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Integration of MELCOR for Fusion and TMAP4 for fusion reactor systems analysis and tritium inventory tracking

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Changing the World's Energy Future

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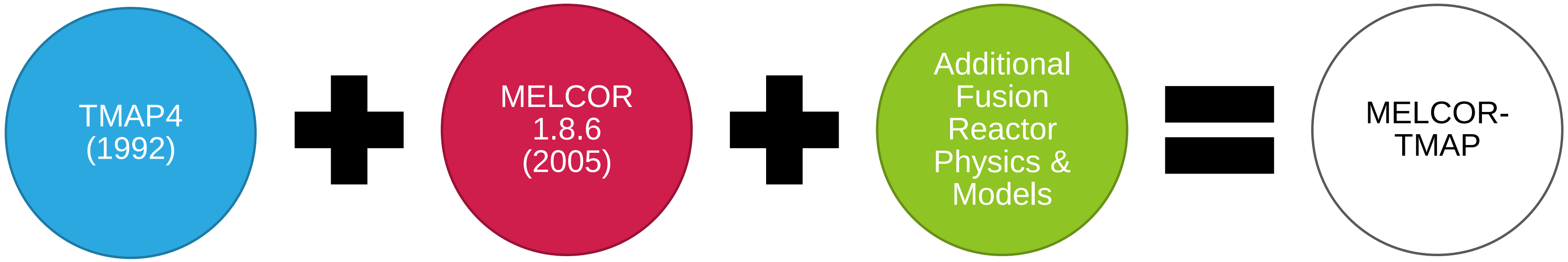
Background on MELCOR-TMAP



- Tritium migration
- Trapping, diffusion, solubility
- Multiple species tracking

- Heat transfer
- Thermal hydraulics
- Vapor & aerosol tracking
- Reactor accidents

- HTO modeling
- Lithium fire accidents

- Fully integrated capabilities
- Steady-state & transient analysis including accident scenario simulations

- Fusion reactors produce radioactive tritium which must be tracked and contained for safe reactor design and operation within DOE Fusion Safety Standard limits
- MELCOR-TMAP, owned and developed by INL, is an integrated system-level simulation code designed to track tritium distributions and performance of fusion technologies
- MELCOR-TMAP is based on MELCOR 1.8.6 developed by Sandia National Laboratory and TMAP4 (Tritium Migration and Permeation) developed at INL
- Thermal-hydraulic modeling and accident analysis capabilities of MELCOR are combined with the hydrogen species diffusion and trapping modeling of TMAP4 & additional fusion reactor physics models

Timeline of MELCOR-TMAP Development

= developed by Sandia National Laboratory (SNL)

= developed by Idaho National Laboratory (INL)

TMAP/MOD1 (1988)
Initial release of the Tritium Migration and Permeation (TMAP) code

TMAP4 (1992)
Improved version went through extensive verification & validation (V&V) efforts; has a wide distribution & user base

MELCOR 1.8.2 (1993)
An improvement on previous versions of MELCOR based on Fortran 77 for analysis of light water reactors (LWRs) & related technologies

MELCOR for ITER (1994)
Enhanced version of MELCOR 1.8.2 with modeling capabilities to address modeling & safety issues for ITER. Continues to be used for ITER analysis & safety documentation: "Rapport Préliminaire de Sûreté" (Preliminary Report on Safety – RPrS), non-specific site safety reports (NSSR-1 & NSSR-2), & Generic Site Safety Report (GSSR)

MELCOR 1.8.6 (2005)
Models for spent fuel pools (SFPs), hydrogen chemistry, flashing, etc. were included in this new release of MELCOR

MELCOR-TMAP
Includes improvements and modifications made in previous versions of MELCOR for fusion added to 1.8.6

Current version of code in use at INL for analysis of fusion reactors & systems involving tritium transport

MELCOR 2.2 (2017)
Improved code architecture based on Fortran 90 including dynamic memory allocation, point kinetics models, turbulent deposition models, etc.

Future Versions of MELCOR-TMAP
Significant software development will be required for integrating MELCOR-TMAP capabilities to the newest version of MELCOR 2.2 in collaboration between INL & SNL

MELCOR-TMAP Tritium Permeation in Structures

- MELCOR-TMAP combines the MELCOR Heat Structure (HS) package with TMAP capabilities for diffusion of heat and atomic species $i =$ (H, D, T, He) through solid walls
- TMAP solves the diffusion equation for multiple species in one-dimensional, Cartesian structures with a user-specified nodalization scheme:

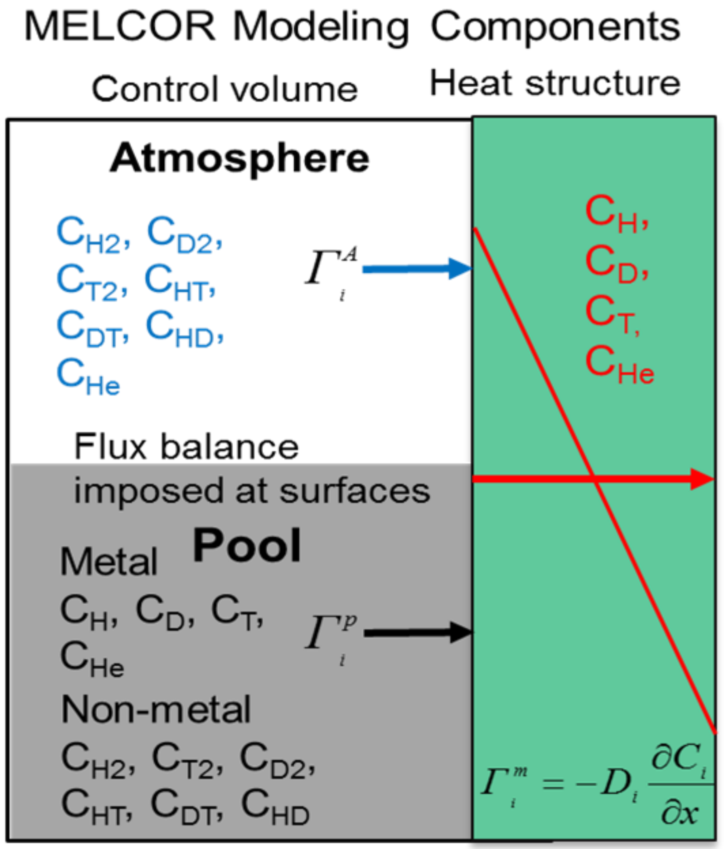
$$\frac{\partial C_s}{\partial t} + \nabla \cdot \left(-D_s \left(\nabla C_s + \frac{Q_s^* C_s}{RT^2} \nabla T \right) \right) = S_s - \frac{\partial C_s^t}{\partial t}$$

where:
C_s = concentration of species "s" in the structure
S_s = local source or production rate of species "s" [user input]
C_s^t = concentration of trapped atoms of species "s"
D_s = diffusivity of atomic species "s" in the structure material [user specified function of temperature]
Q_s^* = heat of transport or Ludwig-Soret coefficient for species "s"
R = universal gas constant
T = temperature [TMAP solution for heat conduction or user input]

- Boundary condition options for species transport currently include:
  - Solution laws: $C = Kp^n$, Henry's $(n = 1)$, Sieverts' $(n = 1/2)$
  - Rate-dependent (directional fluxes dependent on dissociation & recombination rates):

$$J = K_d p - K_r C^2$$

  - Constant concentration
  - Zero flux
  - Link to connecting structure



MELCOR-TMAP Capabilities & Future Development

- Modeling capabilities of MELCOR-TMAP for fusion reactors & tritium experiments is extensive, including such following models:
  - Lithium fire models
  - Aerosol resuspension models (now included in latest version of MELCOR 2.2)
  - Multiple working multiphase fluids
  - Fluid properties based on RELAP/ATHENA for Li, PbLi, FLiBe, Sn, SnLi, and real EOS for hydrogen & helium
  - Fusion dust tracking using MELCOR Radionuclide (RN) package (W, Be, C, RAFM steels, etc.)
  - Time-dependent species dissociation and recombination at surface interfaces
- More features planned for future development and releases:
  - Currently limited to Cartesian coordinates; desire to implement cylindrical and spherical geometries
  - Larger problem sizes, 2D and 3D models, mass transport BC
  - User-requested models from EU collaborators (see list on the right)
- Extensive V&V needed as new features are added