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Two Tube Failure Event for the Helium Cooled Blanket

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Background of this Safety Issue

- **Two tube failure event**
  - **A two tube failure accident scenario begins with the failure of a blanket helium cooling tube that results in the over-pressurization and failure of a blanket module; then a steam generator tube also fails, allowing steam to enter the failed module and react with the beryllium multiplier pebbles**
- **Safety questions:**
  - **What are the safety concerns associated with this accident?**
  - **Given the category of accident we are dealing with, are accident mitigation measures needed for this accident?**
  - **If mitigation measures are required, which measures are preferred?**

Background (cont. 1)

- **The safety concerns with this accident are the production of hydrogen and the potential of hydrogen explosions failing confinement boundaries**
  - **To date a detailed analysis of this accident has not been performed to assess the extent of the problem, including whether or not this accident will be confined to a single module or will propagate to adjacent modules because of the heat produced by the beryllium-steam reactions in the failed module**
  - **We hope to perform an analysis of this accident for the failed module within the next several months; our design point will be the ARIES-I blanket concept**
- **Based on the accident category:**
  - **If the two tube failure scenario falls into the beyond design basis accident (BDBA) category (frequency < 10^{-6}/yr) and if the accident poses no serious safety risks (hydrogen explosions), then mitigation measures will not be required**
  - **If the accident poses serious safety concerns then mitigation measures will be required**

Background (cont. 2)

- There are at least three passive mitigation measures or systems that could be adopted
  - The strong box approach developed for the European Demo blanket design; however, then the blanket modules become safety grade systems which must be qualified and undergo periodic testing over the blanket lifetime
  - Steam dump valves on the secondary cycle that are regulated by pressure lines tied into the primary helium system (i.e., the spring of a standard pressure relief valve replaced by a pressure feed from the primary); however, adding valves adds other possible accident scenarios
  - Eliminate the secondary steam cycle by using a Brayton cycle operating directly on the primary system helium coolant

A Brief Analysis has been Performed

- **To determine the accident category of this two tube failure scenario, three cases were considered:**
  - **Failure of a blanket tube followed by the independent failure of a steam generator (SG) tube**
  - **Failure of a blanket tube combined with a pre-existing steam generator tube leak**
  - **Failure of a blanket tube and the dependent failure of a SG tube; that is, a blanket tube failure that causes an SG tube to fail**

Independent Tube Failures

- **An independent tube failure assessment assumes that the failures of the two tubes being considered are independent events; that is, the failure of the first tube does not result in a condition for the second tube that is outside of the second tubes' design envelope. Based on Gas Cooled Fission safety studies this would appear to be a credible assumption.**
- **For any one of the ~30 blanket modules plumbed to one SG (assuming the torus to be divided into quadrants), we estimated roughly 1 km of He tubing from the EU blanket module design drawings. The helium tube rupture failure rate was taken to be $1x10^{-11}$/h-m. This gave $2.6x10^{-3}$/year as the blanket tube rupture frequency for a 30-module quadrant.**
- **Past GA safety work discussed SG tube failures in HTGRs. A conservatively high value of $7x10^{-3}$/rx-year was used for SG tube rupture. One hour was assumed as the accident duration time before the blanket was too cool for Be-steam reactions.**
- **Therefore, the coincident, independent failure of two tubes would equal $2.6x10^{-3}$/year x $7x10^{-3}$/rx-year x 1 rx/4 SGs x 1 h/8760 h/year = $5x10^{-10}$ /year, which is a BDBA.**

Blanket tube failure with pre-existing SG tube leakage

- PWRs have had troubles with SG integrity, so SG tube leakage was briefly investigated as a safety concern. If a blanket tube failed with pre-existing steam leaks, the accident frequency would be greatly reduced.
- HTGRs have usually operated with the steam pressure higher than the helium pressure since the helium had fission product gases, tritium, CO and CO_2 gases with C-14, etc., that required confinement.
- Past HTGRs have operated very leak tight, ~ 3E-06 atm-cm^3/s. Newer fission plants (HTTR, HTR-10) and designs (NPR, Gen IV, etc.) also indicate that very tight SG systems are expected.
- Steam leaks were not considered to be a problem for ARIES due to the normal operation of helium at higher pressure than the steam and historical experience shows HTGR SGs have low leakage.

Dependent SG Tube Failure

- This assessment investigates failure scenarios where the first tube failure leads to conditions that would fail the second tube. This could be the case if the primary helium coolant blowdown time is extremely short (on the order of one second).
  - Sudden pressure change of 70 atm on the tubes leading to overstress failure
  - Higher gas flow rate leads to higher flow-induced pressure forces on the tube bundle
  - Acoustic waves in helium cause tube vibration, and faster gas flow augments the acoustic waves
- Analysis performed for the Peach Bottom I SGs showed that large breaches of 0.2 and 0.75 m^2 did not damage the SGs. The EU blanket tube breach is only $1.26x10^{-05}$ m^2.
- PWR SGs typically operate with ~80 atm pressure difference from primary (150 atm) to secondary (67 atm).
- Because the primary depressurization time for a single blanket tube break is ~160 s, dependent tube failures are not viewed as a credible result of a blanket cooling tube breach event.

Conclusions

- **The preliminary analysis results are:**
  - **the independent failure of a blanket tube and an SG tube is a BDBA at an occurrence frequency of $5x10^{-10}$/year**
  - **pre-existing tube leaks are not considered to be a significant concern**
  - **dependent SG tube failures are not considered to be a credible result of a small tube breach event**
- **Since this accident is thought to be a BDBA, passive or active measures or systems will only be required if detailed analysis indicates that radiological doses to the public do not meet regulatory limits; which measures to adopt if dose limits are exceeded are entirely up to the designer's discretion.**
- **Brad Merrill will perform a detailed analysis of this accident scenario to determine hydrogen production, heat release, and radioactive material mobilization to characterize the BDBA.**