Contributions of each isotope in structural material on radiation damage in a hybrid reactor

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Abstract. In this study, the fluids were used in the liquid first-wall, blanket and shield zones of the designed hybrid reactor system. In this study, salt-heavy metal mixtures consisting of 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UO_2, 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% NpO_2, and 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UCO were used as fluids. In this study, the effect on the radiation damage of spent fuel-grade (SFG)-PuO_2, UO_2, NpO_2 and UCO contents was investigated in the structural material of a designed fusion–fission hybrid reactor system. In the designed hybrid reactor system were investigated the effect on the radiation damage of the selected fluid according to each isotopes of structural material in the structural material for 30 full power years (FPYs). Three-dimensional analyses were performed using the most recent MCNPX-2.7.0 Monte Carlo radiation transport code and the ENDF/B-VII.0 nuclear data library.

1 Introduction

Hybrid reactor system has been developed where fusion and fission occur at the same time. Hybrid reactor has an enormous potential to provide a clean, cheap and unlimited energy source. Important advantage of hybrid reactor system is that it has a subcritical reactor system in which reactor can operate securely [1-6].

A substantial amount of spent fuel grade (SFG) plutonium (Pu) from current nuclear reactors has been stored for future use. The isotopic distribution of spent fuel-grade plutonium is 2.4% ^{238}Pu, 58.5% ^{239}Pu, 24% ^{240}Pu, 11.2% ^{241}Pu, and 3.9% ^{242}Pu [7]. In this study, $Li_{20}Sn_{80}$ molten salt was used, which has low melting temperatures and low vapour pressure, to acquire sufficient tritium breeding. Beryllium (Be) is used as a neutron multiplier [8]. In this study, a Be zone with a thickness of 3 cm was used between the liquid first-wall and the blanket. In this study, 9Cr2WVTa ferritic steel was chosen as a structural material because it has low activation, which can help to extend the lifetime of the reactor system. The main objective of this study is to investigate the effect of the selected fluid on the radiation damage according to each isotopes of structural material in the structural material for the designed hybrid system.

2 Method
2.1 Numerical calculation and radiation damage

In Table 1 is shown the radial build of the designed hybrid reactor system. Calculation of all the parameters of the fission and fusion reactors, accelerator-driven systems, and other areas of nuclear technology depend on the cross-section data. The experimental data are limited for neutron-produced reactions in certain energy ranges. The data of the ENDF/B-VII libraries are very important for theoretical calculations [9-13]. This study was performed with neutron wall loadings of 10 MW/m^2 and fusion power of 4000 MW.

Table 1. The radial build of the hybrid reactor system design

Inboard side		Outboard side	
Zone	**r (cm)**	**Zone**	**r (cm)**
SS316LN	276	Plasma	667
Vacuum vessel[a]	278	SOL	695
SS316LN	294	Liquid First Wall[d]	697
GAP	296	Be[e]	700
Shield[b]	301	Blanket[d]	750
Ferritic Steel[c]	350	Ferritic Steel[c]	754
Blanket[d]	354	Shield[b]	804
Be[e]	404	GAP	838
Liquid First Wall[d]	407	SS316LN	840
SOL	409	Vacuum vessel[a]	866
Plasma	437	SS316LN	868

[a]   80% SS316LN, 20% H_2O

[b]   60% 9Cr2WVTa, 40% (93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UO_2, 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% NpO_2, and 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UCO)

[c]   100% 9Cr2WVTa

[d]   93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UO_2, 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% NpO_2, and 93–85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 and 2-10% UCO

[e]   100% Be

Structural materials are exposed to high neutron flux, γ-rays, and energetic particles that continuously eject atoms from their lattice sites. This leads to various types of damage in the material due to neutron attenuation such as hardening, swelling and embrittlement, which directly influence its function. The abilities to reduce the activation and radiation damage to structural materials are among the most important advantages of liquid walls, particularly the "thick" liquid wall concept in the fusion reactor. Radiation effects are the consequence of radiation damage on the mechanical and physical properties of the solid. Whereas the hydrogen atom and its isotopes produced by (n, p), (n, d), and (n, t) reactions can diffuse out of the first wall material with high temperatures, the helium atoms produced by (n, α) and (n, He -3) reactions will accumulate in the first wall of the hybrid reactor and produce helium gas bubbles. These reactions will limit the operational lifetime of the structural material of the reactor [14-17].

3 Numerical Results

In this study, the fluids were composed of molten salt 93-85% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 as the main constituent with increasing mole fractions in 2–10% rates of the heavy metals UO_2, NpO_2, and UCO. The effect of UO_2, NpO_2, UCO on the radiation damage parameters were investigated according to each isotopes of structural material.

Fig. 1 and Fig. 2 shows comes from Fe isotope of the biggest contribution and from C isotope of the smallest contribution at the total proton and deuterium production rate, respectively, in the structural material for used fluids. In Fig. 1, contribution at the total proton production rate in the structural material of Fe isotope for used fluids was obtained about $5x10^5$, $1x10^3$, 10, $7x10^2$, $5x10^4$, $4x10^3$ times higher than C, V, Cr, Mn-55, Ta-181, W isotopes, respectively. In Fig. 2, contribution at the total deuterium production rate in the structural material of Fe isotope for used fluids was obtained about $1x10^4$, $3x10^2$, $2x10^2$, $2x10^2$ times higher than C, V, Cr, Mn-55 isotopes, respectively. In Fig. 1 and Fig. 2, the contributions to the total proton and deuterium production rate of Fe isotope in the structural material was found as approximately 93% and 99%, respectively.

Fig. 3 shows comes from Cr isotope of the biggest contribution and from V isotope of the smallest contribution at the total tritium production rate in the structural material for used fluids. In Fig. 3, contribution at the total tritium production rate in the structural material of Cr isotope for used fluids was obtained about $1x10^2$, 20 and 4 times higher than V, Mn-55 and Fe isotopes, respectively. In Fig. 3, the contributions to the total tritium production rate of Cr isotope in the structural material was found as approximately 77%.

Fig. 4 shows comes from Fe isotope of the biggest contribution and from V isotope of the smallest contribution at the total He-3 production rate in the structural material for used fluids. In Fig. 4, contribution at the total He-3 production rate in the structural material

of Fe isotope for used fluids was obtained about $2x10^5$, 6 and 10 times higher than V, Cr and Mn-55 isotopes, respectively. In Fig. 4, the contributions to the total He-3 production rate of Fe isotope in the structural material was found as approximately 79%.
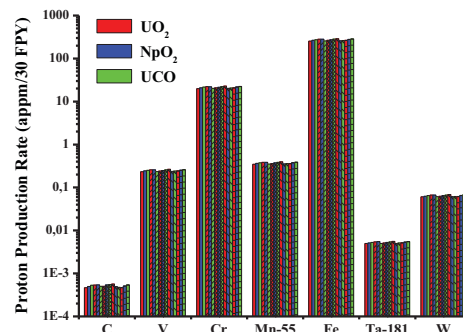

Fig. 1. The contribution of each isotope in the structural material to the total proton production rate for the mixture components of UO_2, NpO_2 and UCO (⬜ 2%, ▨ 4%, ▥ 6%, ⧄ 8%, ▤ 10%) in the system.
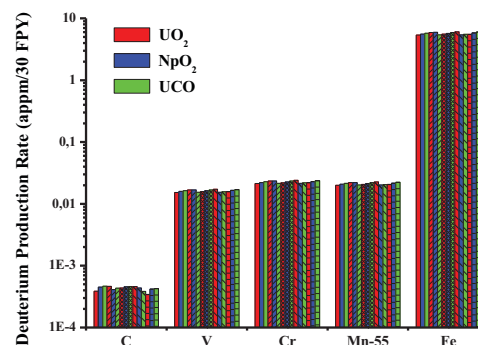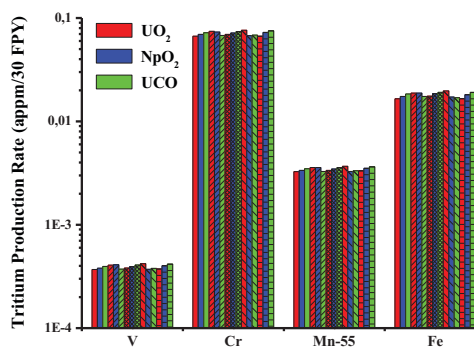

Fig. 2. The contribution of each isotope in the structural material to the total deuterium production rate for the mixture components of UO_2, NpO_2 and UCO (⬜ 2%, ▨ 4%, ▥ 6%, ⧄ 8%, ▤ 10%) in the system.
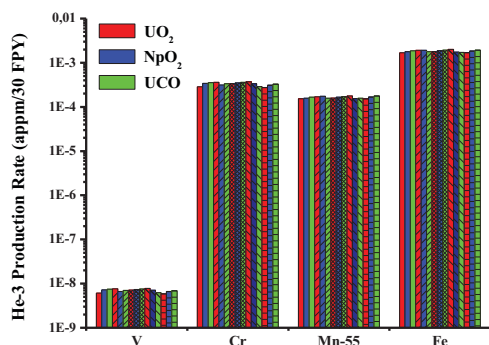

Fig. 3. The contribution of each isotope in the structural material to the total tritium production rate for the mixture components of UO_2, NpO_2 and UCO (⬜ 2%, ▨ 4%, ▥ 6%, ⧄ 8%, ▤ 10%) in the system.

Fig. 4. The contribution of each isotope in the structural material to the total He-3 production rate for the mixture components of UO_2, NpO_2 and UCO (⬜ 2%, ▨ 4%, ▩ 6%, ⬙ 8%, ▤ 10%) in the system.
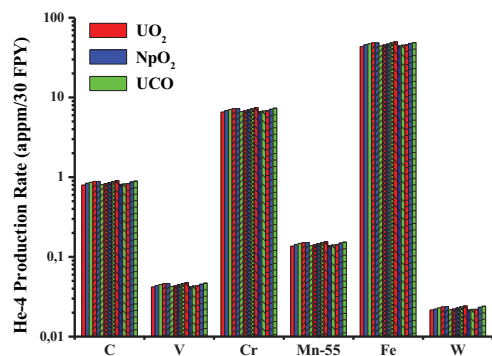

Fig. 5. The contribution of each isotope in the structural material to the total He-4 production rate for the mixture components of UO_2, NpO_2 and UCO (⬜ 2%, ▨ 4%, ▩ 6%, ⬙ 8%, ▤ 10%) in the system.

Fig. 5 shows comes from Fe isotope of the biggest contribution and from W isotope of the smallest contribution at the total He-4 production rate in the structural material for used fluids. In Fig. 5, contribution at the total He-4 production rate in the structural material of Fe isotope for used fluids was obtained about 55, 1×10^3, 7, 3×10^2, 2×10^3 times higher than C, V, Cr, Mn-55, W isotopes, respectively. In Fig. 5, the contributions to the total He-4 production rate of Fe isotope in the structural material was found as approximately 85%.

4 Conclusions

It this study was observed that the biggest contribution comes from Cr isotope with approximately 77% value for the total tritium production rate and from Fe isotope with approximately 80-99% between value for the total proton, deuterium, He-3 and He-4 gas production rates in used the structural material. A minimum of gas production is desired, because gas production reduces reactor life and accelerates deterioration of the structural material. In conclusion, the radiation damage parameters obtained according to each isotopes of the structural

material in the structural material with 93% $Li_{20}Sn_{80}$ + 5% SFG-PuO_2 + 2% UO_2 fluid showed the best performance of the fifteen tested fluids.

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