9. Partial draindown

The partial drain down scenario may extend the critical decay time well beyond 5 years. Current calculations indicate that decay times in excess of 20 years may be needed to preclude fuel damage from a partial drain down.

10. Hydrogen generation from partial draindown.

Steam oxidation will release hydrogen. The hydrogen concentrations or the consequences of any subsequent hydrogen burn or explosion have not been calculated.

11. Energy of reaction for air oxidation.

The draft report is correct. The author of the comment has made a fundamental error. There are 92 grams of Zirconium in a mole. The authors calculation is based on 92 kg in a mole.

13. Zirconium-hydrides

Fuel cladding can contain high concentrations of zirconium hydride at the oxide-cladding interface in high burnup fuel. The effect of zirconium hydride on cladding oxidation rates is unknown at this time. If the oxide layer stays intact the reaction rates should be similar to cladding oxidation rates without zirconium hydride since the rate is determined by the diffusion of oxygen through the zirconium oxide layer. The effect of the hydrogen reaction product on the oxide film and oxidation rate is unknown. It is possible that cladding rupture at a temperature near 700 °C may lead to autoignition of the cladding due to the reaction of oxygen with zirconium hydride. Air oxidation experiments with high burnup cladding are needed to resolve the reaction rate and autoignition issues.

14. Breakaway oxidation.

Breakaway oxidation can have a significant impact. Breakaway oxidation has been observed to occur in experiments Ref [6,7] measuring oxidation rates of zirconium and zircaloy-4 in air. Breakaway oxidation has not been observed in pure oxygen. The lower temperature limit for breakaway oxidation in zircaloy-2, zircaloy-4 or any advanced zircoinium alloy is unknown. An experimental program would be required to quantify the effect of this potentially important physical phenomenon. The experiments should examine the effect of fuel burnup on this phenomenon. The limited data available indicates that the lower temperature limit for breakaway oxidation in zircaloy-4 is lower than the lower limit observed in pure zirconium but the lower limit has not been determined. The mechanisms that induce breakaway oxidation are unknown at the present time. Therefore data should be taken under conditions that are as prototypical as can be achieved.

15. Nitrogen reaction.

It has been shown that the presence of nitrogen increases the rate of oxidation of zirconium. The oxidation rate is a weekly increasing function of nitrogen fraction over a wide range of relative nitrogen fractions. [Ref 6] The reaction rate of nitrogen with zirconium is approximately 20 times lower than the oxidation rate. The energy of reaction of zirconium with nitrogen is also less than the energy of reaction with oxygen. Therefore, the heat input from the nitrogen reaction should be a small perturbation to the oxidation heat input except for very low oxygen

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concentrations and in that case the fuel has already reached its failure point and a large release is underway.

16. Clad rupture can release fission products.

Cladding rupture can release gap gases. Additionally the interaction of the fuel with air can cause the release of fuel fines and fission products such as ruthenium trapped in the fuel that will provide a source term that significantly exceeds the classical gap release.

17. Intermetallic reactions.

RES has not provided the information needed to evaluate this.

18. NEI: need standard methods for T/H analysis.

There is no current technical basis to support a standard methodology for T/H analysis.

19. Gap release temperature too conservative for success criteria.

The criteria for gap release may also be the threshold for releasing fuel fines and Ruthenium. (See 16)

20. Fire propagation to low powered fuel unlikely.

Sufficent research has not been performed to rule out propagation to even the lowest powered assemblies and past (GSI 82) did not evaluate potentially significant effects such as the impact of rubble from failed assemblies on fire propagation. In any event the uncertainty in the source term is probably exceeded by the uncertainty in the PRA.