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INFLUENCE OF HIGH BURNUP ON THE DECAY HEAT POWER OF SPENT FUEL AT LONG-TERM STORAGE

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ABSTRACT

Development and application of advanced fuel with higher burnup is now in practice of NPP with light water reactors in an increasing number of countries. High burnup allows to decrease significantly consumption of uranium. However, spent fuel of this type contains increased amount of high active actinides and fission products in comparison with spent fuel of common-type burnup. Therefore extended time of storage, improved cooling system of the storage facility will be required along with more strong radiation protection during storage, transportation and processing.

Calculated data on decay heat power of spent uranium fuel of light water VVER-1000 type reactor are discussed in the paper. Long-term storage of discharged fuel during 100000 years is considered. Calculations were made for burnups of 40-70 MW·d/kg.

In the initial 50-year period of storage, power of fission products is much higher than that of actinides. Power of gamma-radiation is mainly due to fission products. During subsequent storage power of fission products quickly decreases, the main contribution to the power is given by actinides rather than by fission products.

1 INTRODUCTION

Many countries are now working on the development and introduction in practice of NPP based on light-water reactors with advanced fuel characterized by high burnup. High burnup allows to increase economic efficiency of NPP and to decrease consumption of uranium. Application of high burnup fuel influences strongly the back end of fuel cycle including interim and long-term storage of spent fuel, processing, and ultimate disposal of radwaste. Spent fuel of this type contains increased amount of high active actinides and fission products in comparison with spent fuel of common-type burnup. Therefore extended time of storage, improved cooling system of the storage facility will be required along with more strong radiation protection during storage, transportation and processing.

Calculated decay heat power of high burnup spent fuel is discussed in the paper. We considered long-term storage of long-lived actinides and fission products extracted from one ton of spent fuel of VVER-1000 type reactor. The duration of storage 100000 years was chosen for calculations, which is able to describe both an intermediate and long-term storage including ultimate geological disposal. Analogous mode of storage was discussed in [1] for spent fuel with common-type burnup of 40 MW·d/kg.

2 ACCUMULATION OF HIGH-ACTIVE NUCLIDES IN FUEL AT HIGH BURNUP

High-active actinides and fission products are accumulated in spent fuel in the process of burnup. They determine the decay heat power and gamma-radiation during subsequent storage, transportation, reprocessing. Masses of minor actinides in spent fuel increase with the burnup increase. Short-lives nuclides decay during the short interim storage in several years after the discharge. Therefore nuclides with half-life more than 10 years present the most radiation danger. These nuclides are ^{90}Sr, ^{137}Cs, ^{244}Cm, ^{238}Pu, ^{241}Am. We calculated isotopic composition of spent fuel of VVER-1000 type reactor for burnups of 40-70 MW·d/kg. Calculations were made using MCNP-4b and SCALE codes. Results of calculations of the main actinide masses extracted from one ton of spent fuel of the VVER-1000 reactor for the burnup W of 40-70 MW·d/kg are presented in fig.1. The mass of ^{241}Am includes a part of ^{241}Pu which decays in ^{241}Am during 3-year cooling.

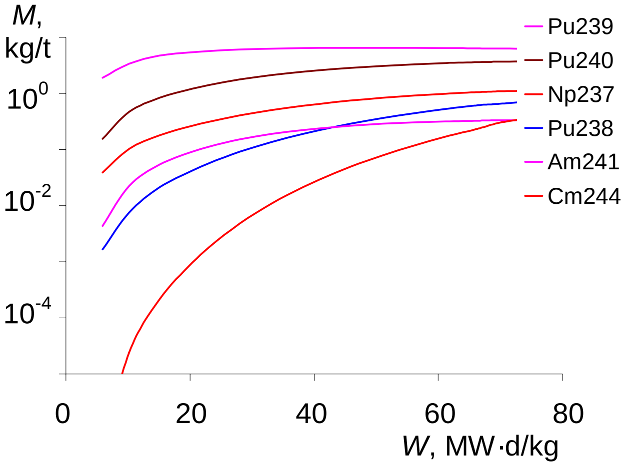

Figure 1: Masses of base actinides in one ton of spent fuel of VVER-1000 type reactor

These data demonstrate that the increase of burnup from 40 to 70 GW·d/kg results in the corresponding increase of the ^{238}Pu mass by 3 times while the mass of ^{244}Cm increases by 10 times.

3 DECAY HEAT POWER OF SPENT FUEL DURING LONG-TERM STORAGE

Decay heat power was calculated separately for actinides and fission products. Power of alpha, beta, and gamma-radiation were calculated. Nuclides with half-life more than 10 years (and also ^{242}Cm) were taken into account. Data on decay heat power presented below are referred to one ton of spent fuel. We should remember that total time of storage of 100000 years simulates ultimate geological disposal.

Decay heat power of actinides and contribution of separate nuclides are presented in fig.2 for burnup of 40 MW·d/kg. Analogous data for burnup of 70 MW·d/kg are given in fig.3.

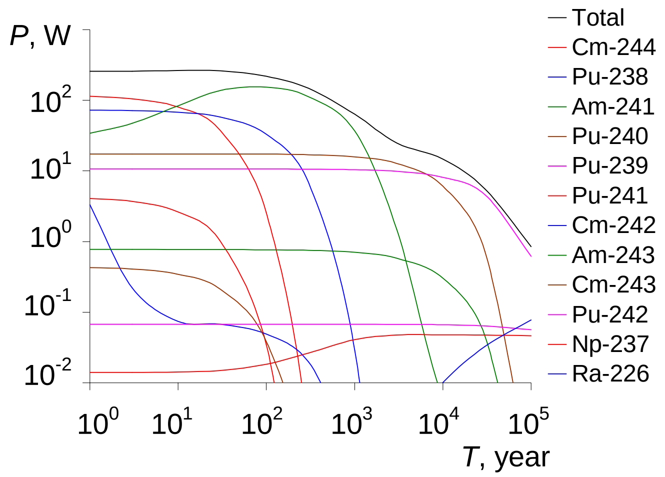

Figure 2: Decay heat power of actinides from one ton of spent fuel during long-term storage for burnup of 40 MW·d/kg

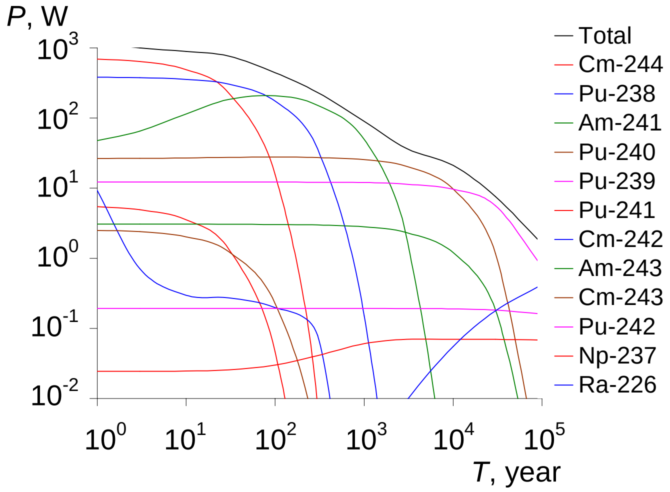

Figure 3: Decay heat power of actinides from one ton of spent fuel during long-term storage for burnup of 70 MW·d/kg

These data demonstrate that for burnup of 40 MW·d/kg (fig.2) in the first 10-years period of storage the power of actinides is mainly determined by ^{244}Cm and ^{238}Pu, while for the burnup of 70 MW·d/kg (fig.3) the first period is extended to 30 years. This fact is explained by an increase of the impact of ^{244}Cm at higher burnup in comparison with ^{241}Am (see fig.1). In the next period of 10-3000 years at burnup of 40 MW·d/kg, the decay heat power is mainly due to ^{241}Am, while ^{240}Pu and ^{239}Pu play the main role after 3000 years. On the contrary, at burnup of 70 MW·d/kg ^{241}Am gives the main impact after about 100 years of storage.

Power of gamma-radiation of actinides is calculated separately as it determines the required radiation protection level. It is presented in fig.4.

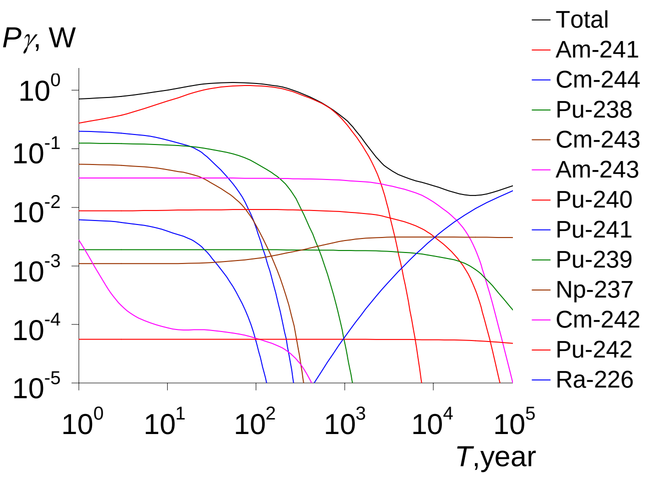

Figure 4: Decay heat power of gamma-radiation of actinides from one ton of spent fuel during long-term storage for burnup of 70 MW·d/kg

Power of gamma-radiation of actinides at burnup of 70 MW·d/kg (fig.4) is 300-1000 times lower than total power. During the period of storage for 3000 years it is mainly due to ^{241}Am. ^{243}Am plays the most important role after 3000 years of storage. In the period of more than 20000 years gamma-radiation is due to accumulated ^{226}Ra.

Decay heat power of all type of radiations for actinides (Ac) and fission products (FP) are presented in fig.5 for burnup of 70 MW·d/kg. Curves for “Alpha Ac” and “Total Ac” are so close that they are marked by the same colour.

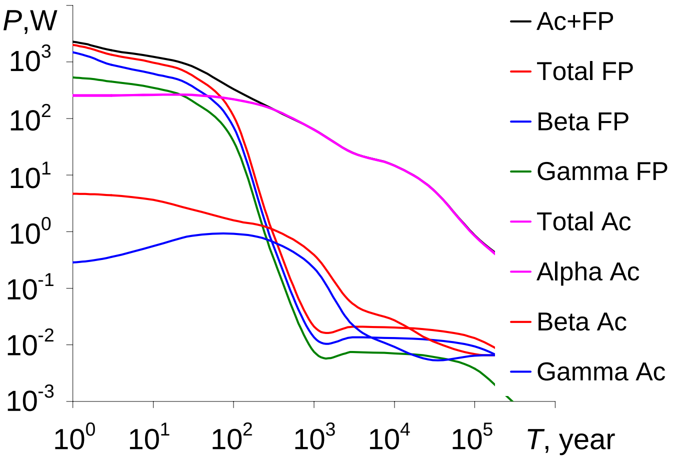

Figure 5: Comparison of decay heat power of alpha, beta, gamma-radiation of actinides with beta and gamma-radiation of fission products from one ton of spent fuel during long-term storage for burnup of 70 MW·d/kg

Comparison of radiations of actinides and fission products (fig.5) demonstrates that in the 30-years period of storage power of fission products is higher than that of actinides. Power of gamma-radiation is mainly due to fission products. During subsequent storage power of fission products quickly decreases, the main contribution to the power is given by actinides rather than by fission products. Power of gamma-radiation after 300 years of storage is mainly due to actinides.

Decay heat power of fission products along with contribution of separate nuclides are given in fig.6 for burnup 40 MW·d/kg and in fig.7 for burnup 70 MW·d/kg.

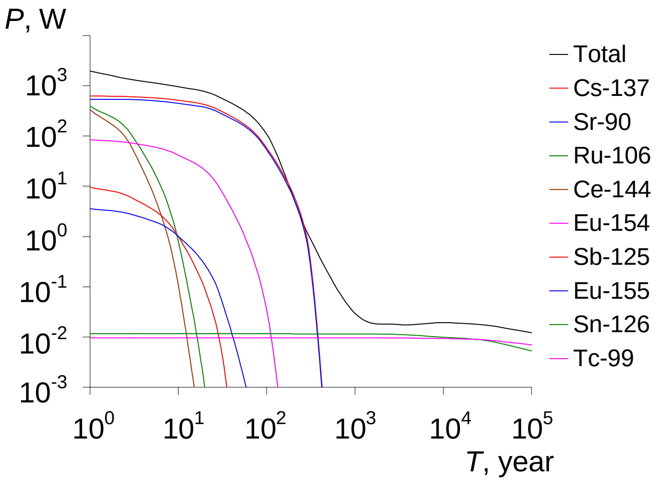

Figure 6: Decay heat power of fission products from one ton of spent fuel during long-term storage for burnup of 40 MW·d/kg

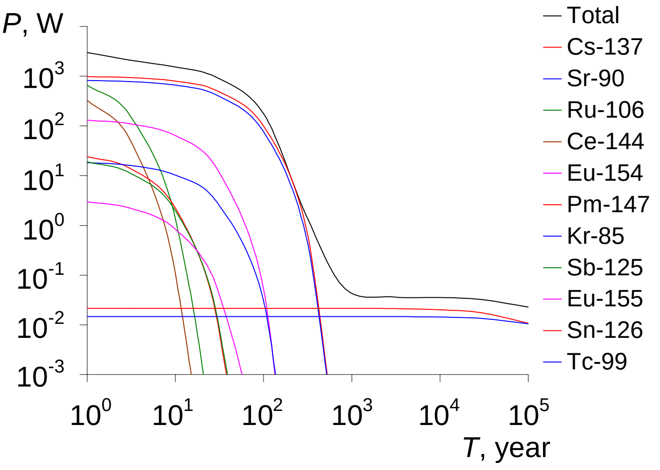

Fig.7. Decay heat power of fission products from one ton of spent fuel during long-term storage for burnup of 70 MW·d/kg

Decay heat power of fission products during the period of 300-year storage is mainly determined by ^{90}Sr and ^{137}Cs with half-life of about 30 years. Other curves in fig.6 and 7 for this period of time describe more short-lived nuclides. Their power decreases quickly. Power of ^{90}Sr and ^{137}Cs decreases after about 300 years. In 1000 years, power will decrease by 105 times in comparison with the beginning of storage. Long-term storage is mostly affected by ^{99}Tc and ^{126}Sn. Total long-term decay heat power of fission products is 100-1000 times lower than that of actinides.

4 CONCLUSIONS

The data presented can be used for the development of the requirements for the system of cooling and radiation protection of the containers and storage facility designed for spent high burnup fuel. The increase in burnup from 40 to 70 MW·d/kg results in the increase of decay heat power of actinides from one ton of spent fuel by 4.6 times, the masses of ^{238}Pu and ^{244}Cm increase by 3 and 10 times respectively. Power of fission products increases by 1.5 times. Power of gamma-radiation increases proportionally to the total power.

Therefore there will be significant increase of requirements to the cooling and radiation protection system of containers, in which spent fuel is stored.

REFERENCES

[1] B.R.Bergelson, A.S.Gerasimov, G.V.Tikhomirov, Radiotoxicity and Decay Heat Power of Spent Nuclear Fuel of VVER Type Reactors at Long-Term Storage, *Proc. Int. Conf. 21st Century Challenges in Radiation Protection and Shielding*, Madeira, Portugal, 9-14 May, 2004, CD-ROM