I. INTRODUCTION

The objective of this work is to evaluate the effect of neutron shield charring due to a regulatory fire on the thermal response and shielding effectiveness of a Multi-Purpose Canister (MPC) and transportation cask. A thermal response model which includes the effect of neutron shield charring is developed. The model is solved using a time dependent finite element code. The maximum fuel temperature-time history and the extent of shield charring are determined. This is used to estimate the primary dose rate from the package in the post-fire condition.

II. DESCRIPTION OF WORK

A. Transportation Package

The transportation package considered in this work is a 125-ton, 21-PWR MPC as described in the Conceptual Design Report. Figure 1 shows a two-dimensional, pie-shaped region which represents one-eighth of the package cross section. The left-hand portion of this figure shows the MPC. It includes a stainless steel/torated aluminum fuel basket, fuel, and a stainless steel shell. The outer transportation cask consists of a stainless steel inner liner, depleted uranium and lead gamma shield, a thick stainless steel structural shell, a neutron shield with stainless steel/copper radial fin/stiffeners, and an outer stainless steel skin. Helium gas fills the void spaces between the fuel and fuel basket, the basket manufacturing gaps, the voids between the fuel basket and MPC shell, and between the MPC shell and transportation cask inner liner.

B. Neutron Shield Char Model

The external neutron shield is assumed fully loaded with B$_4$C (6.5% by weight). The shield material has the potential to char when it is subjected to the high temperatures encountered in a fire. At low temperatures, the thermal conductivity, density, and specific heat of this material are 0.845 W/m-K, 1772 kg/m$^3$, and 1001 J/kg-K, respectively. The neutron shield material begins to lose organic components at 260°C, and all organic material is absent when its temperature reaches 650°C. At this temperature, the thermal conductivity is 0.237 W/m-K, and its density is 1676 kg/m$^3$. The variation of material properties with temperature in this range is assumed to be linear and irreversible. No further property changes are assumed at higher temperatures. The specific heat is assumed to be constant.

C. Thermal Simulations

Transient thermal conduction in the package solid structure and helium-filled void spaces is simulated using ANSYS 5.0. Radiation heat transfer across the void spaces is also included but natural convection is neglected. Each fuel assembly is modeled as a smeared solid having uniform volumetric heat generation (3620 W/m$^3$) and an "effective" temperature-dependent thermal conductivity.

Initially, the package is assumed to be operating at steady state under normal conditions of transportation (38°C ambient air, 388 W/m$^2$ insolation). It is then exposed to a thirty-minute, 800°C, fully-engulfing fire having a thermal emissivity of 0.9. The cask skin is assumed to have a thermal absorptivity of 0.8.

D. Shielding Calculations

The package is modeled as a cylinder with layered sidewalls, enclosing a homogenized mix of MPC design-basis PWR fuel, void, and basket structure. Assembly-average burnup is 42,000 MWD/MTU, ranging from 12,500 at each end to 60,000 in the middle. This yields a source strength of 7.7x10$^{19}$ photons/sec over energies
between 0.85-2.25 MeV. Neutron density varies as \( N(z) = C z^{1.94} \) at distances \( z < 165 \) cm from assembly ends, and is taken constant near the midplane. The source strength is \( 8.2 \times 10^5 \) neutrons/sec, nearly double that of uniform burnup, and follows a Watt spectrum. These calculations are expected to underpredict dose rates since they neglect secondary gammas resulting from neutron capture and secondary fission neutrons from the depleted uranium shield.

III. RESULTS

A. Maximum Fuel Temperature

Figure 2 shows the thermal response of the fuel assembly located at the package centerline. Our analysis shows that this is the maximum fuel clad temperature in the package for an 800°C fire of 30 minute duration. The figure shows thermal response obtained using the char model together with that obtained assuming no char effect (constant thermophysical properties). In both cases the fuel temperature does not change during the fire. It is seen to increase to a maximum of approximately 278°C roughly 16 hours after the fire is extinguished, followed by a gradual return toward the normal operating mode temperature. The constant properties assumption results in a slightly lower maximum temperature (about 1°C). The final fuel temperature predicted using the char model (264°C) is slightly higher than that predicted assuming no char effect (262°C) since the charred shield post-fire thermal conductivity is lower than the pre-fire value. Whereas the simulation predicts cask skin temperatures as high as 763°C at the conclusion of the fire, the maximum fuel temperature observed is well below the "never exceed" temperature limit of 593°C for short term thermal events.¹

B. Neutron Shield Charring

Figure 3 depicts the regions of neutron shield charring, where the gray-tone indicates the extent of shield char. Maximum charring occurs along the outer stainless steel skin and adjacent to the radial fins. For the present test condition, 60% of the neutron shield has experienced some degree of charring. However, the total neutron shield mass has decreased by less than 1%.

Two different models are used to evaluate the effect of neutron shield charring on external dose rates. If it is assumed that material experiencing any level of charring
loses all of its shielding capability, then the post-fire effective shield thickness is only 40% of its original value. On the other hand, if it is assumed that the shield effectiveness is proportional to its density, then the post-fire shield effective thickness is 99% of its pre-fire value.

Figure 4 shows calculated total primary dose rates at the cask surface, and at one and two meters from the surface, as a function of shield effective thickness (expressed as a percent of the original thickness). The figure shows that dose attenuation is nearly exponential and can be fitted with an effective removal cross section of 0.13 cm$^2$. The figure also shows that the present system, with a shielding effective thickness between 40% and 99%, has primary dose rates which fall well below 10-CFR-71 specifications for accident condition ($10^3$ mrem/hr at 1m from the surface).

IV. CONCLUSIONS

A model has been developed to simulate the thermal and shielding response of an MPC transportation package under conditions of a regulatory fire. The model includes the effect of charring on neutron shield characteristics. It is determined that charring has an insignificant effect on the thermal response of the fuel. Furthermore, while charring increases dose rates, these rates remain below NRC limits for accident conditions.

REFERENCES

2. Bisco Products, “Effects of 1300°F on Unfilled NS-

3,” Technical Report No. NS-3-020, Revision 0, Elk Grove Village, IL, 11/20/84.