



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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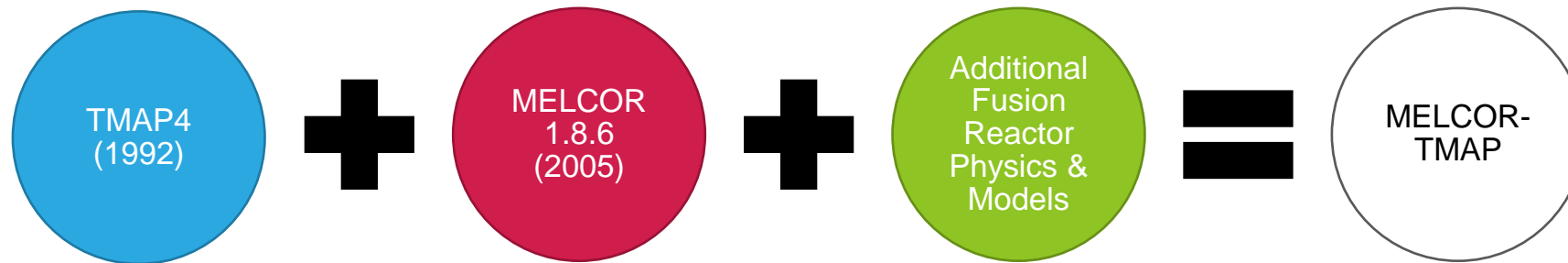
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Fusion Safety Program
Idaho National Laboratory

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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

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 1.8.6 (2005)

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

MELCOR 2.2 (2017)

Improved code architecture based on Fortran 90 including dynamic memory allocation, point kinetics models, turbulent deposition models, etc.

TMAP4 (1992)

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

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 Sécurité" (Preliminary Report on Safety – RPrS), non-specific site safety reports (NSSR-1 & NSSR-2), & Generic Site Safety Report (GSSR)

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

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 $i = (\text{H}, \text{D}, \text{T}, \text{He})$ 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”

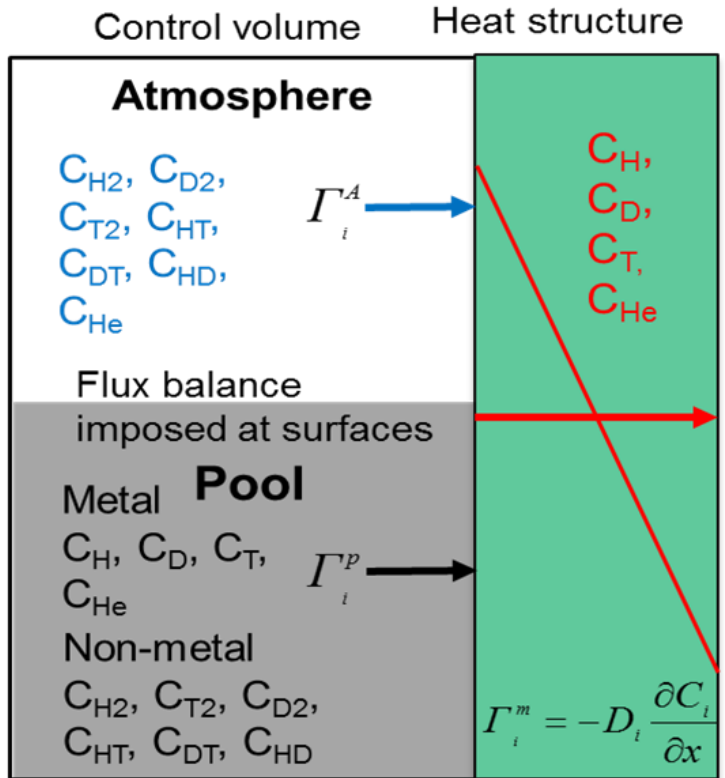
R = universal gas constant

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 Modeling Components



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

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