DRAFT WHITE PAPER
AN ASSESSMENT ON INDUSTRY COMMENTS ON SPENT FUEL ZIRCONIUM FIRES

The industry comments fell into two categories: (1) the ignition temperature of the zirconium (zircalloy, or Zr-4), and (2) the time frame (critical decay rime) during which a Zr-4 fire may occur following a plant shutdown.

1. Ignition Temperature

The staff's review of a wide range of reports lead to a wide range of reported temperatures interpreted as ignition temperatures. This interpretation is not technically accurate.

The fire protection sources, with temperatures ranging from 1,300 °C to 1,600 °C, appear to be concerned with temperature sources that are sufficiently high to reach self-sustaining oxidation, or ignition of the metal. These data likely involved application of the high temperature heat source to the metal surface which may have rapidly developed an oxide layer that could have inhibited the ignition (one paper reported the ignition temperature of ZrO_2 to be about 4,000 °C). SPSB staff has not reviewed the references in detail but discussed them with SXRB. These temperatures are also above the Zr/Zr-4 mono-tetragonal phase point of 1,150 °C.

The second range of values came from sources concerned with the oxidation of zirconium, or zircalloy (Zr-4), in air. The point at which rapid oxidation occurs was reported (page 8) to be in the 850 ° to 950 °C range (based on the 1979 Sandia work). A further review of the Sandia report showed that the lower value was closer to 800 °C, as reported elsewhere in the working group report. (The report should be reviewed to assure the temperatures are consistent between sections.) At this temperature the exothermic reaction leads to an extremely high rate of cladding temperature increase. Although not addressed in the working group report, the onset of oxidation, the point at which the addition of heat to the cladding is significant, is about 600 °C based on the 1979 Sandia correlation for the oxidation rate. A lengthy review of available Zr/Zr-4 oxidation data was documented in NUREG/CR-4982. Unpublished data was used to develop an alternate oxidation rate model. That model would have shown the onset of oxidation at 740 °C but with an oxygen consumption rate about 3-times faster than the Sandia model. There is no reason to believe the Zr/Zr-4 oxidation rate equations are in error.

To preclude rapid ("run away") Zr-4 oxidation, the cladding temperature needs to be below 800 °C (as reported). If the release of gap activity (for example, shortly after shutdown when the noble gases have not decayed) resulting from cladding ballooning and rupture is to be avoided, then the cladding temperature needs to be below 570 °C (as reported).

2. Critical Decay Time

The critical decay time is dependent on several factors, including (1) fuel burnup, (2) storage rack design, and (3) availability of air to provide cooling. In NUREG-1353, the critical decay time was evaluated to be one to two years (high density racks, PWR) based on the fuel burnup and rack designs considered and with adequate ventilation (air flow).

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Current storage configurations and higher burnups have increased the critical decay time. The BWR critical decay times are now similar to the PWR. This is a result of the reduced spacing between fuel assemblies and between the racks and spent fuel pool wall which limits the air cooling capability. The increased burnup also increases the time for the decay heat to be reduced to a decay heat generation level low enough to preclude rapid Zr-4 oxidation, determined to be about 6 kW/MTU. These two factors combine to increase the critical cooling time to about three years.

If inadequate ventilation is considered, the critical cooling time was estimated to be about three to five years. This is consistent with the 1979 Sandia report which reported two to four years for inadequate ventilation — and adding an additional year for the current burnup rates.

SUMMARY

The working group report my need additional editorial review to assure that the information provided in different sections is consistent.

The onset of rapid oxidation is 800 °C. A decay heat generation level of about 6 kW/MTU is a reasonable surrogate that can be used to find the critical decay time for a well-ventilated building to preclude significant spent fuel failure following a loss-of-inventory.

The three to five-year estimate for the critical decay time, based on high density storage racks, high fuel burnup and poor ventilation, is reasonable based on current analytical tools. Binning plants by the three factors may be possible.

Unfortunately the current analytical tools cannot address plant specific storage conditions (for example checker board patterns or new fuel near very old fuel) making it difficult to find the critical decay time. For temperatures above 565 °C, the current analytical tools do not have models for fuel element or storage rack failures further reducing their capabilities to find the critical decay time.