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Parametric Thermal Evaluations of Waste Package Emplacement

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Introduction

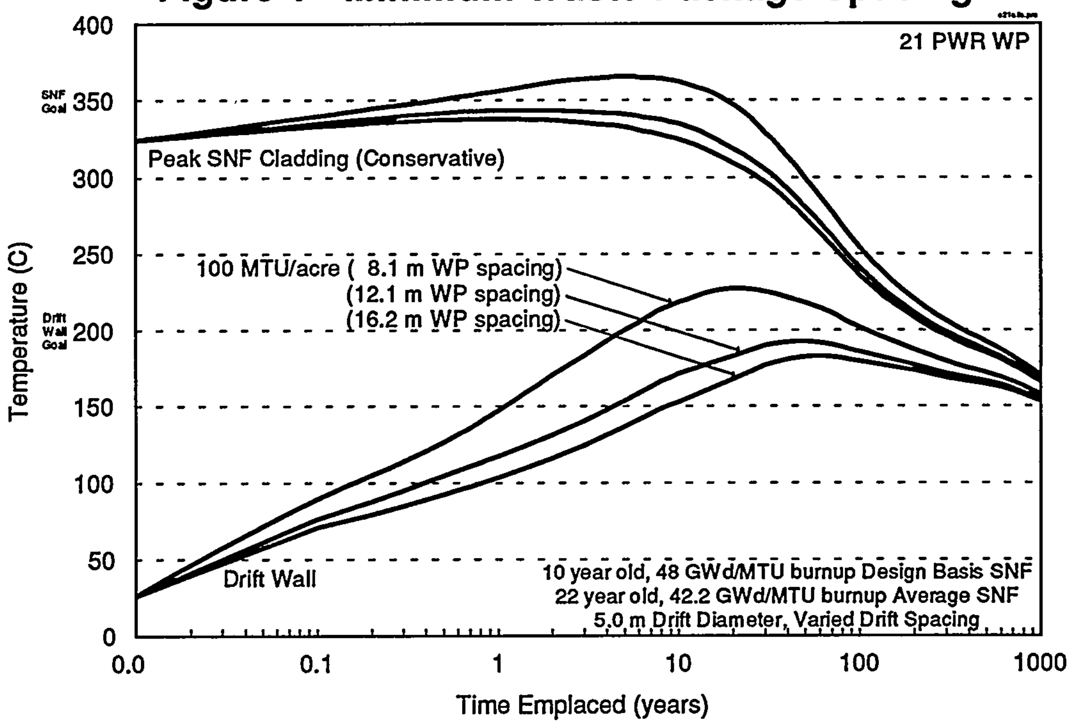
Parametric thermal evaluations of spent nuclear fuel (SNF) waste packages (WPs) emplaced in the potential repository were performed to determine the impact of thermal loading, WP spacing, drift diameter, SNF aging, backfill, and relocation on the design of the Engineered Barrier System. Temperatures in the WP and near-field host rock are key to radionuclide containment, as they directly affect oxidation rates of the metal barriers and the ability of the rock to impede particle movement which must be demonstrated for a safe and licensable repository. Maximum allowable temperatures are based on material performance criteria and are specified as the following design goals for the WP/EBS design[Ref. 1]: SNF cladding 350°C, drift wall 200°C, and TSw3 rock 115°C.

Base Evaluations

Using ANSYS, a 3-D finite element model of the potential repository was built to supply the boundary conditions (WP surface temperatures) for a more detailed model of the WP internals. Benchmarks (of this emplacement scale model) against V-TOUGH calculations at LLNL (mountain scale) have been performed[Ref. 2].

The spacing of the emplacement drifts and individual WPs determine the area mass loading (AML in MTU/acre) and the areal power density (APD, in kW/acre). The emplacement model was evaluated at thermal loadings of 100, 83, and 25 MTU/acre for the 21 and 12 PWR WPs. At the low loading, three different WP spacings were investigated. Thermal loading dominated long-term near-field temperatures which were about 153, 134, and 71°C at 1,000 years for the

Figure 1 - Minimum Waste Package Spacing



three thermal loadings, respectively. At 25 MTU/acre, WP surface temperatures could permit aqueous corrosion if water were present. Further discussion is provided in the WP Conceptual Design Report(Ref. 3).

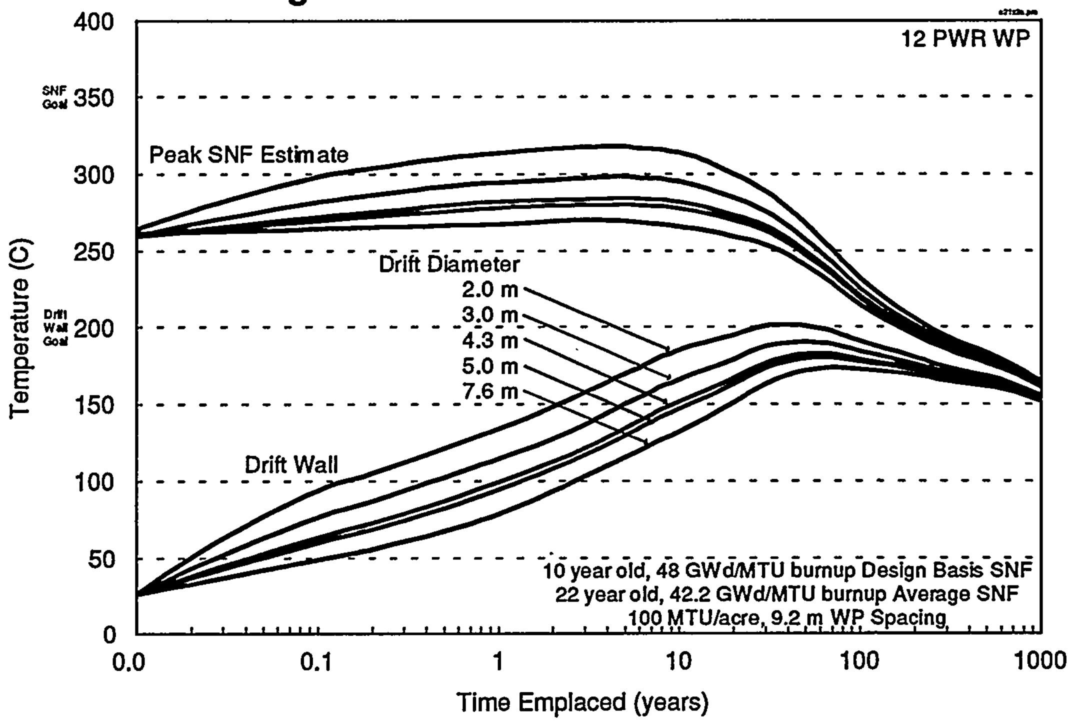
Minimum WP Spacing

At 100 MTU/acre, three variations on WP spacing (16, 12, and 8 m) were considered to determine a minimum WP spacing. Figure 1 displays the effect of shorter WP spacings on peak cladding and drift wall temperatures. Rock and cladding temperature thermal goals are clearly violated for the 8 m WP spacing and are near the limits or marginal with the 12 m WP spacing. Therefore, a minimum WP spacing of 16 m provides a conservative lower bound for large WPs.

Minimum Drift Diameter

Five emplacement drift diameters (7.6, 5.0, 4.3, 3.0, and 2.0 m) were investigated for 21 and 12 PWR WPs at 100 MTU/acre. Figure 2 displays the effect of drift diameter on peak cladding and drift wall temperatures. Rock temperature and cladding thermal goals are violated at diameters less than 4.3 m for the large WP, and 3.0 m is the minimum diameter for the 12 PWR

Figure 2 - Minimum Drift Diameter



WP. The impact (per meter) increases as drift diameters decrease, bounded by the case of borehole emplacement which is prohibitively hot for WP capacities greater than about 4 PWR assemblies. (Hundreds of years after emplacement, the temperature drop from WP surface to drift wall is small and drift diameter is less important.)

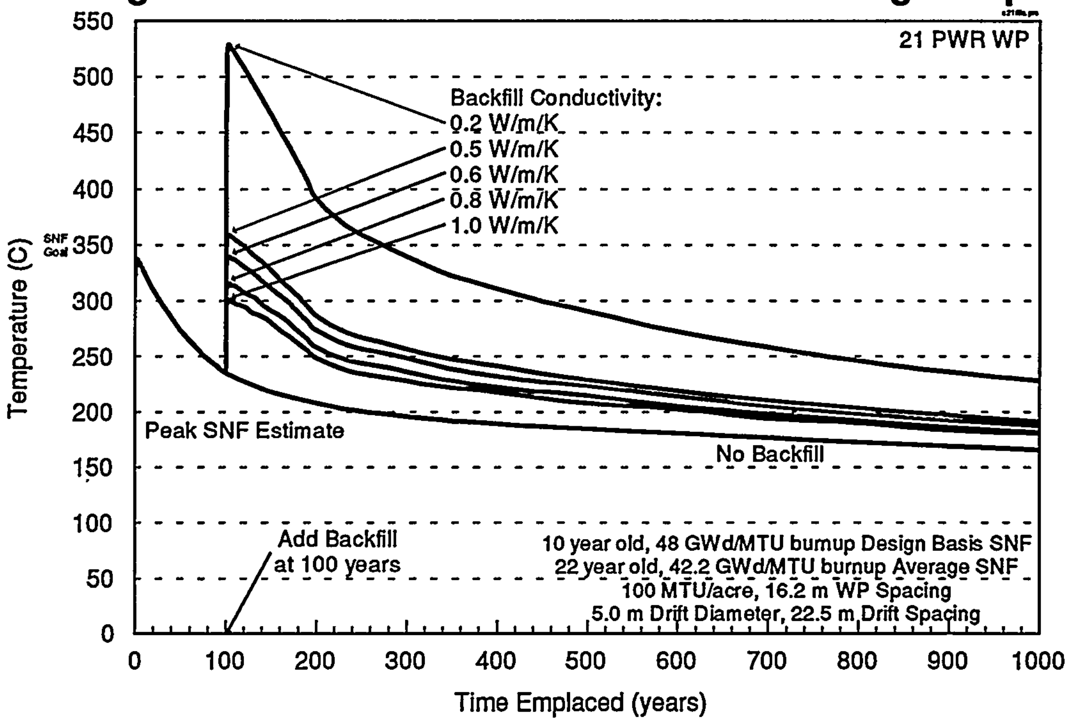
SNF Aging

An analysis was conducted to demonstrate the effect of aging SNF (22, 40, 80, and 100 years) before emplacement in a 21 PWR WP. SNF aging was found to reduce the short-term temperatures, but did not significantly alter the long-term thermal behavior of the repository. SNF aging of 40 years is required to maintain WP surface temperatures below boiling, and aging of over 100 years is needed to keep large WP surface temperatures below the range for aggressive corrosion (60 to 100°C) and may not be feasible.

Effect of Drift Backfill

Since it is not known what the backfill material will be, a parametric was devised to determine what thermal conductivity is needed to maintain cladding temperatures below the thermal goal.

Figure 3 - Effect of Drift Backfill on Cladding Temp.



As seen in Figure 3, a backfill conductivity of no less than 0.6 W/m•K is required to maintain cladding temperatures below 350°C when backfill is added at 100 years. This compares marginally to crushed tuff which can have a conductivity of 0.58 to 0.74 W/m•K(Ref. 4). If the backfill were added before 100 years, a much higher conductivity would be needed. Backfill at the time of emplacement would be much hotter than borehole emplacement, because typical backfill materials have conductivities lower than intact TSw2 rock (2.1 W/m•K).

WP Relocation

Conceptually, WPs could be repositioned in the emplacement drifts at repository closure (assumed 100 years) to increase AML and manage high initial WP heat loads. An evaluation was performed that doubled the AML (from 100 MTU/acre to 200 MTU/acre). Because the relocation takes place after 100 years, the SNF has aged sufficiently to avoid a violation of SNF cladding goals. However, the relocation does result in TSw2 rock temperatures much higher that the thermal goal of 200°C. Not only do maximum drift wall temperatures exceed the thermal goal, but average repository horizon temperatures exceed 250°C for more than 600 years and TSw3 goals are violated. It is concluded that relocations resulting in AMLs much above the maximum (100 MTU/acre) recommended by the FY 1993 Thermal Loading System Study[Ref. 5] will result in a violation of thermal goals.

Conclusions

Thermal loading (AML) will be the primary determination of long-term repository temperatures which affects engineered barrier corrosion mechanisms and rates and the ability of the host rock to impede the migration of radionuclides. However, several engineered barrier design issues are also important to meeting disposal thermal goals, repository operability, and containment lifetime; some affect short-term peak temperatures, and some affect the long-term. The impact of thermal loading, WP spacing, drift diameter, SNF aging, backfill, and other thermal management issues must all be understood to demonstrate the safety and licensability of the potential repository.

References

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