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Radiation Damage of SMR Reactor Vessel

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ABSTRACT

Radiation damage of reactor pressure vessel in a large reactor units is a key lifetime indicator. Number of newly proposed Small Modular Reactors (SMR) utilize a compact pressure reactor vessel that is a scaled version of larger ones. These types of SMR typically utilize nuclear fuel at a high volumetric power and along with a small reflector, resulting in fundamentally similar reactor vessel lifetime as in the large reactor units. However, there are SMR designs that operates at lower volumetric power. TEPLATOR district heating SMR is a reactor design with low pressure, low temperature and low volumetric power for district heating purposes. In this paper, radiation damage in terms of displacement per atom of TEPLATOR reactor vessel is calculated by MCNP code.

1 INTRODUCTION

TEPLATOR district heating Small Modular Reactor (SMR) [1] is designed with low pressure, low temperature and low volumetric power for district heating purposes. The reactor has 50 MW nominal power and it is assumed to operate up to 300 effective full power days each year. The core consists of 55 fuel assemblies of VVER-440 type in separate pressure tubes filled with heavy water coolant. Heavy water moderator between pressure tubes is separated from graphite radial reflector by zirconium and the whole core is placed inside the reactor vessel from type 304 stainless steel. Two options are possible for core loading. Either fresh fuel with low enrichment or previously used fuel from VVER-440 reactor can be loaded into the core.

Radiation damage is currently based on neutron fluence greater than 1 MeV [2], [3], but the use of displacements per atom (DPA) is more general for radiation damage [4]. Fast neutron fluence lower than 1.0E+17 n/cm^2 (E>1 MeV) is regarded as negligible [3]. Fast neutron fluence limit depends on the reactor design, but according to various sources [5], [6] and design analyses [7], [8], a value of 1.0E+19 n/cm^2 is considered as low fluences. Therefore, maximum fast neutron fluence of TEPLATOR reactor vessel during core lifetime is maintained below 1.0E+19 n/cm^2.

2 CALCULATION MODEL

Transport geometry model of the reactor core and its surroundings can be shown in Figure 1 and Figure 2. Coolant is modelled in 20 layers with separate temperatures and densities. Fuel assemblies of VVER-440 type are placed in triangular lattice with 40 cm pitch. Graphite radial reflector surrounding the heavy water moderator is placed in the reactor vessel with 210 cm radius.

For a 50 MW core thermal power, the source strength can be transformed to 3.77E+18 fission neutrons per second. 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 are comparable to fission neutrons, SNF neutrons can be neglected. Pin-wise neutron source in 20 axial layers was used, radial neutron source distribution is shown in Figure 3.

MCNP6 Monte Carlo transport code with ENDF/B-VIII.0 nuclear data library was used for radiation damage calculations. IAEA DXS cross sections with NRT-based DPA cross sections were used for DPA calculations.

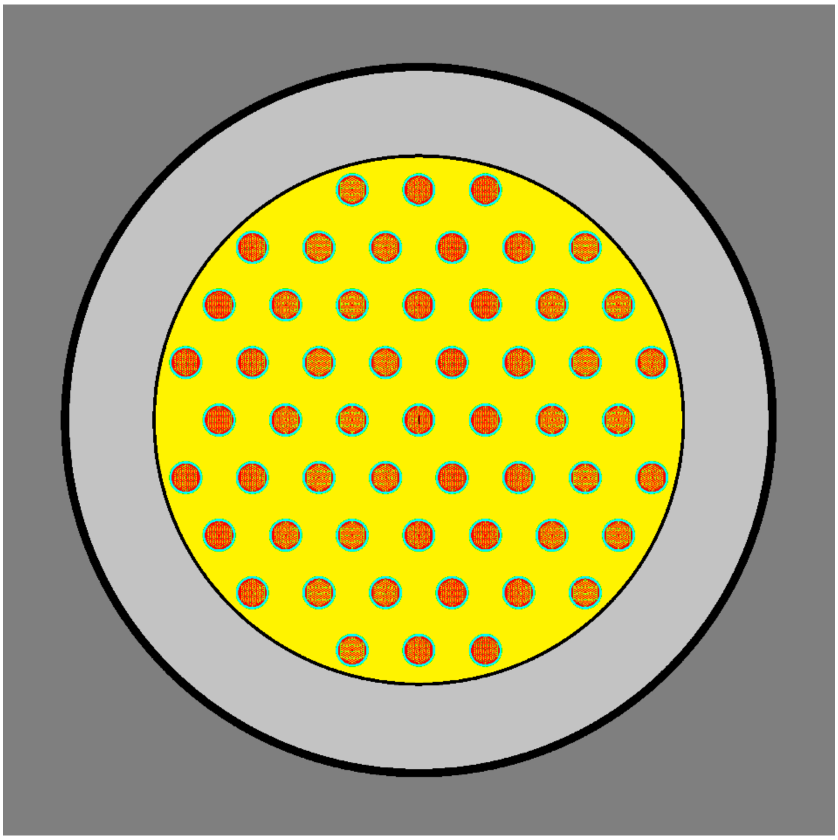

Figure 1: Reactor core in xy plane.

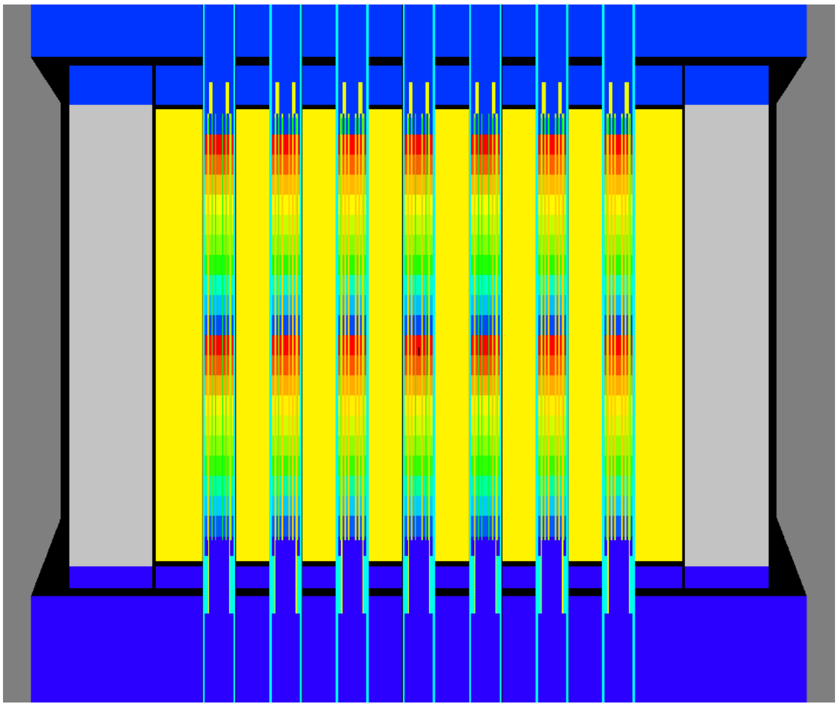

Figure 2: Reactor core in xz plane.

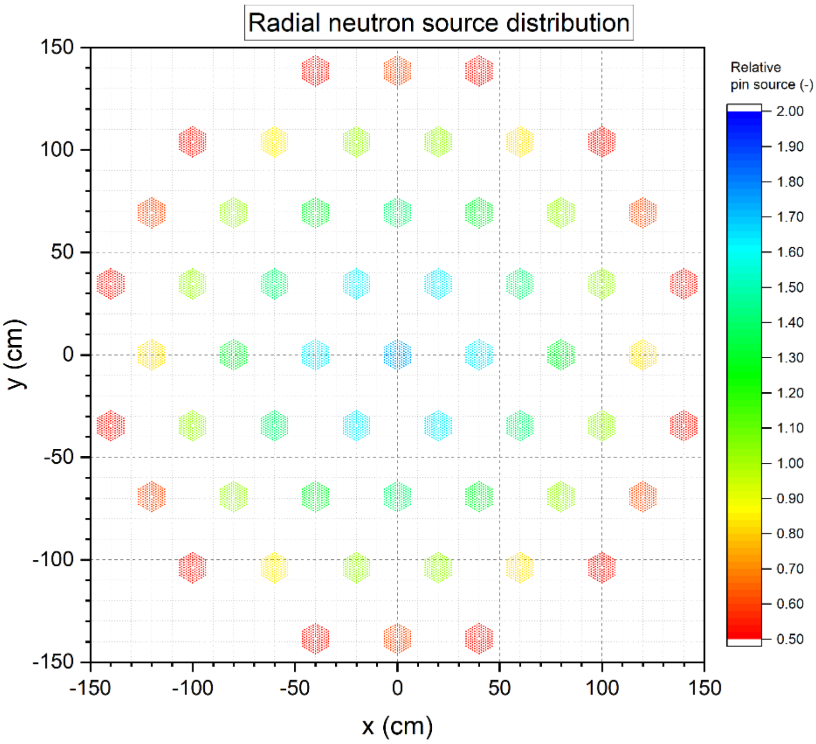

Figure 3: Neutron source distribution.

3 CALCULATION RESULTS

Radial and axial profile of radiation damage was calculated for the reactor vessel on its inner surface. There is almost linear relationship between fast neutron fluence and DPA for this reactor design, 1 dpa = 1.88E+20 n/cm^2 (this relationship is relevant only for the reactor pressure vessel inner surface for the studied reactor design). Therefore, fast neutron fluence and DPA can be shown in double axis plot with one curve.

The radial profile in Figure 4 shows that maximum radiation damage at core midplane is at 15° azimuth, for which the axial profile in Figure 5 was calculated. Maximum fast neutron fluence is 5.38E+16 n/cm^2/efpy, where effective full power year is equivalent to 300 effective full power days. Radiation damage is under 1.0E+19 n/cm^2 limit for up to 186 years, corresponding maximum DPA is 0.053 dpa.

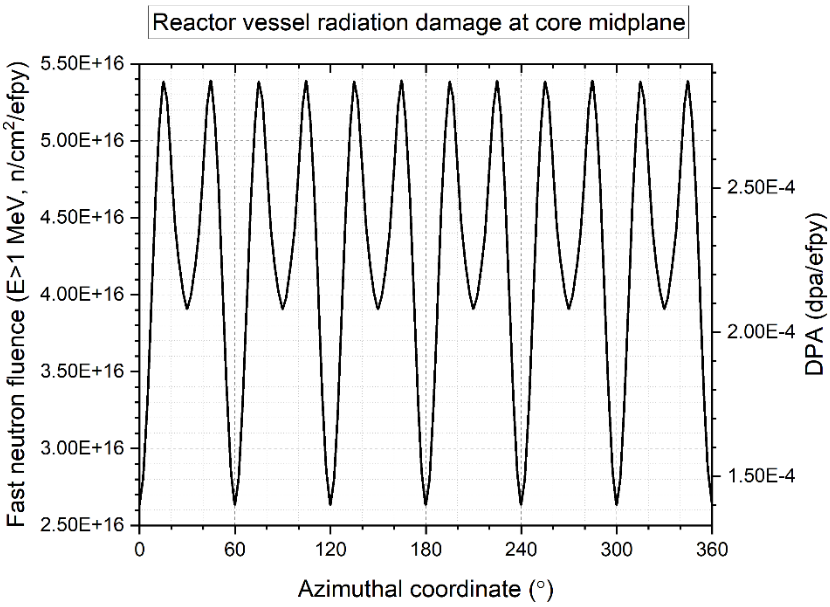

Figure 4: Radial profile of the reactor vessel radiation damage.

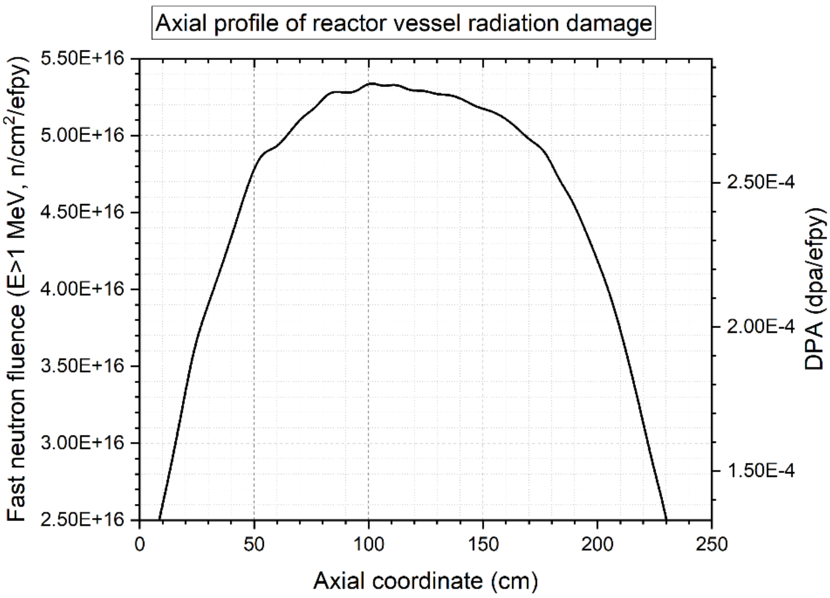

Figure 5: Axial profile of the reactor vessel radiation damage.

4 CONCLUSIONS

TEPLATOR district heating SMR is a reactor design with low pressure, low temperature and low volumetric power for district heating purposes. In the paper, radiation damage as both fast neutron fluence above 1 MeV and displacements per atom are calculated for the reactor vessel as typical component defining reactor lifetime.

Typical value commonly regarded as low fast neutron fluence is 1.0E+19 n/cm^2 and is achieved at the reactor vessel inner surface after 186 effective full power years. At this time, cumulative DPA is 0.053 dpa.

ACKNOWLEDGMENTS

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