Idaho National Engineering and Environmental Laboratory

Progress on Accident Initiating Events Study for IFE Power Plant Designs

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Accident Initiator Identification for IFE Systems

- ***Current work is focused on SOMBRERO as a representative of dry wall IFE designs***
- ***SOMBRERO also uses krypton fluoride lasers***
- ***Other designs (OSIRIS, HYLIFE II) will be examined later this year***

Accident Initiator Identification Uses Several Approaches

- ***Review of historical IFE safety work***
- ***Review of safety work for similar facilities (tritium handling, lasers, NIF, etc.)***
- ***Preliminary hazards analysis***
- ***Master logic diagram (basically a facility-level fault tree of potential offsite releases) - discussed last time***
- ***Multiple methods are used to give completeness to the identification task***

Expected Classes of Accident Initiators have been Identified

- *Loss of Coolant Accident (in-vessel and ex-vessel)*
- *Loss of Flow Accident*
- *Loss of Vacuum Accident (e.g., window breach)*
- *Loss of Heat Sink event*
- *Loss of chemical confinement event*
- *Off-normal shots*
  - *Excessive yield (overpower)*
  - *Non-symmetric burn (localized overheating)*
  - *Shrapnel production (impacts to wall)*
- *Others initiators may also be identified*

Review of the SOMBRERO Design has Raised Many Safety Questions

- ***Lithium oxide issues and concerns***
  - ***Bucket lifters are known to produce dust in the chemical processing industry. How effective is damaged granule removal?***
  - ***Electrostatic charges may be generated with oxide (insulative) granules. Fortunately, the granule flow velocity is low at 1 m/s. If a charge did build up over time, discharge to grounded walls could produce wall surface damage. We are searching for Li_2O electrical properties to determine the extent of this concern.***
  - ***Li_2O at elevated temperature can react with traces of steam to form caustic LiOH.***

Lithium Oxide Safety Issues

- ***If granules mixed with 60 Pa traces of steam do not form LiOH, the mixture could potentially "clump up". Foreign material intrusion, especially water, is a major concern for granules in the chemical processing industry.***
- ***The design is not clear on how the 0.2 MPa helium and steam are introduced and separated from the granule streams in a 0.5 Torr (67 Pa) xenon atmosphere.***
- ***What motors are to be used for the bucket lifters? 0.5 Torr xenon will not cool motor windings very effectively. If jacket cooling is used, the coolant must be compatible with 700°C Li_2O (e.g., helium gas). Healthy motors mean higher plant availability by having fewer LOFA events.***

Radiological Confinement Safety Concerns

- ***The SOMBRERO building is very large.***
- ***Radioactive and chemical contamination would slowly spread throughout the 900,000 m^3 building:***
  - ***Xenon activation products***
  - ***Ablated material from neutron-activated mirrors and their vaporized surface deposits***
  - ***Tritium and other materials (e.g., hydrocarbons) from target debris***
  - ***Lithium oxide dust from the bucket lifter***
  - ***Carbon erosion dust from chamber walls***
  - ***Possibly other materials (e.g., glass dusts)***

Radiological Confinement Safety (continued)

- ***The traditional, and economic, safety approach is to confine hazardous material close to its source; the confinement boundary construction cost is smaller, periodic boundary testing is typically less costly, decontamination treats less volume, less sweep gas is used in operation, etc.***
- ***The US DOE approach is to control contamination at its source as a demonstration of good stewardship of radioactive materials (DOE-STD-1098-99, Radiological Control). Personnel contamination events are reportable occurrences (DOE M 232.1-1A, 1997).***
- ***There are 60 beam clusters in the SOMBRERO design, making the beam paths very complex. Nonetheless, consideration should be given to using confinement ducts to encase the beams.***

Radiological Confinement Safety (continued)

- ***The US DOE gives guidance in Primer on Tritium Safe Handling Practices (DOE-HDBK-1079-94) and Tritium Handling and Safe Storage (DOE-HDBK-1129-99)***
- ***The Capture, Contain, and Cleanup Process is used for tritium systems. Secondary containers (SCs) are treated by gas-to-liquid cleanup systems. SCs can be high quality [leak less than 1 Ci over 4 to 40 days], medium quality [leak less than 1 Ci in 3 to 30 hours], or low quality [leak up to 8 Ci/minute]. Barrier quality is chosen based on allowable site doses.***
- ***The Fusion Safety Standard (DOE-STD-6003-96) states that tritium generally has primary and secondary barriers, and the secondary barrier should have recirculating N_2 or other gas at subatmospheric pressure, routed through a tritium cleanup system.***

Radiological Confinement in OSIRIS and HYLIFE-II

- The OSIRIS strategy is a high vacuum chamber, double confinement of systems, a confinement building operated at 0.5 mm of Hg below atmospheric pressure, with tritium and other cleanup systems. A Pb IHX loop was specified to reduce tritium migration leaks to the environment.
- The initial HYLIFE had a sealed vacuum vessel, a concrete confinement building with an inert atmosphere and SS liner plates for lithium safety, and a sodium IHX loop with cold trapping to reduce tritium migration leaks to the environment.
- For HYLIFE-II there is the vacuum chamber as the primary and a building as the secondary boundary. The building is rather large which suffers from leak testing issues and cost for such a large 2nd boundary. Confinement of vessel penetrations is not mentioned. Some sort of valves or shutters are probably needed. More work is needed on the confinement strategy here.

Flibe Safety Issues

- A benefit of Flibe is high temperature operation. OSIRIS operates between 500 and 650°C. However, hot Flibe must be kept away from water and other liquid coolants to avoid phase-change pressure explosions.
- Hot Flibe contacting water or humid air will produce HF gas, which is a chemically hazardous material. The FSP will investigate mobilization from Flibe in steam and humid air.
- Flibe activation products include F-19, F-20, Li-7, Li-8, Li-9, Be-8, and Be-10. These must be confined for safety. Impurities will also be activated
- There is additional concern about the chemical toxicity of Be. DOE has reduced the TLV concentration by a factor of 4 to 0.5 microg/m^3
- Flibe dissociation under neutron and x-ray irradiation may quickly recombine, or could form TF. OSIRIS also discussed the possibility of SiF_4, CF_4, and metallic fluoride formation. REDOX control of the Flibe is needed to control chemistry in the reactor.

Laser Safety Issues

- ***If an amplifier cavity suffered an extremely unlikely material failure or wall breach event, on the order of 2 m^3 of near-STP Kr + F_2 gas could be released.***
- ***Fluorine is a highly reactive and toxic element. F_2 will rapidly form HF in air. The Emergency Response Planning Guidelines (ERPGs) for less than 1-hour public exposure to HF are:***
  - ***ERPG-1 (mild, transient health effects) is 1.64 mg/m^3***
  - ***ERPG-2 (level below serious health effects) is 16.40 mg/m^3***
  - ***ERPG-3 (level below life-threatening effects) is 41.0 mg/m^3***
- ***A conservative calculation is a ground level puff of F_2 from one amplifier cavity ($\approx$ 2800 g of F_2), forming HF in air. Using class D stability, 4.5 m/s wind, and 1 km boundary, gives ERPG-2. This level may require an evacuation plan for public safety.***

Laser Safety Issues (continued)

- ***The 10CFR68 (Chemical Accident Prevention Provisions) requires an Emergency Response Plan, which includes public evacuation per 42USC11003, for fluorine quantities over 1,000 pounds on site. SOMBRERO is below this amount. Nonetheless, if there is a public hazard, a plan must be written.***
- ***The threshold limit value (TLV) for worker exposure to fluorine gas is 0.2 mg/m^3 and the HF TLV is 2.5 mg/m^3. The Immediately Dangerous to Life or Health (IDLH) worker exposure*** [the level requiring workers to don respirators] ***for pure F is 39 mg/m^3 and HF is 25 mg/m^3. On-site safety precautions are needed.****
- ***Secondary confinement and capture of released fluorine or hydrogen fluoride gas should be examined for personnel and public safety. If a passive system can be designed, it may negate the need for an evacuation plan for chemical releases.***

****** Note the public value is 41 mg/m^3 for 1 hour. The IDLH is set so that workers are protected by respirators and will not be overcome or incapacitated in a high exposure area***

Laser Safety Issues (continued)

- *An attractive feature of SOMBRERO is the heat recovery from the Kr + F_2 lasing gas. The heat is used for feedwater heating.*
- *The intermediate heat exchange fluid between the Kr + F_2 gas and the steam plant feedwater was not specified in the 1992 design report.*
- *The coolant must be compatible with both the lasing gas and water. The lasing gas must be kept pure for laser reliability.*
  - *Perhaps a Fluorinert liquid or Kel-F oil might suffice as a heat transfer fluid; these are already fluorinated so a gas leak to the fluid should not pose reaction concerns, and a liquid leak to the water would be reasonably insoluble and not pose a large BOP operations concern.*

Accident Initiator Work will Continue Between INEEL and LLNL

- *The SOMBRERO work will be completed and made available for review by interested parties in the IFE community.*
- *HYLIFE II initiator work has begun; the first task is plant design familiarization. A master logic diagram will be constructed.*
- *The OSIRIS design will also be studied, and a master logic diagram will be constructed.*
- *A trip to visit the Micron computer chip manufacturer is being planned for late June. Computer chips are batch manufacturing of many units under tightly controlled conditions using statistical quality control, similar to laser fusion fuel pellet fabrication.*
- *An overview of the results of this task will be presented at the SOFE meeting in October.*