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Considerations on LOCA criteria including high burn-up effect

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ABSTRACT

The current LOCA criteria state that the cladding must retain some ductility after having been exposed to high temperature oxidation in steam environment. In practice, this means that the LOCA transient must have a limited duration and/or limited temperature. How limited time and/or temperature should be depends on the cladding material, on its thickness and, for irradiated cladding, on the corrosion during irradiation.

In this paper, the zero-ductility LOCA criterion is treated in terms of a temperature parameter called T_{300s}, which is the temperature a given cladding would withstand for 300 seconds. Why this parameter has been chosen is explained in the paper. The higher this temperature is, better is the quality of the cladding in term of LOCA resistance.

Three types of cladding have been considered, namely Zr-4, E110 and M5. Based on the data considered in this paper, non-irradiated Zr-4 and M5 behave similarly, whereas the E110 has somewhat lower LOCA endurance. Quantitatively, this is expressed through the T_{300s} parameter as follows:

- For Zr-4 wall thickness=0.576mm T_{300s} = 1157ºC at zero burn-up
- For E110 wall thickness=0.650mm T_{300s} = 1040ºC at zero burn-up
- For M5 wall thickness=0.576mm T_{300s} = 1157ºC at zero burn-up

This means that for a given transient, Zr-4 and M5 would have a ~100ºC greater margin than the E110 cladding. The effect of cladding thickness is discussed in the paper, showing that a 0.1 mm thickness reduction results in a ~30ºC decrease of T_{300s}.

A provisional burn-up dependent criterion has been derived on the basis of the few useful data available in the literature. These refer to separate effect tests made at JAERI with non-irradiated cladding containing different amount of hydrogen to simulate hydrogen pick-up during base irradiation. Considering the corrosion of the three materials, it is inferred that:

- For Zr-4 wall thickness=0.576mm T_{300s} = 944ºC at 70 MWd/kg
- For E110 wall thickness=0.650mm T_{300s} = 1020ºC at 50 MWd/kg
- For M5 wall thickness=0.576mm T_{300s} = 1128ºC at 70 MWd/kg

As one can notice, Zr-4 is predicted to loose 200ºC on ductility limit at high burn-up, whereas the limit changes only slightly, i.e. by 20-30ºC, for the E110 and M5. The reason is in the low base-irradiation corrosion for E110 and M5 as compared with Zr-4.

The paper addresses the determination of an equivalent temperature and time, such that transients with different temperature history can be compared with each other as well as with a constant

high temperature condition. At the end, the paper discusses very briefly the 1204ºC temperature limit, observing that it seems unreasonable to prohibit that temperature exceeds 1204ºC for few seconds, when we accept it can stay at 1200ºC for over 2 minutes. A possible way to comply with this is outlined in the paper.

No standpoint has been taken on the experimental method for defining the zero-ductility threshold, as this was beyond the intent of this exercise. However, since the current criteria are based ring compression tests after two-side oxidation, it appears that one would need a very good justification for choosing other types of testing. In any case, unirradiated Zr-4 material should always be used as reference. Finally, it should be noted that in spite of many investigations the source of useful LOCA data on high burn-up materials remains very limited.