The influence of the accuracy of the calculation of residual energy release on corium catcher justification during BDBA

F D Bondar, N V Artamonov and A S Sidorov
JSC Atomenergoproekt, Moscow
E-mail: Bondar_FD@aep.ru, Artamonov_NV@aep.ru, Sidorov_AS@aep.ru

Abstract. To ensure the performance and safety of the corium catcher necessary to carry out a series of calculations including thermal calculation, which uses the residual energy release as results of neutron-physical calculation. This paper examines the impact of the accuracy of the calculation of the residual energy release in the neutron-physical calculation on the results of thermal calculation.

1. Introduction
In NPP designs with VVER are available management of severe beyond design basis accidents (BDBA), i.e. accidents with core melt. In the course of BDBA melted structural elements of reactor constructions and core are moved to the bottom of the reactor pressure vessel (RPV), which leads to the formation at the bottom of the RPV high-temperature corium, which heats the RPV, melt it down and fall into the corium catcher (CC) - special technical means for management of BDBA.

CC is designed to improve the safety of unit in the course of severe BDBA with the destruction of the core and the release of the melt outside the RPV. Improved safety is achieved by eliminating liquid and solid radioactive materials outside of the CC, which is achieved due to the presence in CC special sacrificial material (SM), which partially absorbs the heat of the corium, and binds it chemically active components.

To confirm the performance of CC there are design and analytical justification, one of which is the thermal calculation. The initial data are results of neutron-physical calculation (NPC), which are designed to provide residual energy release. But since NPC has its own accuracy depending on the adopted models, it is necessary to determine the accuracy impact of NPC on the thermal calculation. This is the purpose of this paper.

2. Design description
CC is located directly under the bottom of the RPV and is a structure with a total mass of about 750 tons. The CC model with its main elements is shown in figure 1.
3. Calculation of residual energy release

One of the sources of heat in the corium is the energy deposition from the radioactive decay of the fission products of uranium and plutonium. As a result of prolonged operation of the reactor composed of uranium-gadolinium fuel is accumulated, a new and actively fissile heavy isotopes, such as long-lived $^{243}$Cm atoms, the atoms of $^{241}$Pu and $^{233}$U, $^{239}$Pu, $^{244}$Cm, which in practice can be considered stable. The largest contribution to the value of the residual energy release make the following radionuclides: $^{106}$Rh, $^{144}$Pr, $^{134}$Cs, $^{90}$Y, $^{137m}$Ba, $^{137}$Cs, $^{90}$Sr, $^{144}$Ce, $^{154}$Pm, $^{154}$Eu, $^{85}$Kr, $^{244}$Cm, $^{238}$Pu and $^{241}$Am. To calculate their savings it was used the software package CONCORD [1]. This software package is intended for carrying out two-dimensional cell multigroup calculations of nuclear reactors and the evolution of their physical characteristics, associated with changing nuclide composition of the fuel during its burnup. Currently, the calculation of the kinetics of isotopes, including the value of the residual energy release in the package CONCORD is the software module CRYSTAL (Code Calculating the Isotopic composition of FA).

Module CRYSTAL can be used for the calculation of both thermal and fast reactors. The main objectives of the module are the following:

- non-stationary calculation of the isotopic composition of FA on the stage of criticality of the reactor, based on the well-known field of neutron density;
- non-stationary calculation of fission decayed neutron source in the fuel rods (TVEL, TVEG) at the stage of criticality of the reactor;
- non-stationary calculation of the isotopic composition and residual energy release of spent FA;
- non-stationary calculation of the sources of neutron and gamma radiation of spent FA.

To calculate the kinetics of isotope fuel in the module KRISTALL, uses a standard chain U-Np-Pu-
Am-Cm from 50 varieties of atoms relating to uranium the type shown in figure 2. To calculate the longer (heavy) actinides to the specified chain may be added to the isotopes of Bk, Cf, Fm, this circuit is shown in figure 3.

![Standard U-Cm chain of 50 isotopes and isomers](image1)

**Figure 2.** Standard transformations of the radionuclides U-Np-Pu-Am-Cm.

![Actinide kinetics](image2)

**Actinide kinetics**

*If necessary, a long Th–Fm chain can be set. In total, ~100 isotopes and isomers.*

![Extended transformations of radionuclides](image3)

**Figure 3.** Extended transformations of radionuclides.

Under this program, were obtained the value of residual energy release in core corium of pressurized water reactors under pressure, equal of 12.81 MW. It's assumed, that the minimum error of the results of neutron-physical calculations is 5%, this error is due to the error in the estimated nuclear data [2]. It's assumed the change in the value of the residual energy of ±5% from the base value equal
of 12.81 MW. It should be noted that performed in the work [3] studies have shown that the majority of modern specialized calculation programs "understate" the concentrations of younger actinides (Np, Am, Cm) 20...30 %.

4. The computational domain and mesh
The calculation was computed using programm package STAR-CCM+[4]. For the calculation was chosen three-dimensional computational domain, simulating a equipment of CC, a interior space of CC, a molten corium bath, a protective slag layer, the bottom of the RPV. The computational domain is shown in figure 4.

Figure 4. Computational domain.

On the basis of the geometry of the computational domain mesh is constructed, including about 1.4 million cells. The mesh is shown in figure 5.
a) section of a volume mesh

b) view A (enlarged)
5. Calculation options
In all variants of calculation heat to the computational domain is supplied due to residual energy release in the corium in the lower part of CC casing and is discharged through the casing, membrane, ferm-console.

In the CC inner space, filled water vapor, implementing processes [5] of radiant heat exchange and heat conductivity. As a model of radiative heat transfer the DOM (Discrete Ordinate Method) model is accepted, in which water vapor is involved in the heat exchange process, i.e. there is the heat
absorption in it. Convection in the environment is not considered, so water vapor is modeled solid transparent body.

In all other simulated regions: the metal constructions, corium, protective slag layer – it takes into account only the thermal conductivity of the materials.

According to the results of NPC were obtained the following results:

- the residual energy release of 12.17 MW;
- the residual energy release of 12.81 MW;
- the residual energy release of 13.45 MW.

6. The results of the calculation

The temperature fields in CC were obtained at different values of the residual energy. Temperature fields are shown in figure 6.

- a) the residual energy release is 12.17 MW;
- b) the residual energy release is 12.81 MW;
- c) the residual energy release is 13.45 MW;

Figure 6. Temperature fields.
By results of calculations under different energy release, the structure of the temperature fields is similar, the maximum temperature in the corium bath reaches 1941 °C, 1956 °C, 2009 °C respectively.

The temperature difference when comparing the options a) and b) (figure 4) is not greater than 21 °C, when compared to options b) and c) (figure 4) - 57 °C.

Analysis of the results shows that 5% of power variation of the residual energy release leads to a change of the temperature field, and the difference in the metal constructions does not exceed 3% of the maximum temperature.

7. Conclusion
The power of the residual energy release of the corium determines several factors:

- concentration of radionuclides in it: \(^{106}\)Rh, \(^{144}\)Pr, \(^{134}\)Cs, \(^{90}\)Y, \(^{137m}\)Ba, \(^{137}\)Cs, \(^{90}\)Sr, \(^{144}\)Ce, \(^{147}\)Pm, \(^{154}\)Eu, \(^{85}\)Kr, \(^{244}\)Cm, \(^{238}\)Pu and \(^{241}\)Am;
- the value of the specific intensity of the fuel in the core during normal operation;
- the depth of fuel burn.

The largest error in determining the values of residual energy release of corium occurs when the calculation of concentrations of radionuclides: \(^{106}\)Rh, \(^{144}\)Pr, \(^{134}\)Cs, \(^{90}\)Y, \(^{137m}\)Ba, \(^{137}\)Cs, \(^{90}\)Sr, \(^{144}\)Ce, \(^{147}\)Pm, \(^{154}\)Eu, \(^{85}\)Kr, \(^{244}\)Cm, \(^{238}\)Pu and \(^{241}\)Am.

Thus, the greatest influence on the accuracy of determination of temperature fields in the equipment CC after the first hour after receipt of the corium in CC has the accuracy of the calculations of radionuclide concentrations in corium: \(^{106}\)Rh, \(^{144}\)Pr, \(^{134}\)Cs, \(^{90}\)Y, \(^{137m}\)Ba, \(^{137}\)Cs, \(^{90}\)Sr, \(^{144}\)Ce, \(^{147}\)Pm, \(^{154}\)Eu, \(^{85}\)Kr, \(^{244}\)Cm, \(^{238}\)Pu and \(^{241}\)Am.

The calculations of the temperature fields has allowed to establish the following:

- the accuracy of NPC affects the accuracy of the calculation of temperature fields in the elements of CC;
- the value of residual energy release power affects the value of the maximum temperature;
- 5% of power variation of the residual energy release leads to a change of the temperature field, and the difference in the metal constructions does not exceed 3% of the maximum temperature.
- small deviations of the source data according to the residual energy release correspond to small deviations of the temperature field.

References
[1] Alekseev A V, Kasatkin S S and Bochkov A I Program complex for calculating cell constants CONCORD. Parallel version // Conference theses report "Neutronics -2011". Neutron-physical and thermophysical problems of nuclear power with a closed fuel cycle. Obninsk, October 24–26, 2011
[2] Alekseev P N, Manturov G N and Nikolaev M N Estimation of errors in the calculation of the criticality coëfficients and reproduction of power fast reactors due to inaccuracy of neutron data. Atomic energy v.49, no. October 4, 1980
[3] Okumara K and Mori T Validation of a continuous energy Monte-Carlo burn up code MVP_BURN // Journal of Nuclear Science and Technology. - 2000. - V. 24. - № 2. - P. 71–77
[4] User guide, STAR-CCM+ Version 7.02, 2012
[5] Siegel R., Howell J. Thermal Radition Heat Transfer. Washington: Hemisphere, 1992