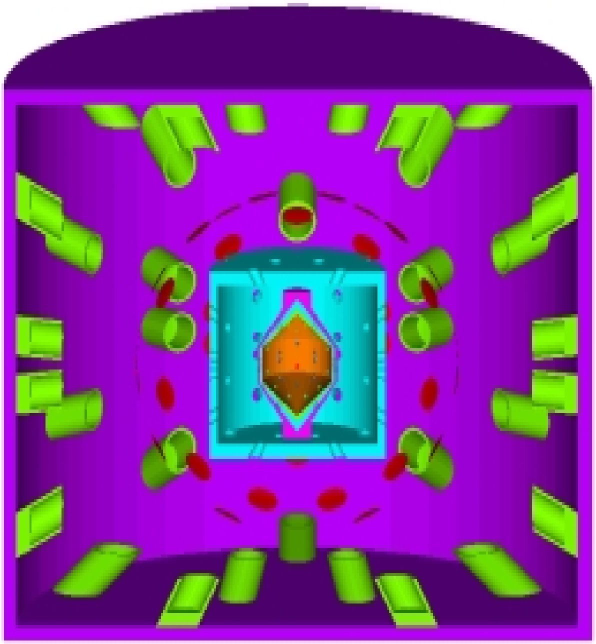
SOMBRERO is an attractive conceptual IFE power plant of relatively simple design

- 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



- 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 U. Wisconsin and INEEL 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) 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.

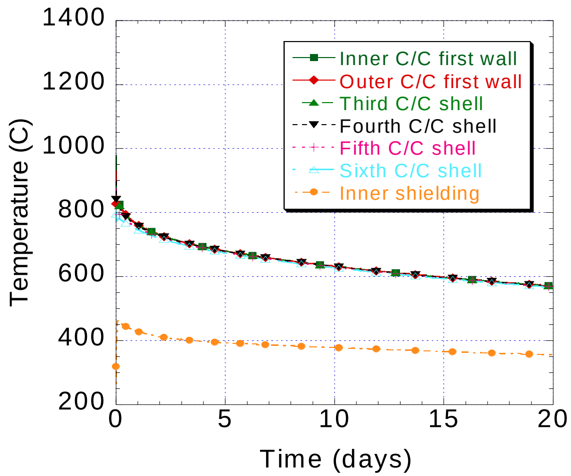
Time-temperature history of reactor components

- 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

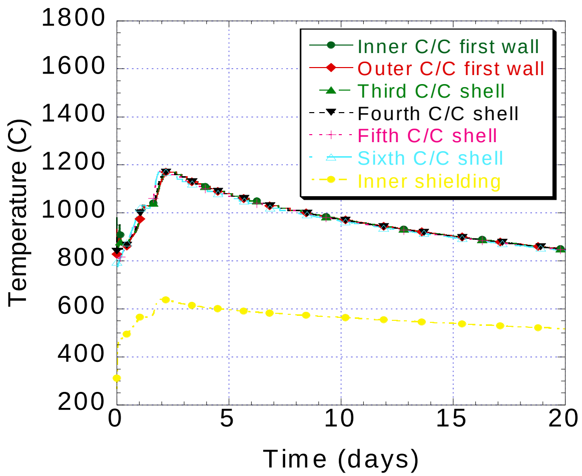
Time-temperature history of reactor components (cont)

- Iterative process and feedback is needed using the CHEMCON (oxidation code) to get the CO source and MELCOR (thermal-hydraulics code) to get the oxygen partial pressure

- Convergent solution shows that FW burns in ~ 7 hours (oxidation rate is still significant at T < 1000 °C)



Time-temperature evolution of reactor components due to decay heat



Time-temperature evolution of reactor components due to oxidation and decay heat

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 **chamber 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 chamber gas and 0.173 kg of tritium would be mobilized during the accident

Radioactivity release and off-site doses: with oxidation

Radioactive source	Mobilized activity (Bq)	Release fraction (%)	Dose at site boundary (rem)
C_FW	6.1E+14	100	0.05
C_blanket	1.4E+15	100	0.12
Li_2O	5.8E+18	1.5E-04	0.00
HTO	4.2E+17	19	0.78
Xe/Xe*/Kr	1.4E+16/1.4E+16/8.8E+15	100/100/100	4.69/0.24/0.11
Total with Xe/Xe*/Kr	**6.2E+18/6.2E+18/6.2E+18**		**5.64/1.19/1.06**

Xe* = Xe with clean up of iodine and cesium activation products

- The total dose is dominated by the activated Xe chamber gas, which contributes 4.69 rem to the global result
- Design using Xe would lead to a dose of **5.64 rem** if the iodine and cesium activation products are included in the release (would be **1.19 rem** if these isotopes can be removed by the chamber vacuum system)
- For a modified Sombrero using Kr, we calculate a total off-site dose of **1.06 rem**

Radioactivity release and off-site doses: with oxidation (cont)

- DOE requires dose ≤ **1 rem** (10 mSv) for no public evacuation
- Assuming Xe* (with clean up) or Kr is used as the chamber gas, the dose is dominated by the tritium
- Reducing the temperature of the concrete building by increasing its thermal conductivity will enhance HTO condensation on walls
- Two options are proposed:
  - increasing steel content in concrete form 2.8 % to 5% vol. would reduce the tritium release to 14% and the final dose to **1 rem** case of Xe*, and **0.87 rem** case of Kr
  - using concrete with 3% vol. aluminum would give a tritium release fraction of 11% and a total dose of **0.81 rem** case of Xe*, and **0.68 rem** case of Kr
- Any of these design modifications results in dose ≤ 1 rem → no evacuation plan would be needed

Radioactivity release and off-site doses: without oxidation

Radioactive source	Mobilized activity (Bq)	Release fraction (%)	Dose at site boundary (rem)
HTO	6.2E+16	2.8	0.02
Xe/Xe*/Kr	1.4E+16/ 1.4E+16/8.8E+15	100/100/100	4.69/0.24/0.11
Total with Xe/Xe*/Kr	**7.6E+16/ 7.6E+16/ 7.1E+16**		**4.71/0.26/0.13**

Xe* = Xe with clean up of iodine and cesium activation products

- In this case the only radioactive source terms are the chamber gas and the 172.6 g of tritium trapped in structures other than the carbon FW/blanket

- Design using Xe results in **4.71 rem** if the non-xenon activation products were included in the release (only **0.26 rem** if the iodine and cesium isotopes were removed by the chamber vacuum system)

- For a modified version using Kr instead of Xe, the final off-site dose is **0.13 rem**

Conclusions

- Assuming oxidation of carbon structures, dose is **5.64 rem** in the case of Xe as chamber gas and **1.06 rem** if Kr is used instead
- Simple modifications in the confinement building material would reduce the dose below **1 rem** for case with Kr or Xe* (with iodine and cesium removal) ⇒ evacuation plan not needed
- If oxidation does not take place then the dose would be **0.26 rem** in the case of Xe* (with iodine and cesium removal) and **0.13 rem** if Kr was used ⇒ would not require an evacuation plan
- Oxidation could 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

Future work in SOMBRERO safety analysis

- 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

- Oxidation prevention:
  - passive safety feature could prevent oxygen from reaching carbon structures
  - protective coatings for carbon composites may be appropriate for oxidation protection of FW and blanket
  - alternate materials for FW and/or blanket structures should be considered

- We plan to complete our safety analysis including alternate severe accidents as well as other more credible, less severe scenarios