Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Residual Decay Energy Sensitivity for Long-term Cooling of Spent Nuclear Fuel

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1. Introduction

High density spent fuel racks must be so demonstrated to have sufficient cooling capacity for both previously stored refueling batch and freshly discharged fuels during all operation and accident conditions. Maximum spent fuel pool (SFP) bulk temperatures are below allowable limits of each nuclear power plant. Additionally, it must be shown that the local water and fuel clad temperatures do not exceed saturation temperature in any fuel cell location. In order to evaluate the maximum temperature, it is important to calculate decay heat contributions from both previously stored fuels and freshly discharged fuels. Decay heat used to be calculated in accordance with USNRC Branch Technical Position (BTP) ASB 9-2 as incorporated in validated computer code. According to recently revised SRP of NUREG-0800, ANSI/ANS 5.1 methods can be used in the calculation of residual decay heat. The difference of decay heat energy that compared BTP ASB 9-2 and ANSI/ANS 5.1 methods was evaluated.

2. Methods and Results

2.1 USNRC BTP ASB 9-2

According to branch technical position of NUREG-0800 para. 9.2.5. Rev.2, BTP ASB 9-2 has developed to calculate residual decay energy release rate using acceptable assumptions and formulations. The total residual decay heat is sum of decay heat generated by the fission product and the heavy elements. The fission product decay is calculated by cumulative reactor operating time and time after shutdown with uncertainty factor. Uncertainty factor is 0.2 (20%) for any cooling time less than 10^3 seconds and uncertainty factor is 0.1 (10%) for cooling time between 10^3 and 10^7 seconds. Experimental data used in fission product decay have been considered reliable for decay times of 10^3 to 10^7 seconds. Over this decay time, the decay heat rate can be predicted to within 10% of experimental data.

2.2 ANSI/ANS 5.1

This standard calculate the decay heat energy from fission products and actinides after shutdown of reactors using initial enrichment of U-235 and U-238. The equation of ANSI/ANS 5.1 consist of fission products decay heat, neutron capture decay heat, contributions from the decay of uranium and neptunium and contributions from all other actinides. It increases the accuracy of fission product decay heat results without complex calculations. This method applies to shutdowns times up to 10^{10} seconds and should not be extrapolated over 10^{10} seconds.

2.3 Discharge Scenarios for SFP

The fuel assemblies are conservatively assumed to be irradiated for 3 period in reactor prior to discharge. The decay heat calculation for both old fuels and freshly discharged fuels is performed using BTP ASB 9-2 and ANSI/ANS 5.1 in accordance with discharge scenarios. Three discharge scenarios are considered for decay heat energy sensitivity evaluations. The design of individual storage cells and total racks can be kept sufficiently cool by natural convection cooling water flow past the fuel assemblies for meeting the following design bases.

a. Case 1: This case is normal power operating scenario. Spent nuclear fuel pool cooling train is capable of removing the decay heat from one(1) refueling batch discharged 150 hours after shutdown plus the maximum number of previous refueling batches to maintain a bulk temperature of spent nuclear fuel pool water not exceeding criteria.
b. Case 2: Spent nuclear fuel pool cooling train is capable of removing the decay heat from one(1) full core discharged 150 hours after shutdown plus the maximum number of previous refueling batches to maintain a bulk temperature of spent nuclear fuel pool water not exceeding criteria.
c. Case 3: Two(2) combined spent nuclear fuel cooling pool trains are capable of removing the decay heat from one(1) full core discharged 150 hours after shutdown plus one refueling batch 480 hours after shutdown in addition to the maximum number of previous refueling batches to maintain a bulk temperature of spent nuclear fuel pool water not exceeding criteria.

2.4 Analytical Results

BTP ASB 9-2 and ANSI/ANS 5.1 methods are compared to evaluate residual decay heat sensitivity. Figure 1 and 2 show residual decay heat rate dependent on time after reactor shutdown using each method. For the shutdown times less than 10^5 seconds, residual decay heat using BTP ASB 9-2 methods is 2 to 23% greater than ANSI/ANS 5.1 methods. However, if the shutdown time is greater than 10^6 but less than 10^7

seconds, residual decay heat using BTP ASB 9-2 methods is 1 to 4% less than ANSI/ANS 5.1 methods.

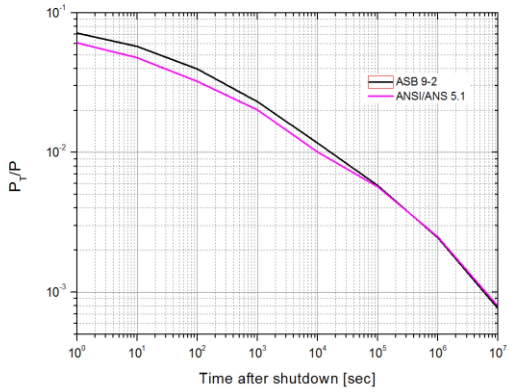

Fig. 1. Comparison of time-dependent decay heat generation rate between ASB 9-2 and ANS 5.1

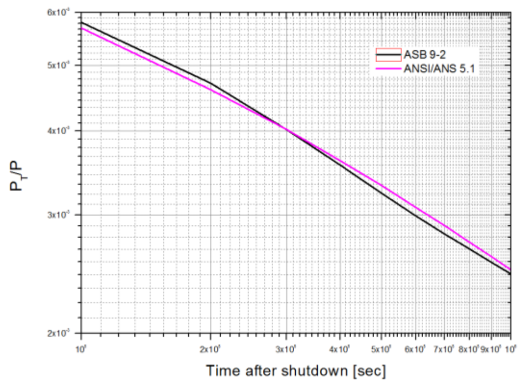

Fig. 2. Comparison of time-dependent decay heat generation rate between ASB 9-2 and ANS 5.1(10^5<t<10^6)

Figure 3 to 5 show residual decay heat rate dependent on time after reactor shutdown in each discharge scenarios. All of these cases shows residual decay heat using ANSI/ANS 5.1 methods is greater than BTP ASB 9-2 methods.

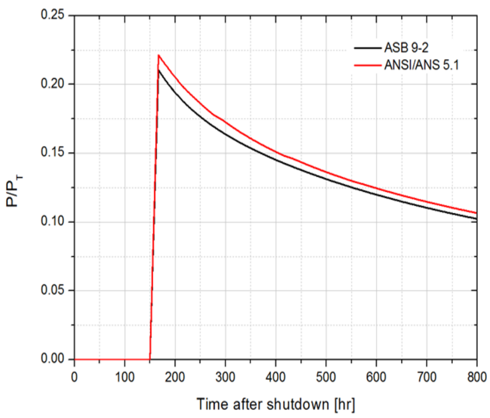

Fig. 3. Comparison of decay heat generation for Case 1

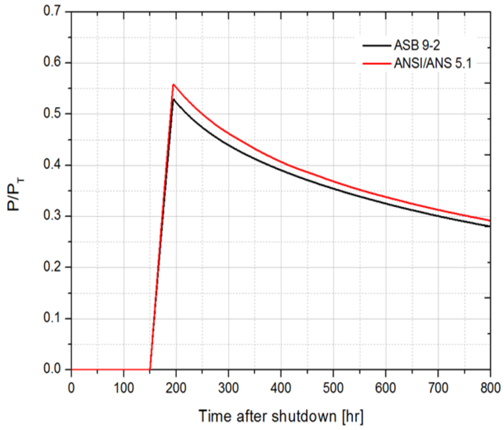

Fig. 4. Comparison of decay heat generation rate for Case 2

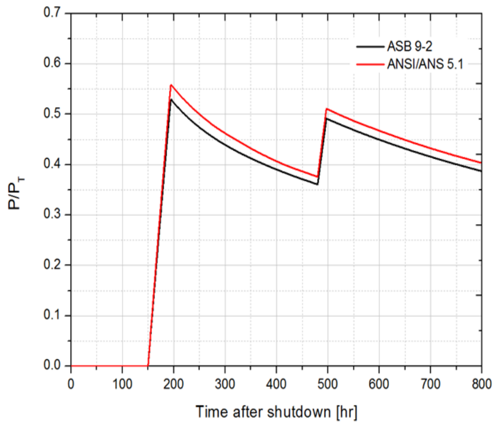

Fig. 5. Comparison of decay heat generation rate for Case 3

3. Conclusions

Residual decay heat energy calculation results was compared using BTP ASB 9-2 and ANSI/ANS 5.1 methods. Since the SNF is discharged to the SFP after 150 hour of shutdown in the reactor, ANSI/ANS 5.1 method is more conservative, even though BTP ASB 9-2 method has a higher decay heat energy at 10^5 seconds or less.

REFERENCES

[1] NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", Section 9.1.3 Spent Fuel Pool Cooling and Cleanup System.

[2] Regulatory Guide 1.13, "Spent Fuel Storage Facility and Design Basis".

[3] ANSI/ANS-5.1, "Decay Heat Power in Light Water Reactors", 2014

[4] NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", Section 9.2.5 Ultimate Heat Sink. Rev. 2.