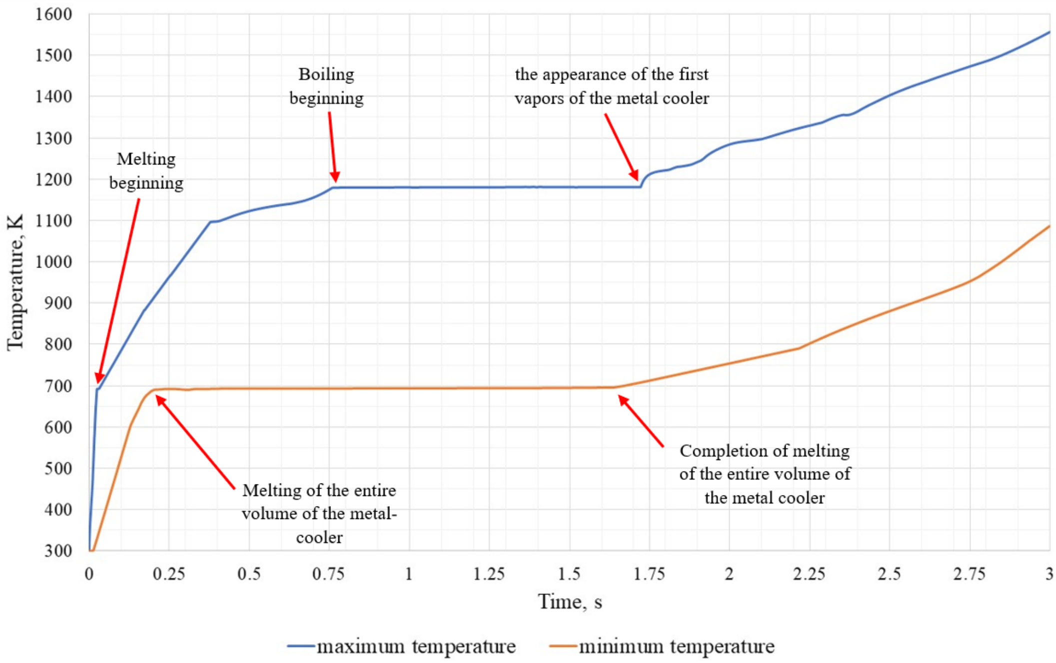


*Figure 2. The change in the calculated temperatures of zinc in the core catcher*

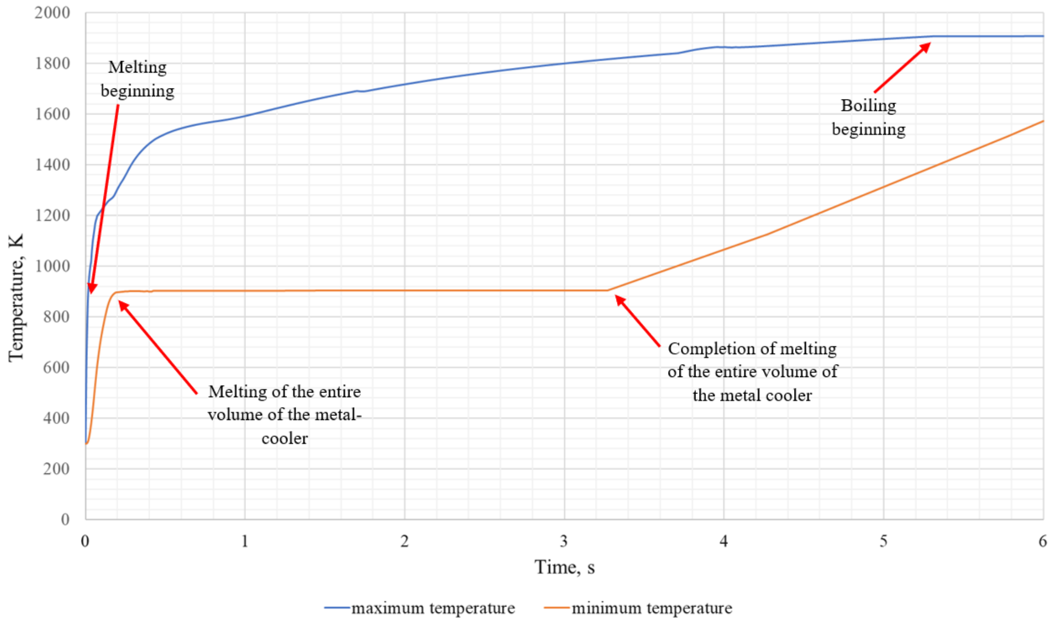


*Figure 3. The change in the calculated temperatures of antimony in the core catcher*

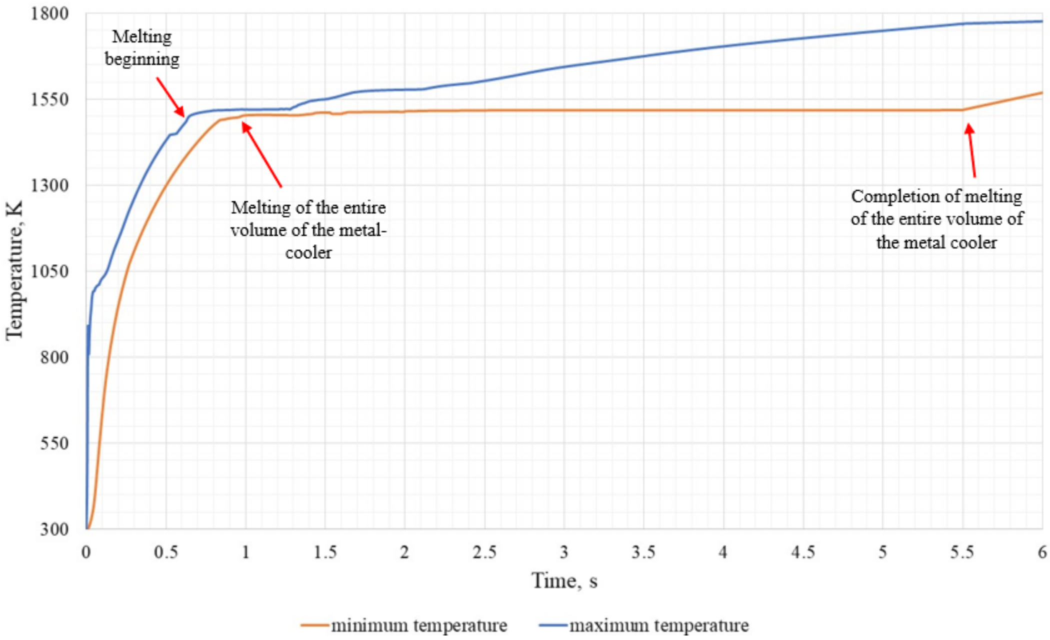


*Figure 4. The change in the calculated temperatures of manganese in the core catcher*

Figure 5 shows the change in the calculated maximum and minimum temperature of the magnesium volume in the core catcher. As we can see, the time intervals of phase transitions of magnesium in the core catcher during its interaction with corium is similar with zinc (Figure 2). At the same time, the complete melting of magnesium occurs rapidly despite the higher points of phase transitions and the energy required to complete them. This can be explained, first of all, by the higher heat-conducting properties of magnesium relative to zinc.

When comparing the diagrams of changes in the calculated temperatures, it was found that intensive heat exchange will occur during metals-coolers interaction with corium. This leads to the melting of the metal – cooler in a short period of time (the maximum time is ~5.5 s for manganese). Based on the results of computer modeling, the boiling of entire volume of zinc and magnesium isn't in dispute, however it was made following conclusion about antimony: antimony boiling is most likely to be local in certain volumes of liquid metal. It's most likely that manganese won't reach the boiling point and will be in the system as a liquid interacting with other elements of the core catcher.

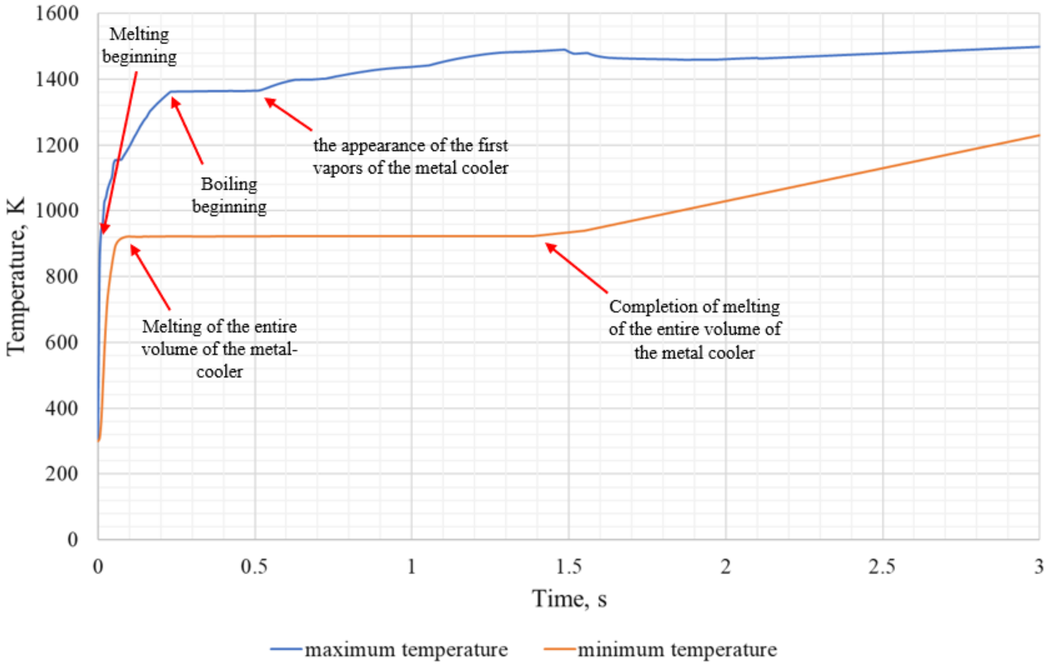


*Figure 5. The change in the calculated temperatures of magnesium in the core catcher*

Due to the rapid melting of metals – coolers, it can be supposed that they will not reach the surface of the corium melt. The metal – cooler will leave the core catcher as steam formed in the bottom part of the core catcher. Also, the average temperature of corium will decrease in the area of metals-coolers interaction with corium due to active heat exchange processes.

On first consideration, this assumption is a positive moment since the decrease of the corium temperature is one of the goals of operation of the core catcher. At the same time, a decrease of the corium temperature at the bottom part of the core catcher due to using of metals-coolers can increase the time of activation of mass exchange processes between corium and sacrificial materials and eventually harm the process of gravitational inversion.

In this regard, the case was considered when metal – cooler comes the core catcher after corium flow out from the reactor vessel. This approach will allow to organize the process of the heat removal directly on the surface of the corium melt. Zinc was considered as a metal – cooler in this calculation. A computational domain of the core catcher is two-dimensional axisymmetric model which is shown in Figure 6.

Figure 7 shows the change in the calculated maximum and minimum temperature of the zinc volume in the core catcher.

It can see from the graph that the time intervals of the phase transitions of zinc in the case under consideration are almost identical to the previous calculation with zinc (Figure 2). The melting process of zinc in the core catcher will occur in parallel its boiling process since according the graph, the start of zinc boiling process is recorded at 0.75 s. The time of complete zinc melting is estimated at ~2 s approximately. The process of boiling zinc in the trap will take longer time intervals because heat exchange processes with the core catcher's air environment (thermal conductivity, convection, radiation) are added.

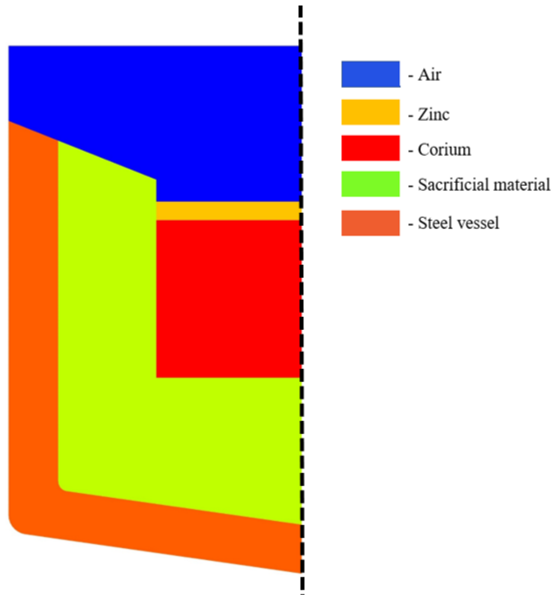


*Figure 6. The computational model of corium interaction with metals – coolers in the core catcher*

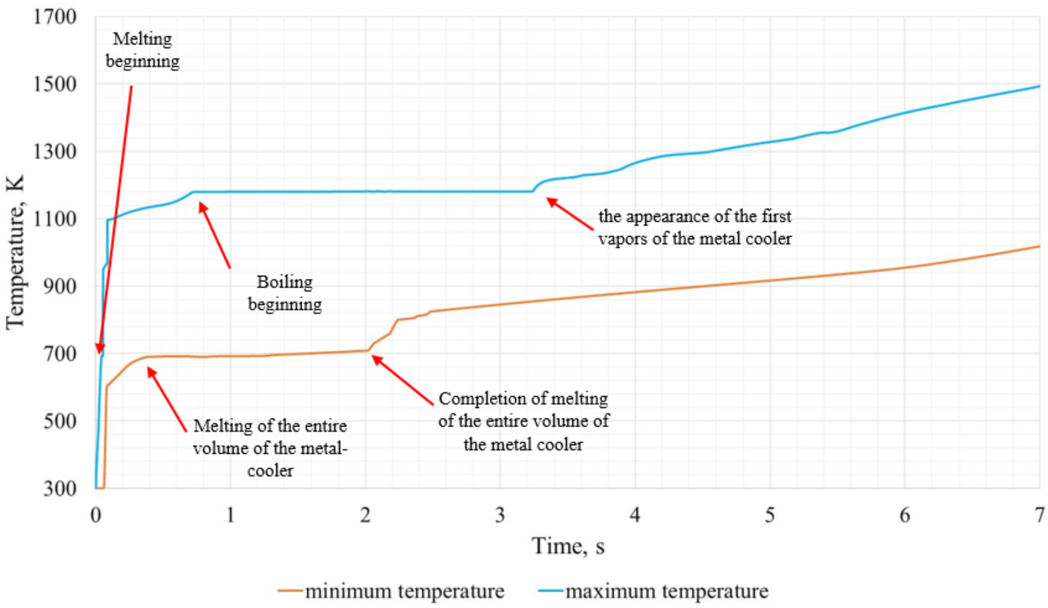


*Figure 7. The change in the calculated temperatures of zinc in the core catcher*

## CONCLUSION

The computer modeling of the interaction of corium with candidate metals – coolers in the core catcher of a light water reactor was conducted in the ANSYS FLUENT software. The modeling was conducted under the same initial conditions to compare selected candidate metals – coolers to justify their using in the core catcher in the case of a severe accident with core meltdown and corium leaving the reactor vessel.

The modeling showed that the melting of metals – coolers implement in a short period of time (the maximum time is ~5.5 s for manganese). The analysis of graphs of the change temperature of metals – coolers during time shows that the transition of zinc and magnesium into steam will occur in the entire volume while the boiling of antimony will be local in a certain volume of a liquid metal. Analysis of graphs of temperature change of metals – coolers with time shows that the transition of zinc and magnesium into steam will occur in the full volume while the boiling of antimony is likely to be local in a certain volume of liquid metal. Manganese most likely will not reach the boiling point and will be in the system in a liquid state and will enter into various chemical interactions.

Based on the modeling results, it was concluded that in the case of the proposed approach, there is a possibility that the cooling of corium on its surface will not be organized due to the melting of cooling metals in a short period of time. With this outcome of events, the case was considered when metal – cooler comes into the core catcher after corium leaving the reactor vessel. This approach will allow to organize the process of heat removal directly on the surface of the corium melt. Zinc was considered as a metal – cooler in this calculation. The results of modeling show that in the case of zinc using as metal – cooler, the time of the transition of zinc in vaporous state will occur with a sufficient speed to complete this process in the set interval of time within the framework of proposed concept.

Like magnesium, manganese and zinc can also react with water vapor to form hydrogen. At the same time, the basket with sacrificial materials is drained and completely sealed. In this regard, there are no water vapors in the trap basket until the end of the gravitational inversion process, thereby excluding the above-mentioned reactions. However, there is a possibility of water vapor entering the core catcher from the reactor vessel during its depressurization.

Considering these factors, we decided to consider in this article the thermophysical interaction of the selected materials with corium, taking into account the inert medium. These conditions will be recreated when conducting experiments with corium directly. In case of a positive conclusion regarding the proposed cooling method, it will be advisable to conduct experiments taking into account the presence of water vapor in the medium and their effect on hydrogen safety.

Thus, based on the computer modeling and analysis of the results, it can be concluded about the possible practical implementation of the proposed method of cooling corium. The next stage of work is to conduct a series of experimental studies of the interaction of corium with selected materials to study issues related to the nature of the interaction of cooling metals with corium in a severe accident with core meltdown.

## ACKNOWLEDGEMENT

*This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP14870512)*

## REFERENCES

1. Kukhtevich I.V., Bezlepkin V.V., Khabenskiy V.B., Granovskiy V.S., Asmolov V.G., Beshta S.V., Sidorov A.S., Berkovich V.M., Strizhev V.F., Khua Min' Chan, Rogov M.F., Novak V.P. Kontseptsiya lokalizatsii rasplava koriuma na vnekorpusnoy stadii zaproektnoy avarii AES s VVER-1000 // Otraslevaya konferentsiya «Voprosy bezopasnosti AES s VVER». SPb., 2000.
2. Molchanov I. A., Shumilin M. P. Uderzhanie rasplava aktivnoy zony vnutri kontaymenta pri tyazhelykh avariyakh yadernykh energoblokov // Vostochno-Evropeyskiy zhurnal peredovykh tekhnologiy. – 2011. – No. 2(8). – P. 65–67.
3. Sidorov A.S., Rogov M.F., Novak V.P., Kukhtevich I.V., Bezlepkin V.V., Khabenskiy V.B., Granovskiy V.S., Beshta S.V., Asmolov V.G. Ustroystvo lokalizatsii rasplava Tyan'van'skoy AES. Konstruktsiya i funktsionirovanie // Otraslevaya konferentsiya «Voprosy bezopasnosti AES s VVER». SPb., 2000.
4. Stolyarevskiy A.Ya. Problema uderzhaniya rasplava topliva v zashchitnoy obolochke AES s VVER // Al'ternativnaya energetika i ekologiya. – 2014. No. 6 (146). – P. 25–35.
5. Sidorov A.S., Nosenko G.E., Granovskiy V.S. i dr., Sistema zashchity zashchitnoy obolochki reaktornoy ustanovki vodo-vodyanogo tipa, Pat. RF No. 2165108, 04.10.2001, byul. No. 32.
6. Melt-Structure-Water Interactions During Severe Accident in LWRs. B.R. Sehgal et al, NPSD, Royal Institute of Technology, Annual Report, Sweden, Nov. 2000.
7. Gusarov V.V., Al'myashev V.I., Beshta S.V., Khabenskiy V.B., Udalov Yu.P., Granovskiy V.S. Zhertvennye materialy sistemy bezopasnosti atomnykh elektrostantsiy – novyy klass funktsional'nykh materialov // Teploenergetika. – 2001. – No. 9, sentyabr'. – P. 22–24.
8. Asmolov V.G. i dr. Vybor bufernogo materiala lovushki dlya uderzhaniya rasplava aktivnoy zony VVER-1000 // Atomnaya energiya. – 2002. – T. 92. – Issue 1. – P. 7–18
9. Morozov A. V., Remizov O. V. Tyazhelye avarii na AES s VVER. – 2012. – 136 p.
10. Stolyarevskiy A.Ya., Atomnye stantsii: teper' s «lovushkoy», – «Energiya», 2002. – No. 4, – P. 9–17
11. Skakov M., Toleubekov K., Baklanov V., Gradoboev A., Akayev A., & Bekmuldin M. The method of corium cooling in a core catcher of a light-water nuclear reactor. Eurasian Physical Technical Journal, 19(3(41), 2022, 69–77. https://doi.org/10.31489/2022No3/69-77.
12. ANSYS Fluent Tutorial Guide, 2016.
13. Sidorov A.S. Lokalizatsiya i ohlajdenie koriuma v zaproektnoi avarii vodo-vodyanogo energeticheskogo reaktora pri razruşenii aktivnoi zony // dissertatsiya na soiskanie uchenoi stepeni kandidata tehnicheskih nauk, Moscow, 2004 g.
14. Chirkin V.S., «Teplofizicheskie svoystva materialov yadernoy tekhniki», Moscow: ATOMIZDAT. – 1968.
15. Bechta, S.V., Granovsky, V.S., Khabensky, et al. VVER steel corrosion during in-vessel retention of corium melt. European Review Meeting on Severe Accident Research (ERMSAR Meeting), 23–25 September, 2008b, Nessebar, Bulgaria.
16. V. G. Asmolov, V. N. Zagryazkin, E. V. Astakhova, i dr. Plotnost' $UO_2$–$ZrO_2$-rasplavov, TVT, 2003. – Tom 41. – Issue 5. – P. 714–719.

## ЛИТЕРАТУРА

1. Кухтевич И.В., Безлепкин В.В., Хабенский В.Б., Грановский В.С., Асмолов В.Г., Бешта С.В., Сидоров А.С., Беркович В.М., Стрижев В.Ф., Хуа Минь Чан, Рогов М.Ф., Новак В.П. Концепция локализации расплава кориума на внекорпусной стадии запроектной аварии АЭС с ВВЭР-1000 // Отраслевая конференция «Вопросы безопасности АЭС с ВВЭР». СПб., 2000.
2. Молчанов И. А., Шумилин М. П. Удержание расплава активной зоны внутри контаймента при тяжелых авариях ядерных энергоблоков // Восточно-Европейский журнал передовых технологий. – 2011. – № 2(8). – С. 65–67.
3. Сидоров А.С., Рогов М.Ф., Новак В.П., Кухтевич И.В., Безлепкин В.В., Хабенский В.Б., Грановский В.С., Бешта С.В., Асмолов В.Г. Устройство локализации расплава Тяньваньской АЭС. Конструкция и функционирование // Отраслевая конференция «Вопросы безопасности АЭС с ВВЭР». СПб., 2000.
4. Столяревский А.Я. Проблема удержания расплава топлива в защитной оболочке АЭС с ВВЭР // Альтернативная энергетика и экология. № 6 (146). 2014, с. 25–35.
5. Сидоров А.С., Носенко Г.Е., Грановский В.С. и др., Система защиты защитной оболочки реакторной установки водо-водяного типа, Пат. РФ № 2165108, 04.10.2001, бюл. № 32.
6. Melt-Structure-Water Interactions During Severe Accident in LWRs. B.R. Sehgal et al, NPSD, Royal Institute of Technology, Annual Report, Sweden, Nov. 2000.
7. Гусаров В.В., Альмяшев В.И., Бешта С.В., Хабенский В.Б., Удалов Ю.П., Грановский В.С. Жертвенные материалы системы безопасности атомных электростанций – новый класс функциональных материалов // Теплоэнергетика. 2001. №9, сентябрь. С. 22–24.
8. Асмолов В.Г. и др. Выбор буферного материала ловушки для удержания расплава активной зоны ВВЭР-1000 // Атомная энергия. 2002. Т. 92. Вып. 1. С. 7–18
9. Морозов А. В., Ремизов О. В. Тяжелые аварии на АЭС с ВВЭР. – 2012. – 136 с.
10. Столяревский А.Я., Атомные станции: теперь с «ловушкой», – «Энергия», 2002, № 4, с. 9–17
11. Skakov M., Toleubekov K., Baklanov V., Gradoboev A., Akayev A., & Bekmuldin M. The method of corium cooling in a core catcher of a light-water nuclear reactor. Eurasian Physical Technical Journal, 19(3(41), 2022, 69–77. https://doi.org/10.31489/2022No3/69-77
12. ANSYS Fluent Tutorial Guide, 2016.
13. Сидоров А.С. Локализация и охлаждение кориума в запроектной аварии водо-водяного энергетического реактора при разрушении активной зоны // дисс. на соискание уч. ст. к.т.н., Москва, 2004 г.
14. Чиркин В.С., «Теплофизические свойства материалов ядерной техники», М.: АТОМИЗДАТ. – 1968.
15. Bechta, S.V., Granovsky, V.S., Khabensky, et al. VVER steel corrosion during in-vessel retention of corium melt // European Review Meeting on Severe Accident Research (ERMSAR Meeting), 23–25 September, 2008b, Nessebar, Bulgaria.
16. В. Г. Асмолов, В. Н. Загрязкин, Е. В. Астахова, и др. Плотность $UO_2$–$ZrO_2$-расплавов // ТВТ, 2003, том 41, выпуск 5, 714–719.

## ЖЕҢІЛ СУ РЕАКТОРЫНЫҢ БАЛҚУ ТҰЗАҒЫНДАҒЫ КАНДИДАТТЫҚ МЕТАЛЛ САЛҚЫНДАТҚЫШ МАТЕРИАЛДАРМЕН КОРИУМНЫҢ ӨЗАРА ӘРЕКЕТТЕСУІН МОДЕЛЬДЕУ

**М. К. Скаков[1], В. В. Бакланов[2], К. О. Толеубеков[2,3*], А. С. Акаев[2], М. К. Бекмулдин[2,3], А. В. Градобоев[4]**

*[1] Қазақстан Республикасының Ұлттық ядролық орталығы, Курчатов, Қазақстан*
*[2] ҚР ҰЯО РМК «Атом энергиясы институты» филиалы, Курчатов, Қазақстан*
*[3] Шәкәрім атындағы Семей мемлекеттік университеті, Қазақстан*
*[4] Томск политехникалық университеті, Томск, Ресей*

* *Байланыс үшін E-mail: toleubekov@nnc.kz*

Ауыр апат кезінде реактордың өзегі материалдарының шығуына жол бермейтін реактордың қауіпсіздік жүйесінің міндетті элементтерінің бірі – балқыма тұзағы, ол құрбандық материалдарымен (ҚМ) толытырылған болат корпус және белсенді аймақтан келетін кориум ваннасы пайда болатын ыдысты құрайды. Тұзақта пайда болған балқытылған ваннаны салқындату болат корпустың қабығы арқылы салқындатқыш суға жылуды, сондай-ақ кориумда (гравитациялық инверсия) ҚМ еріту процесі аяқталғаннан кейін балқыманың бетіне тікелей берілетін суды бұру арқылы жүзеге асырылады. Балқымаға су берудің кешігуі кориумның компоненттік құрамының ерекшеліктерімен және оның сумен өзара әрекеттесуімен байланысты (жарылғыш сутектің пайда болуы және оның жарылу мүмкіндігі, сондай-ақ будың жарылу қаупі).
Алайда, гравитациялық инверсияны жүзеге асыруға біраз уақыт жұмсалады, ал кориумдағы қалдық жылу шығарудың арқасында жүйенің рұқсат етілген шектерден (уран диоксидінің қайнауының басталуы) шығу қаупіне байланысты кориум тұзаққа түскен кезде балқымаға су беруді бірден бастаған жөн. Осыған байланысты авторлар гравитациялық инверсия процесі аяқталғанға дейінгі кезеңде үздіксіз жылу жинауды ұйымдастыру және кориум температурасын төмендету мақсатында кориум бетін қосымша салқындату үшін жеңіл балқитын металды пайдалану идеясын дамытты.
Ұсынылған мақалада кориумның кандидаттық жеңіл балқитын металдармен – салқындатқыштармен өзара әрекеттесуін модельдеу нәтижелері келтірілген. Модельдеу ANSYS бағдарламалық кешенінің көмегімен жүзеге асырылды. Жүргізілген жұмыстың нәтижесінде қарастырылып отырған салқындатқыш металдардың әрқайсысы балқу мен қайнаудың фазалық ауысу нүктелеріне жететін уақыт анықталды. Нәтижелерді талдау кориумды салқындатудың ұсынылған әдісін практикалық іске асыру туралы тиісті қорытынды жасауға мүмкіндік берді.

***Түйін сөздер**: жеңіл су ректоры, кориум, ауып апат, балқыма тұзағы, моделдеу, ANSYS, стационарлық емес есептеу, сутектің пайда болуы, бу жарылысы.*

## МОДЕЛИРОВАНИЕ ВЗАИМОДЕЙСТВИЯ КОРИУМА С КАНДИДАТНЫМИ МЕТАЛЛИЧЕСКИМИ МАТЕРИАЛАМИ –- ОХЛАДИТЕЛЯМИ В ЛОВУШКЕ РАСПЛАВА ЛЕГКОВОДНОГО РЕАКТОРА

**М. К. Скаков[1], В. В. Бакланов[2], К. О. Толеубеков[2,3*], А. С. Акаев[2], М. К. Бекмулдин[2,3], А. В. Градобоев[4]**

*[1] Национальный ядерный центр Республики Казахстан, Курчатов, Казахстан*
*[2] Филиал «Институт атомной энергии» РГП НЯЦ РК, Курчатов, Казахстан*
*[3] Университет имени Шакарима, Семей, Казахстан*
*[4] Томский политехнический университет, Томск, Россия*

* *E-mail для контактов: toleubekov@nnc.kz*

Одним из обязательных элементов системы безопасности реактора, предотвращающей выход материалов активной зоны реактора при тяжелой аварии, является ловушка расплава, которая представляет собой стальной корпус, заполненный жертвенными материалами (ЖМ), и образующий сосуд, где формируется ванна кориума, поступающая из активной зоны. Охлаждение образующейся в ловушке ванны расплава происходит отводом тепла к охлаждающей воде через оболочку стального корпуса, а также водой, подаваемой непосредственно на поверхность расплава после завершения процесса растворения ЖМ в кориуме (гравитационная инверсия). Задержка подачи воды на расплав связана с особенностями компонентного состава кориума и его взаимодействием с водой (образование взрывоопасного водорода и возможность его детонации, а также угроза парового взрыва).
Однако на осуществление гравитационной инверсии затрачивается некоторое количество времени, а подачу воды на расплав желательно начинать сразу в момент выхода кориума в ловушку ввиду опасности выхода системы за допустимые пределы (начало кипения диоксида урана) благодаря остаточным тепловыделениям в кориуме. В связи с этим у авторов возникла идея – использовать легкоплавкий металл для дополнительного охлаждения

поверхности кориума с целью организации непрерывного теплосъема и уменьшения температуры кориума в период до окончания процесса гравитационной инверсии.
В представленной статье приведены результаты моделирования взаимодействия кориума с кандидатными легкоплавкими металлами – охладителями. Моделирование осуществлялось с помощью программного комплекса ANSYS. В результате проведенной работы определено время, за которое каждый из рассматриваемых металлов – охладителей достигнет точек фазовых переходов плавления и кипения. Анализ результатов позволил сделать соответствующие выводы об возможной практической реализации предложенного способа охлаждения кориума.

***Ключевые слова***: *легководный реактор, кориум, тяжелая авария, ловушка расплава, моделирование, ANSYS, нестационарный расчет, образование водорода, паровой взрыв.*