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Moderator Heat Sources in TEPLATOR District Heating SMR

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ABSTRACT

Moderator temperature needs to be maintained below safe values in reactors with separated moderator and coolant volumes. For reactor during full power operation, main heat sources relevant to moderator volume temperature are heat transfer from nuclear fission source and radiation heating caused by various nuclear reactions. These reactions include radiation heating from fission neutrons, secondary photons from (n,γ) reactions, fission photons, spent nuclear fuel neutrons, spent nuclear fuel photons and Co-60 photons from activated steel components. Although the radiation heating can represent less intensive heat source, it is a direct source in the moderator volume and it can affect moderator volume temperature more than relatively distant heat sources in the fuel. For reactor during outage before core unloading, heat transfer from nuclear fission is replaced by heat transfer from spent nuclear fuel decay heat. In the paper, radiation heating and its components along with spent nuclear fuel decay heat for TEPLATOR district heating Small Modular Reactor is calculated by MCNP and SCALE codes.

1 INTRODUCTION

TEPLATOR district heating Small Modular Reactor (SMR) [1] is designed with separated moderator and coolant volumes. Moderator temperature is affected by heat transfer from coolant channel and radiation heating directly in the moderator volume. Various nuclear reactions contribute to radiation heating in the moderator. The most important contributors during full power operation are fission neutrons and secondary photons from (n,γ) reactions of fission neutrons. After reactor shutdown, spent nuclear fuel photons are the main contributor to moderator radiation heating.

Monte Carlo transport calculation of radiation heating was performed with MCNP6.1 code with ENDF/B-VIII.0 nuclear data library. The transport calculation represents a fixed source problem for all nuclear reaction contributions. The tally directly estimates radiation heating as energy deposition average over a spatial cell. SCALE code package was used to calculate neutron and photon sources.

2 CALCULATION MODEL

Geometry model of the reactor core and its surroundings can be shown in Figure 1. Core thermal power is 50 MW. Fuel assemblies of VVER-440 type are placed in triangular lattice with 40 cm pitch. Fuel channel with heavy water coolant is thermally isolated from heavy water moderator.

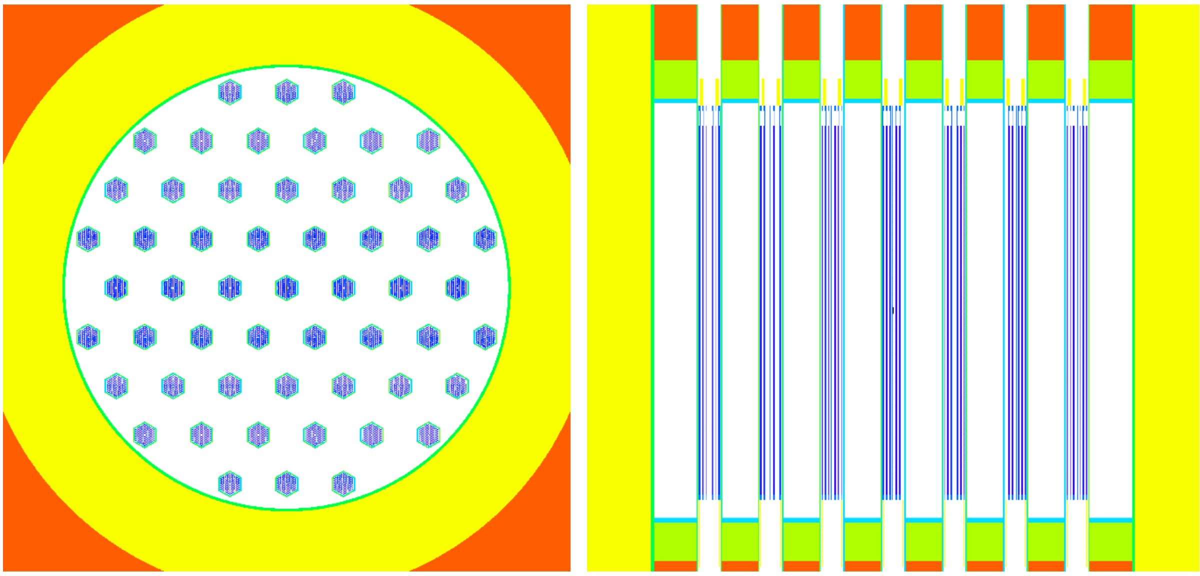

Figure 1: TEPLATOR radiation heating model.

During full power operations, fission sources were assumed to have U-235 prompt fission neutron spectrum distribution. Each fission emits 7.0437 photons and 2.4367 neutrons. For a 50 MW thermal power, the source strength can be transformed to 1.09E+19 fission photons and 3.77E+18 fission neutrons per second. Spent nuclear fuel photons have a strength of 1.87E+19 photons per second for 3.60 wt% U-235 fuel with 37300 MWd/MTU (35000 MWd/MTU in VVER core and 2300 MWd/MTU in TEPLATOR core) with zero cooling time. Spent nuclear fuel (SNF) neutron strength is less than 1.0E+09 neutrons per second in one fuel assembly, 9 orders of magnitude lower than fission neutron source. Because the energy spectra of SNF neutrons in thermal energy are comparable to fission neutrons, SNF neutrons can be neglected.

Fuel outage starts with reactor shutdown. Fission sources including delayed neutrons drop to zero shortly after the shutdown and are not part of heat sources relevant to moderator volume. During the outage, moderator radiation heating has only one contributor of SNF photons. In the fuel channel, decay heat is the second heat source present during fuel outage. Decay heat and SNF photon characteristics were calculated by fuel depletion calculations with SCALE/TRITON codes from SCALE-6.2.4 code package with ENDF/B-VII.1 nuclear data library.

3 CALCULATION RESULTS

Full power operation at 50 MW level results in 1654 kW moderator radiation heating, see Table 1. Moderator heating represents 3.3 % of TEPLATOR thermal power, slightly lower than 5 % fraction of moderator heating in CANDU reactors [2], [3].

Almost a half of moderator radiation heating is caused by fission neutrons. Along with secondary photons, these two main paths linked to fission neutrons contribute to 83 % of total moderator radiation heating. Primary photons and spent fuel photons complete the list of moderator radiation heating during full power operation.

Radial and axial distribution of moderator radiation heating can be seen in Figures 2 to 4. Axial shape is linked to power profile. In radial direction, two dependencies can be seen. First, moderator radiation heating decreases along core radial coordinate. Second, fission neutrons that are the dominant contributor to moderator radiation heating are not dominant in all parts of the calandria. In the space between two adjacent fuel channels, neutrons are more important in the vicinity of fuel channels. On the other hand, secondary photons are characterised by more uniform distribution and are the most important part of moderation at half pitch between the adjacent fuel channels.

Table 1: Moderator radiation heating summary.

Contributor (-)	Fraction of radiation heating (-)
Fission photons	0.054
Secondary photons	0.361
Fission neutrons	0.467
Spent fuel photons	0.118
Total (kW)	1654

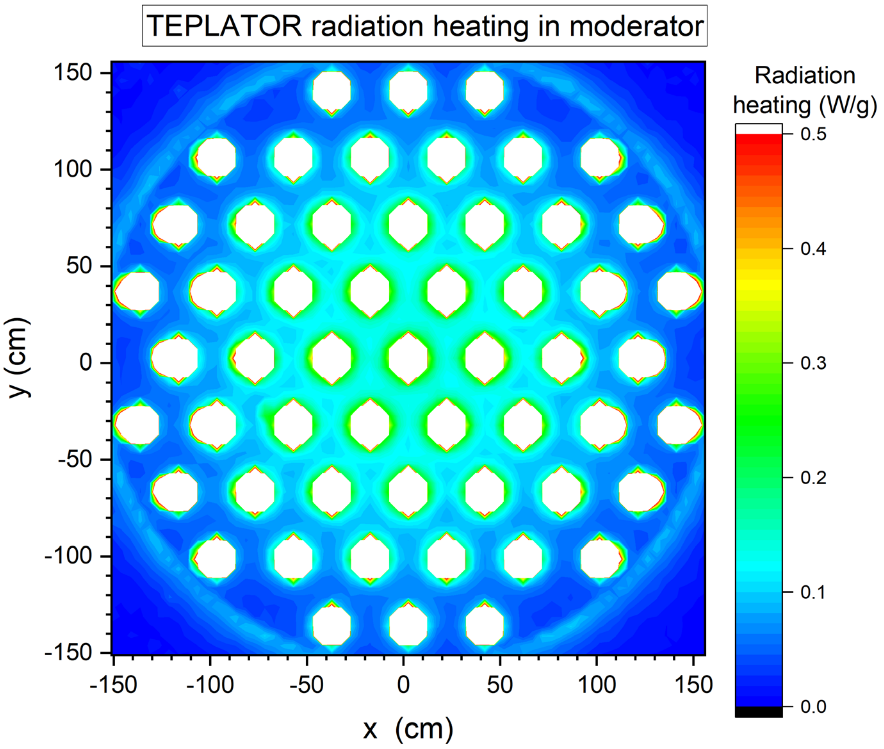

Figure 2: Moderator radiation heating at core midplane.

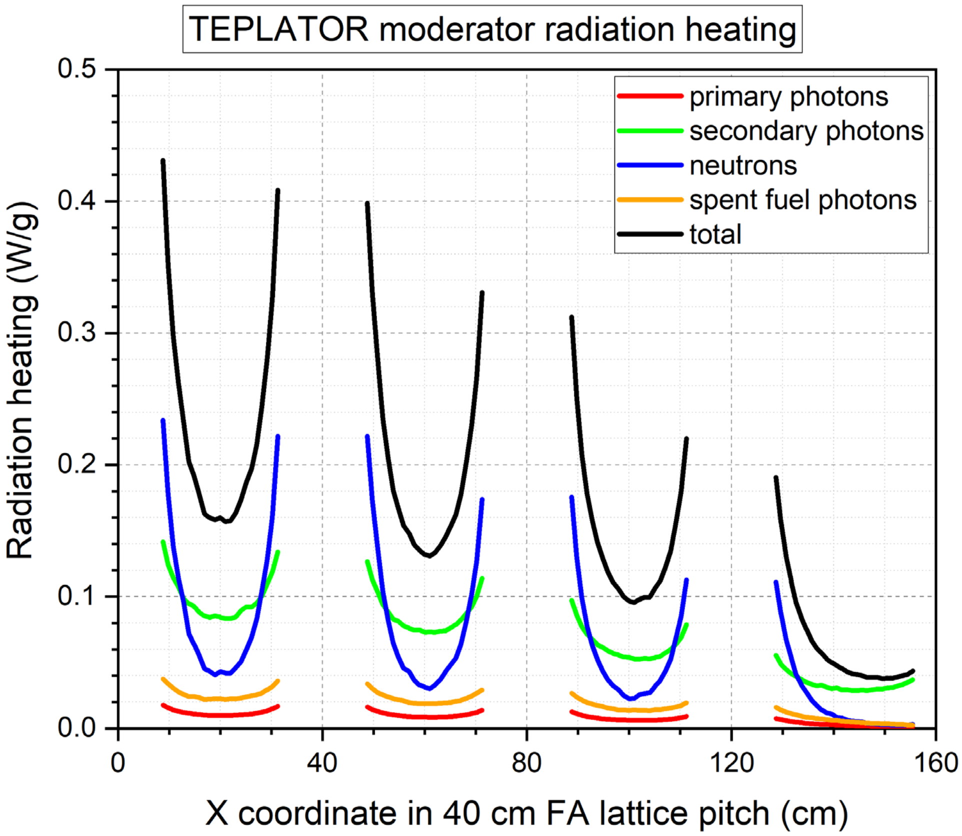

Figure 3: Moderator radial radiation heating at core midplane along y=0.

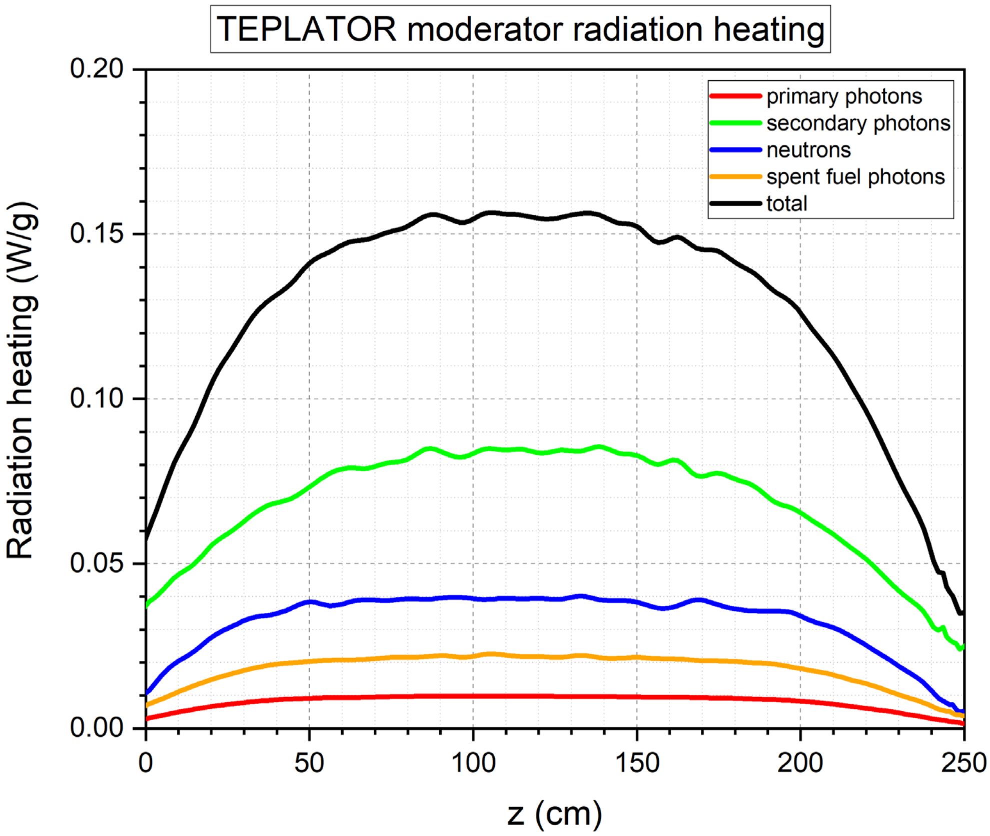

Figure 4: Moderator axial radiation heating along (x,y=20,0) cm.

For reactor during outage before core unloading, heat transfer from nuclear fission is replaced by heat transfer from spent nuclear fuel decay heat that is summarized in Figure 5. Decay heat drops significantly from 3094 kW at shutdown (6.2 % of reactor thermal power) to 349 kW after 24 hours and 202 kW after 7 days.

During outage, moderator radiation heating continues similarly to decay heat in fuel channels. Spent nuclear fuel photons are causing the heating in moderator volume. Moderator heating decrease during cooling time in similar trend as decay heat, because both are the result of short lived fission products decay. Moderator heating drops from 195 kW at shutdown to 21 kW after 24 hours and 3 kW after 7 days, see Figure 5.

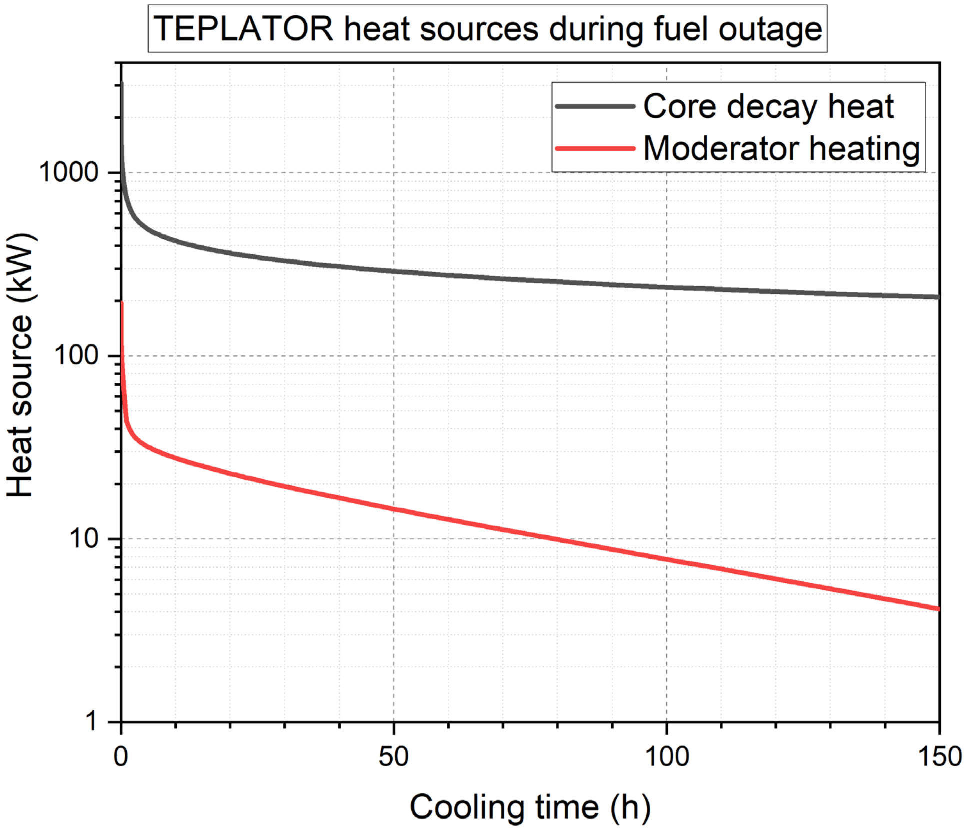

Figure 5: TEPLATOR heat sources after core shutdown.

4 CONCLUSIONS

TEPLATOR district heating SMR is designed with separated moderator and coolant volumes. Moderator temperature is affected by heat transfer from coolant channel and radiation heating directly in the moderator volume.

During full power operation, total moderator radiation heating is 3.3 % of reactor thermal power. Main contributors are fission photons (5 %), secondary photons (36 %), fission neutrons (47 %) and spent fuel photons (12 %).

For reactor during outage before core unloading, heat transfer from nuclear fission is replaced by heat transfer from spent nuclear fuel decay heat. Decay heat drops significantly from 3094 kW at shutdown (6.2 % of 50 MW reactor thermal power) to 349 kW after 24 hours and 202 kW after 7 days.

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ACKNOWLEDGMENTS

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