IMPACT OF HIGHER BURNUPS ON THE TRANSPORTATION PACKAGE DESIGN: DOSE RATE PERSPECTIVE

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ABSTRACT

The improvements in the fuel designs and fuel performance in the operating nuclear power plants have led to an increase in the discharge burnup of the used fuel assemblies. This increase in burnup also has resulted in the design of used fuel storage and transportation systems to accommodate these discharged fuel assemblies. The impact of higher burnups on the design of transportation packages offers unique challenges from a dose rate and radiation shielding perspective.

The transportation cask radiological design is characterized by the applicable dose rate limits on and around the package surface under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). For most transport cask designs, the 10 mrem/hour at 2m from the vehicle edge at NCT is the controlling dose rate limit.

Used fuel assemblies with acceptable combinations of burnup, enrichment and cooling time (BECT) are considered eligible for loading in a transportation cask. Fuel qualification is the method of selecting these acceptable BECT combinations for loading in a transportation cask. The increase in fuel assembly burnup results in an increase in the decay heat of the fuel assembly and also results in an increase in the neutron source term of the fuel assembly. Therefore, cask designs to accommodate fuel assemblies with higher burnups need to be modified to enhance neutron shielding. Zone loading of fuel assemblies to effect self-shielding within the basket is also necessary for this purpose. Finally, the geometry and material modeling uncertainties in the shielding models need to be reduced to provide additional margins in the dose rate calculations.

This paper examines the important considerations for qualification of high burnup fuel assemblies from a radiation protection perspective. This paper also evaluates the impact of higher burnups on the source terms and discusses the enhancements to the dose rate calculation methods. The qualification of fuel with higher burnups is truly an optimization problem that balances shielding material design, fuel qualification and shielding analysis methodologies.

INTRODUCTION

In the United States of America (USA) and rest of the world, nuclear power plants are using higher performance fuel designs to increase efficiency and reduce cost of fuel. This is resulting in fuel assemblies with increased U235 initial enrichments that can support higher burnups up to 70,000 MWD/MTU. These high burnup used fuel assemblies (greater than 45,000 MWD/MTU and up to 70,000 MWD/MTU) following irradiation in the reactor get discharged in the used fuel pool. Utilities have currently very few options to manage this high burnup used fuel. The typical options considered and employed are as follows:

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1. Use used fuel pool to store fuel in wet storage depending on the capacity of the used fuel pool and/or the availability of other options described below
2. Use an appropriately licensed transportation package to transport this fuel to a reprocessing facility
3. Use an appropriately licensed transportation package to transport this fuel to an interim storage facility where the fuel is stored in the dual purpose cask or transferred to a storage overpack which is then stored in the interim storage facility
4. Use an appropriately licensed dry storage system to store fuel on-site in dry storage till it is ready for either reprocessing or transfer to a repository for ultimate disposal

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Higher burned fuel assemblies have significantly higher neutron and gamma source strengths which also result in higher decay heat compared to fuel assemblies with burnups lower than 45,000 MWD/MTU. These characteristics have significant impact on the design of the transportation packages that can be used for these high burnup fuel assemblies. This paper examines the design challenges that are offered by these high burnup fuel assemblies in radiation shielding areas and how they control the design of the neutron and gamma shielding materials used in the transportation packages.

NEUTRON AND GAMMA SOURCE TERMS WITH HIGH BURNUP FUEL

Figure 1 shows the neutron and gamma source terms as a function of cooling time for three different burnup and enrichment combinations. Typically, the neutron source term is dependent on the initial enrichment of the fuel. For the same burnups, the neutron source terms for fuel assemblies with lower initial U-235 enrichment are higher than those for fuel with higher initial U235 enrichment. This is illustrated in Figure 1 where the neutron source terms at an enrichment of 3.0 wt. % U-235 are significantly higher than those at an enrichment of 4.5 wt. % U-235 at a burnup of 60,000 MWD/MTU. The neutron source terms also do not undergo any rapid reduction in their intensity since the half-life is of the order of 20 years.

The gamma source terms, on the other hand, undergo a rapid exponential decay (reduction) as a function of time after discharge from the reactor as illustrated in Figure 1. Further, the gamma source terms are not highly dependent on initial enrichment indicating that burnup and cooling time alone are sufficient to determine the intensity of primary gamma source terms.

Therefore, for high burnup fuel, shielding design considerations for transportation packages will include additional neutron shielding to account for higher neutron source intensities that are relatively unchanged decay over time.

DECAY HEAT WITH HIGH BURNUP FUEL

Figure 2 shows the fuel assembly decay heat as a function of cooling time for three different burnup and enrichment combinations. The fuel assembly decay heat comprises of two components – actinides and fission products. Typically, the actinide component is a function of both the enrichment and burnup (like neutron source term) while the fission product component is a strong function of burnup (like the gamma source term). With the increase in burnup, the actinide component of the total decay heat also increases as illustrated in Figure 2.

NEUTRON AND GAMMA DOSE RATES WITH HIGH BURNUP FUEL

The transportation packages that were initially designed for low burnup fuel assemblies (Burnps <45,000 MWD/MTU) typically did not require a significant amount of neutron shielding because of the lower intensities of the neutron source terms. The significant shielding requirements were for gamma source terms as they controlled the total dose rate from the package. For the high burnup fuel assemblies, the relative contribution of the neutron dose rate to the total dose rate from the package is significantly higher due to significant increase in the neutron source terms, resulting in a need for more neutron shielding material for the transportation package

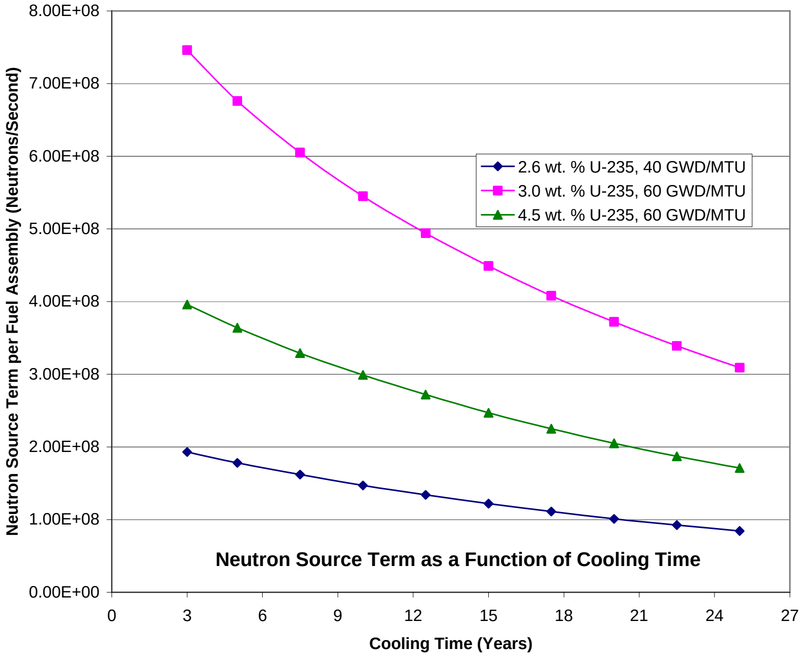
An example fuel qualification evaluation is illustrated in Figure 3 and Figure 4. These fuel qualification evaluations are performed to determine acceptable combinations of burnup, enrichment and cooling time (BECT) to ensure that the used fuel assemblies are eligible for transport. In order to qualify the fuel assemblies for transport under the requirements of 10CFR71 for normal conditions of transport, the dose rate at 2 meters shall be less than 2 mrem/hr from the transport package. Additional dose rate limits under 10CFR71 typically do not control the package design.

Figure 3 shows the dose rate contribution from neutron and gamma sources as a function of burnup and enrichment. Based on the results shown herein, it is very clear that the gamma dose rates are dominant (greater than 75% of the total) at lower burnups while the neutron dose rates are dominant at higher burnups, particularly at high burnup, low enrichment combinations. The required cooling times and the resulting per assembly decay heat as a function of enrichment and burnup are shown in Figure 4. These results indicate that the required cooling time, to ensure that the applicable dose rate limits are met, increases with burnup and for a given burnup, increases with decrease in enrichment. The trend observed for the decay heat indicates that it increases with burnup and for a given burnup increases with increase in enrichment.

This effect is more pronounced at higher burnups confirming that the effect of the neutron sources have a more significant contribution to the total dose rates.

SHIELDING DESIGN OPTIMIZATION FOR HIGH BURNUP FUEL

The qualification of fuel with higher burnups is truly an optimization problem that balances shielding material design, fuel qualification and shielding analysis methodologies. The shielding material design is dependent on the material mass limits associated with the transportation package and its used fuel payload. Depending on the available material mass limits, the mass of neutron and gamma shielding can be adjusted to obtain the optimum material design. Further, the use of more advanced neutron shielding materials that offer more effective gamma shielding improves the overall shielding effectiveness.



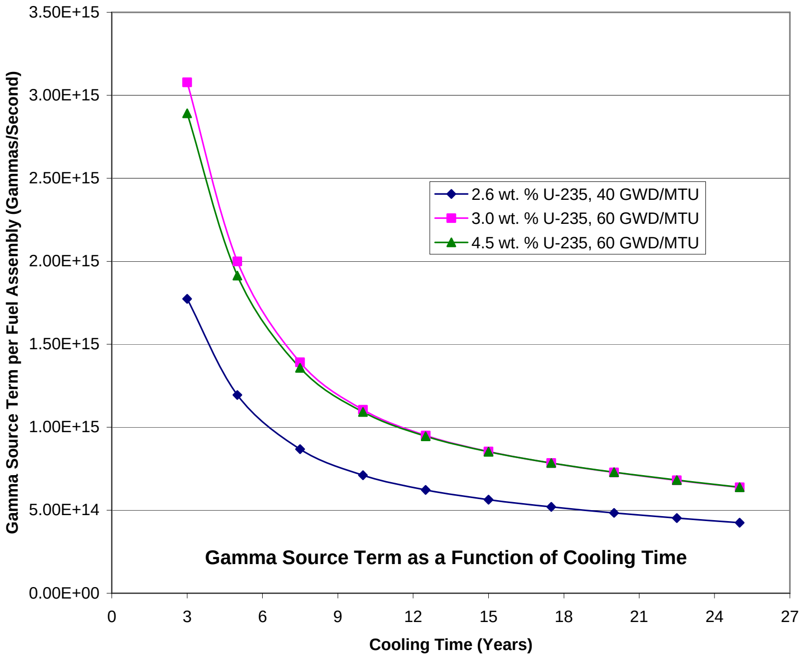


Figure 1. Neutron and Gamma Source Terms as a Function of Cooling Time

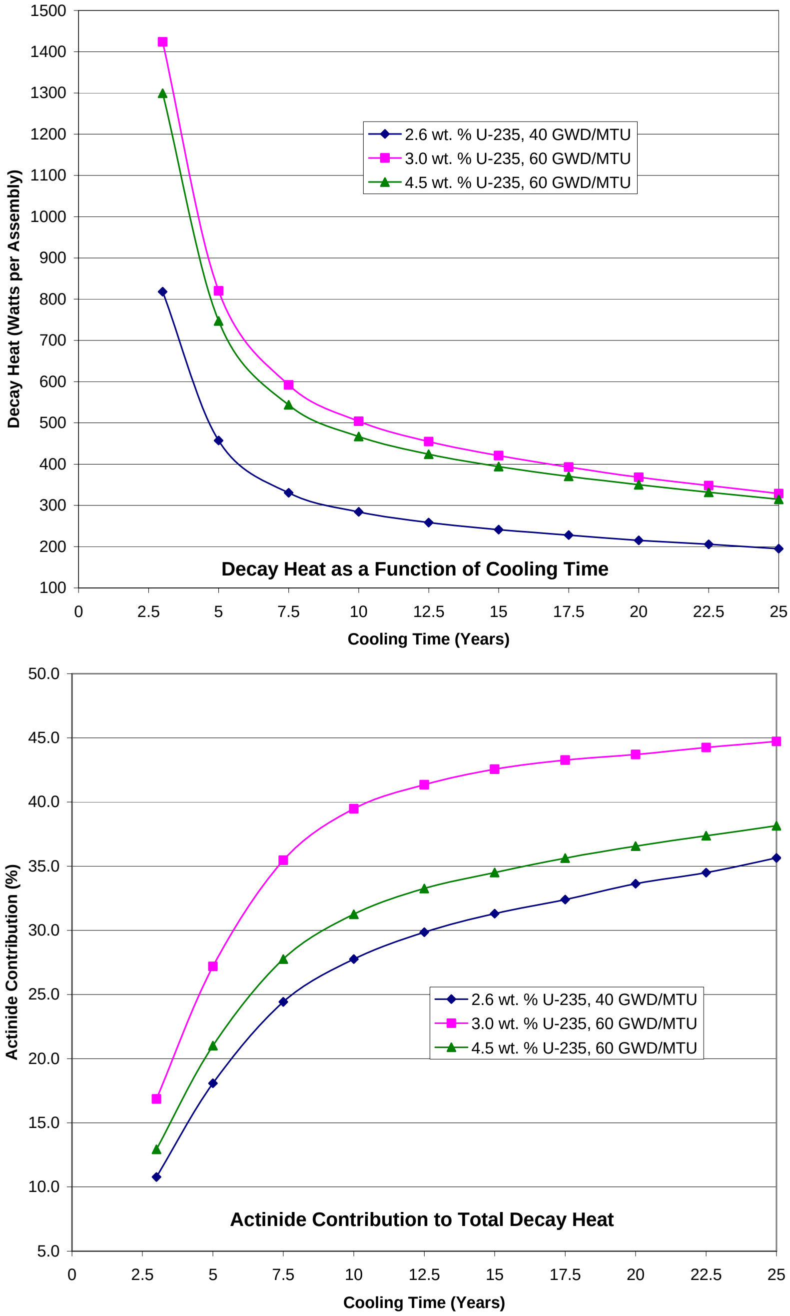
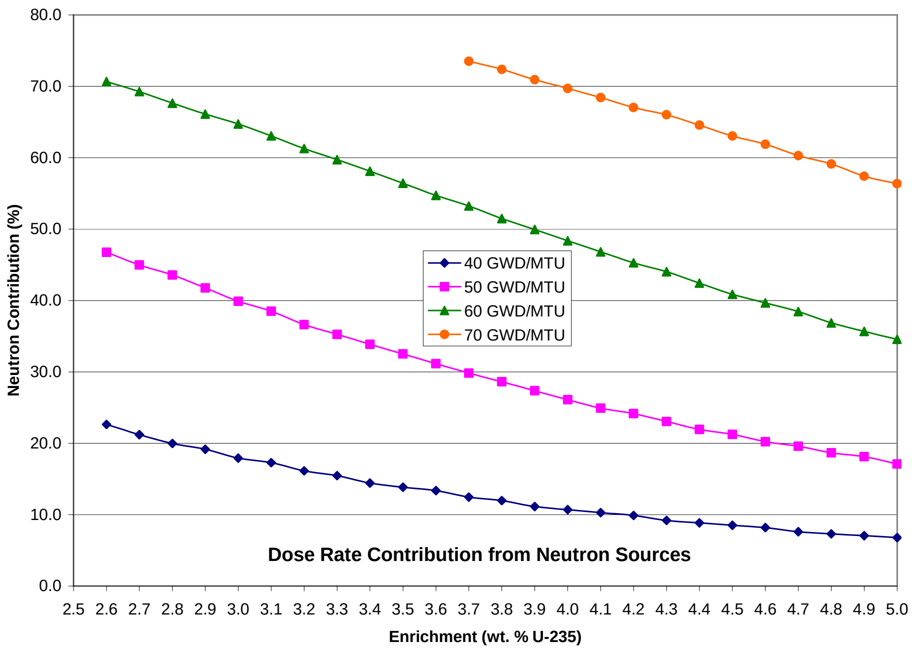


Figure 2. Decay Heat as a Function of Cooling Time



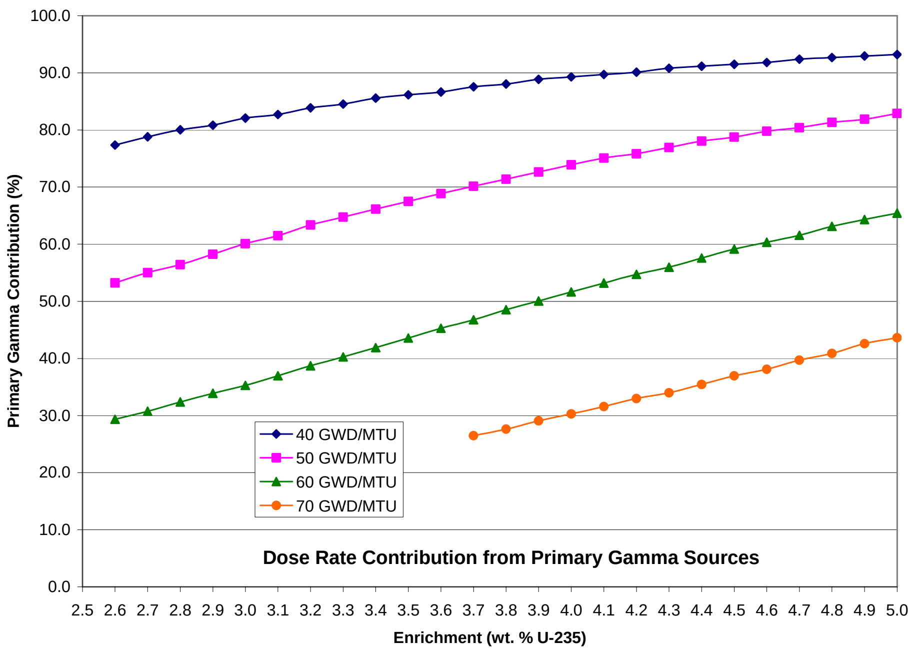
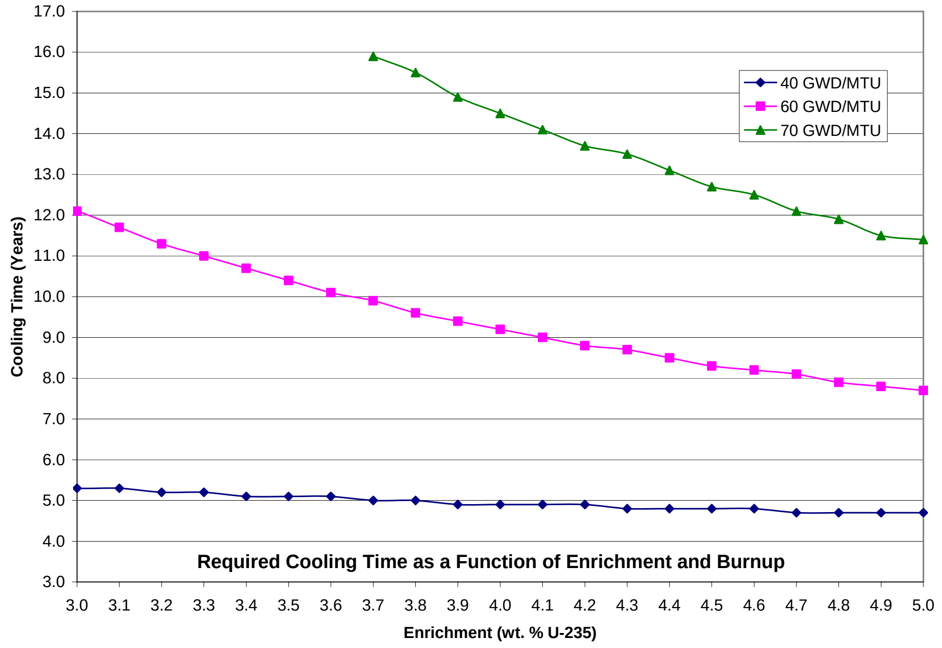


Figure 3. Neutron and Gamma Dose Rate Contributions



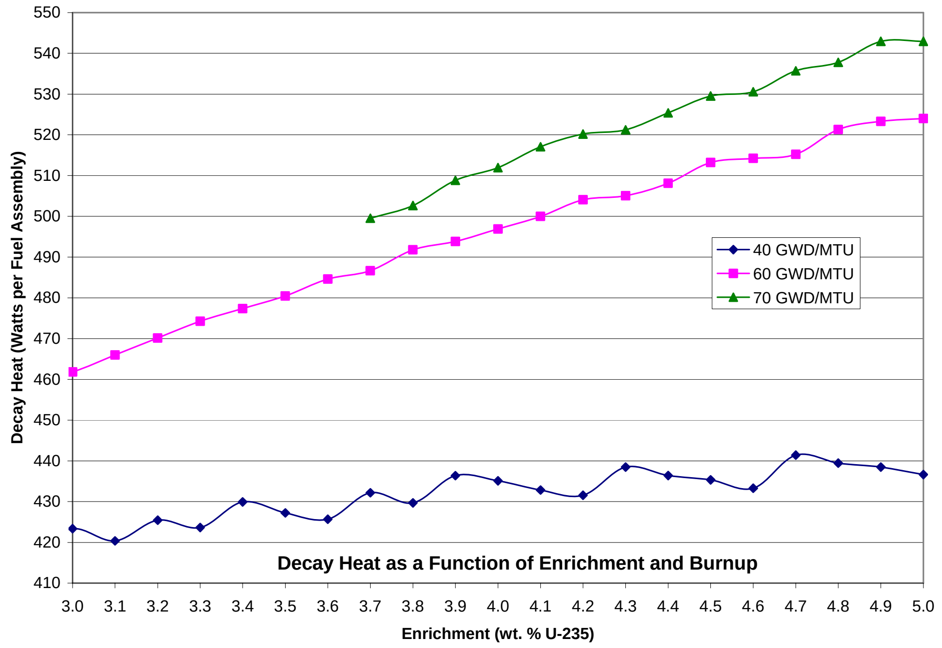


Figure 4. Cooling Times and Decay Heats for Fuel Qualification

CONCLUSIONS

The principal design considerations from a shielding standpoint for the transportation of high burnup used fuel assemblies is in the form of higher neutron source terms. Due to the relatively slower reduction in these source terms as a function of cooling time, it is necessary to optimize the shielding material thicknesses to enhance the neutron shielding capabilities. Depending on the decay heat removal capabilities of the cask system, fuel qualification can also include zone loading to improve the effectiveness of the gamma shielding within the fuel basket.