Oxidation of Graphite Walls: Preliminary Results from SOMBRERO Safety Analysis

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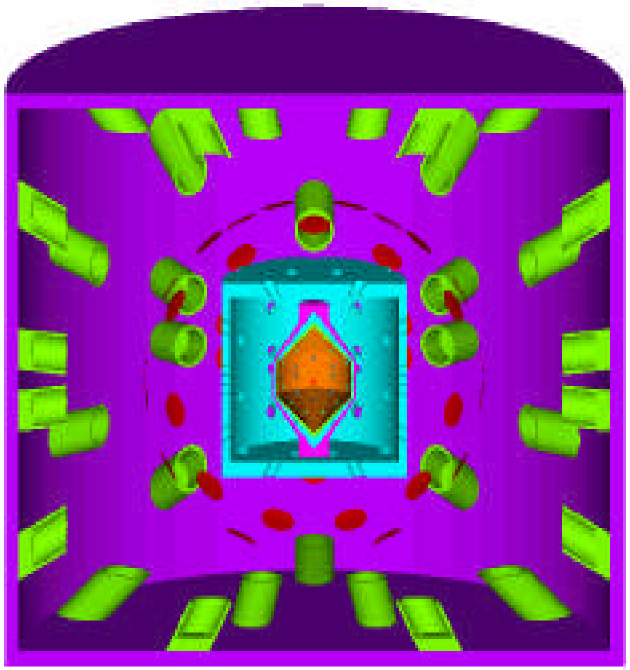
SOMBRERO is an attractive conceptual IFE power plant of relatively simple design



- SOMBRERO is a conceptual design for a 1000 MW_e laser-driven IFE power plant
- Safety and environmental attractiveness has been given strong emphasis since the original report
- Design uses a low activation material (C/C composite) for chamber structures
- Xe gas atmosphere (0.5 torr) used to protect FW from target emissions
- Blanket consists of a moving bed of solid Li_2O particles flowing in a He carrier gas through the chamber

LLNL is conducting safety analyses for SOMBRERO

- Recent work has pointed out the need to address key safety issues
  - tritium retention in C/C composites (seems to be more important than reported originally)
  - graphite oxidation with air (appears to be significant even at T < 1000 °C)
  - discussions with INEEL and U. Wisconsin colleagues have been great help
- We have performed a worst-case accident analysis for SOMBRERO
  - need to be conservative at this early stage
  - similar analysis will be performed for more credible, less severe accidents
- Accident consists of
  - total ***loss of flow accident*** (LOFA) in the 4 circuits of the coolant loop
  - simultaneous ***loss of vacuum accident*** (LOVA) with air ingress produced by 1 m^2 breach in confinement
- Our goal is to meet DOE requirement of accident dose ≤ 1 rem (10 mSv) in a worst-case scenario for no public evacuation

Codes and methodologies

- Codes traditionally used for MFE safety studies have been adopted and adapted for IFE safety analysis

- **CHEMCON** heat transfer code:
  - simulates time-temperature excursions of components due to radioactive afterheat and carbon oxidation (oxidation package has been enhanced)
  - time-temperature histories are then used to evaluate mobilization fractions during the transient

- **MELCOR** thermal hydraulics code:
  - uses the calculated radioactive source term available for mobilization
  - models thermal-hydraulics and aerosol and fusion products transport and release
  - new module introduced by INEEL allows simulation of HTO transport and condensation.

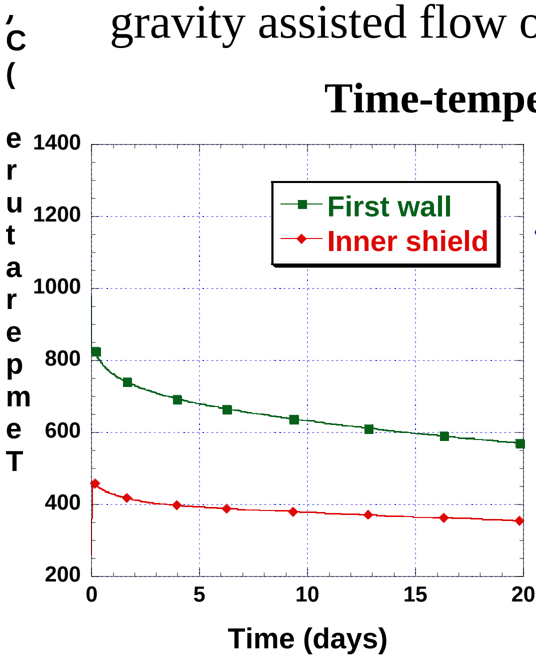
Time-temperature history of reactor components

- There are various energy sources to be considered during the accident:
  - **fusion reactions** will stop due to graphite evaporation increasing the pressure of the building and stopping beam propagation (shutdown)
  - **radioactive decay heat** from activated structures is low enough to allow a rapid cooling of FW/blanket structures (T < 1000 °C in less than 1 minute)
  - **oxidation heat** from exothermic graphite/air reaction must be considered
- 1D cylindrical CHEMCON model used to calculate heat transfer and graphite oxidation
- Preliminary calculations showed that the FW burnt in only 2 hours (the whole FW/blanket structure in about a day and a half)
- Oxidation should be limited by the partial pressure of oxygen in the surroundings of the FW/blanket
  - chamber/confinement initially at vacuum and oxygen must travel through the building
  - oxygen must diffuse across CO gas layer generated by the oxidation

Oxidation of carbon with air can be an issue

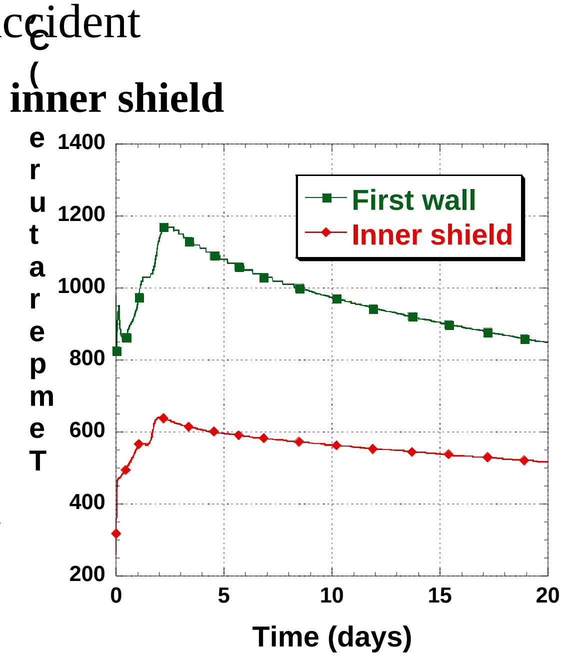
- Iterative process and feedback using the CHEMCON to get the CO source and MELCOR to obtain the oxygen partial pressure
- Convergent solution shows that FW burns in ~ 7 hours (oxidation rate is still significant at T < 1000 °C)
- INEEL has recently introduced a new oxidation module in MELCOR, and preliminary calculations confirm our results
- Future work will consider possibility of some level of passive cooling due to gravity assisted flow of Li_2O at the beginning of the accident

Time-temperature evolution of first wall and inner shield



DUE TO AFTERHEAT ONLY

DUE TO AFTERHEAT + OXIDATION



Activation products source term

- Assuming that oxidation takes place, the radioactivity source terms available for mobilization are:
  - total mass of **carbon** from FW/blanket structures (due to graphite oxidation with air)
  - fraction of **Li_2O** inventory present in the chamber in the moment of the accident (1/3 of the total 2000 tonnes)
  - we assume 1 kg of **tritium** trapped in the FW (instead of 10 g from original report), getting a total of 1.173 kg of tritium in all reactor structures which will be mobilized during the accident
  - the **target bay gas** (Xe in the SOMBRERO report) with all its activation products
- If oxidation could be avoided (thus eliminating a significant temperature excursion) then only the target bay gas and 0.173 kg of tritium would be mobilized during the accident

Safety analysis for SOMBRERO: results

- Afterheat is low enough to allow rapid cooling of structures (T < 1000 ºC in less than 1 minute)

- Oxidation of carbon structures is still significant at T   1000 ºC

- The activation products for Xe (cesium and iodine) are the main contributors to accident dose, possible solutions are:
  - removal of I and Cs by the chamber vacuum system
  - alternative gas such as Kr

- Simple modifications in the confinement building material would enhance HTO condensation on walls, reducing off-site dose

- The work on SOMBRERO safety analysis obtained the “Best Student Paper” Award at the last TOFE meeting (Park City, October 2000)

Conclusions

- Oxidation of graphite structures may be an issue in case of an air ingress event in the chamber
- The reaction rate seems to be significant even at the low accident temperatures (T 1000 ºC)
- Oxidation should be avoided
  - passive safety feature should be easy to implement (inert gas released from tank by rupture disk failure when a differential pressure is reached)
  - protective coatings for C/C composites (Si-B-C coatings)
  - alternative materials for FW and/or blanket structures
- Tritium inventory:
  - tritium trapped in FW/blanket may be greater than 1 kg according to available data (need more accurate estimation)
  - use of steam in the He carrier gas may reduce tritium inventory but needs to be evaluated