Idaho National Engineering and Environmental Laboratory

Status of Safety and Environmental Activities in the US Fusion Program

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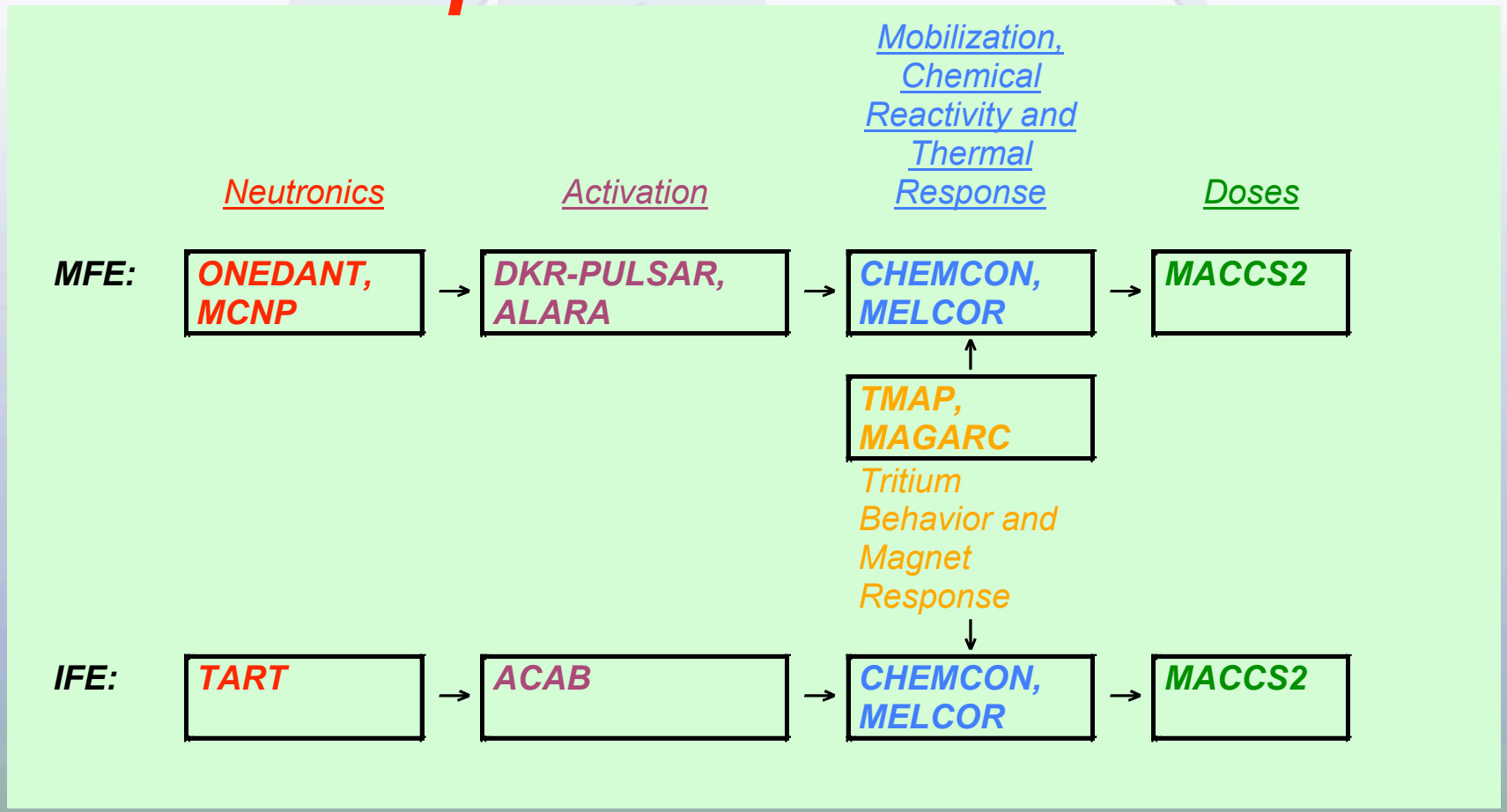
Safety Assessment begins with Hazard Characterization

- *Fusion has both radiological and toxicological hazards:*
  - *Tritium fuel, activated structural material, activated dust, activated coolants or coolant impurities, and activated gases*
  - *Chemically toxic materials*
- *Energy sources that can mobilize these hazardous materials include:*
  - *chemical energy (PFC or coolant oxidation), stored magnetic energy, after heat, pressure energy (pressurized coolants), electrical energy and radiation*

Safety Tests on Materials have Characterized many Hazards

Material	Test environments	Temperature range (C)	Mobilization tests	Ion implantation tests
Steels (Austenitic, Ferritic)	Air, steam	500-800	yes	yes
Refractories (V, W, Mo,Ta)	Air, some in steam	500-1200	partial	partial
Beryllium (many forms)	Steam	400-600	yes	yes
Graphite and CFC	Air, steam	1000-1700	partial	no
Copper Alloys	Air, steam	600-1200	partial	yes

Safety Assessment Code Suites in both MFE and IFE Analyses use Experiment Results



Safety-related results from recent conceptual design studies

- *Weather conditions for no-evacuation dose calculations were made ~ 10x more restrictive based on recent DOE guidance; this impacted the FIRE safety calculations*
- *Restrictive dose calculations also affect the SOMBRERO, HYLIFE II, and IFE target fabrication plant designs*
- *In MFE, ELMs in addition to disruptions can create large quantities of divertor dust*
- *Regulatory limits for hazardous chemical have been tightened (more so than corresponding radiological limits)*
- *Chemical safety studies have been performed for MFE and IFE conceptual designs; in a few cases the chemical releases were as severe, or more severe, than radiological releases (Be in Flibe; Hg and Pb in IFE targets)*

Safety-related results from recent conceptual design studies

- *The ARIES-IFE study improved structural material choices available for a liquid wall chamber concept*
  - *Originally, SS 304 was the material of interest*
  - *Now, ODS ferritic steel also shows promise*
- *The HAPL program has used INEEL FSP CFC oxidation test data and accident assessment results to support chamber material selection*
- *Safety analysis of APEX high power density molten salt Flinabe coolant/ferritic steel blanket showed that the peak blanket temperatures remained below values where structural integrity would be lost, provided that natural convection in the vacuum vessel cooling system was initiated. A passive drain tank was proposed to gravity flow the Flinabe away from the blanket in loss of flow situations.*
- *Safety assessments are being performed for the ITER Test Blanket Module conceptual designs*

Recent Environmental Studies

- *The IAEA has proposed radionuclide concentrations for free release or "clearance" of very mildly activated materials*
- *Analysis has shown that a dual strategy is needed to address both the hazard and volume of waste associated with fusion*
  - *Low activation material usage*
  - *Optimized radiation shielding to reduce activation in the shield and vacuum vessel so those components can be classified as low level waste rather than high level waste*
  - *Details of the optimization are different in Europe and US*
- *Recent IFE work has shown that the HYLIFE-II confinement building - which dominates the waste volume - could be cleared after 1 year of cooldown*

Future Directions in Safety

- *In the past 15 years, safety analyses have matured significantly. The behavior of the tokamak system with respect to public safety is better understood than ever before based on safety analysis during ITER-EDA*
- *Uncertainties remain for NIF and ITER; safety codes require validation & verification; dust and tritium in-vessel inventories require validation*
  - *It is anticipated that further R&D can help validate these safety limits but only NIF and ITER operations will yield answers to dust generation and tritium uptake definitive enough to convince regulators.*
  - *ITER regulators will likely use a graduated licensing approach, such as was used at JET for the preliminary tritium experiment and the deuterium tritium experiment campaigns.*
  - *Licensing ITER for each operating stage will help regulators to gain confidence in the behavior of the facility, and the operating experience results from each stage will provide data useful to benchmark the safety limits and assumptions for the following stage.*

Future Directions (con't)

- *Probabilistic safety assessment is growing in importance for fusion, but ITER licensing decisions will set a regulatory precedent for future tokamaks*
- *Chemical safety analyses are becoming more important in both IFE and MFE as more chemically toxic materials are used*
- *Radioactive waste issues continue to be a concern; how the DOE remediates waste sites can affect fusion and what - if any - changes occur to the definition of low level waste and, in particular, the definition of clearance of materials for recycling back into processes or clearance for free release*
- *While public safety is better understood, occupational safety requires more study*
  - *Will need more detailed design to be effective*
  - *More work is needed to estimate occupational exposures and concentrations of airborne releases*
- *Safety codes will require updating for future MFE and IFE designs to account for new materials, updated mobilization and radiological data*

Fusion safety professionals will continue to support the fusion community to improve the safety and environmental potential of fusion

- *Safety supports US national efforts, such as NIF, Z-IFE, HAPL, as well as FIRE, ARIES, and other designs*
- *Safety will support any ITER regulatory needs once the site is selected*
- *IFE safety researchers at LLNL will continue focusing on IFE safety in cooperation with domestic and international collaborators*
- *MFE safety researchers at INEEL will continue to work on domestic programs and with ITER participants and the IEA/ESE-Fusion Power agreement participants*
- *Safety researchers will support the ongoing ITER TBM work*