SAND2022-7732C

Non-LWR MELCOR Capability Development for MSRs and SFRs

JUNE 9, 2022

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SFR-specific Modeling Enhancements

Existing physics models and capabilities

- User-defined materials and COR component primary material substitutions
- Candling
  - Occlusion of intact component surface area by conglomerate debris formation
  - Flow blockage formation (impeding downward molten material relocation and CVH fluid flow)
  - Special consideration of the SFR fuel assembly and duct
- Point kinetics

SFR Modeling Approach – Core Degradation

Pre-transient condition of burned core

- User specification of geometry changes (fuel swelling) and in-pin fission product distribution
- Pre-transient calculation(s)

Transient (severe accident) response

- Core/fuel degradation and disassembly
  - In-pin conditions and fission product transport prior to pin failure
  - Fuel and clad failure (mechanical, eutectic thinning, molten fuel motion)
  - Pin collapse and effluent expulsion (varying degrees of disruption)

SFR Modeling – Calculated Burned Core

Thermal hydraulic response of fuel

Mechanical response of fuel including geometry changes

Fission product transport in/from fuel

- Gaseous FPs build into fuel as closed porosity
- Close porosity can grow in volume, eventually coalesce into open porosity
- Pin plenum communicates with open porosity
- Formation of molten cavity in fuel (isolated in axial levels or contiguous across 2+ axial levels)
- Pin plenum and/or molten cavity pressures are boundary conditions on fuel/clad mechanics models
- Solid fission products transport with fuel and release according to CORSOR-Booth release models

Longer Term Modeling Enhancements

- Representation of multiple working fluids in MELCOR thermal hydraulics modeling
- SAS4A DEFORM-IV type algebraic approach to solving pin mechanics
- Volume accounting, ideal gas treatment, empiricisms for fission gas dynamics
- Improved transport of solid fission products (e.g., diffusion as in HTGR)
- Pre-transient empirical correlations for release of fission products into sodium bond

User Input Burned Core

Bypass complexity of calculating a pre-transient

User defines via MELGEN input

- Fuel geometry changes during burn-up
- Fuel porosity distribution after burn-up
- Fuel, sodium bond, and gas plena fission product inventory (gaseous & solid)
- DCH/RN classes associated with “fission gas”

COR_SFR	*Parameters to configure SFR calculation*	**RN1_FPN**	*Specify FU gas/solid FP inventory*
COR_SFRFUEL	*Parameters defining SFR fuel pins*	**RN1_GAP**	*Specify sodium bond solid FP inventory*
COR_SFRDRR	*User-defined radial dimensional changes*	**RN1_SFRMAP**	*Declare gaseous FP RN class(es)*
COR_SFRDZH	*User-defined axial dimensional change*	**RN1_SFRPLEN**	*Specify pin plenum gaseous FP inventory*
COR_SFRPLEN	*User-defined initial plenum conditions*		
COR_SFRPOR	*User-defined fuel porosity distribution*		

SFR Transient Response

Intact fuel pins can experience clad melting

- Conventional candling
- “Reverse candling” due to local entrainment of molten clad by sodium coolant

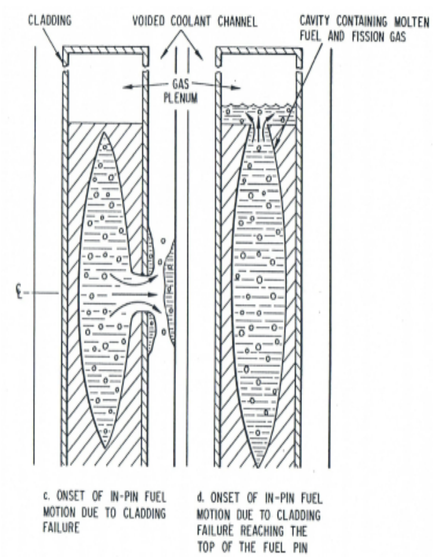
Intact fuel pins can contain molten fuel

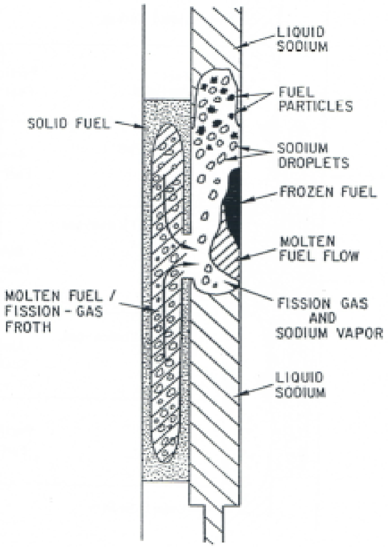
- Molten cavities form and subsume fission gas previously trapped in solid fuel
- Contiguous molten cavities in communication with pin plenum could move
- Molten fuel can eject from a compromised pin

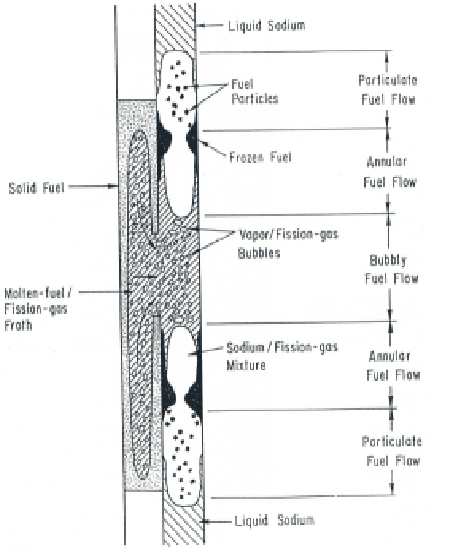
Intact pins can eventually fail in several ways:

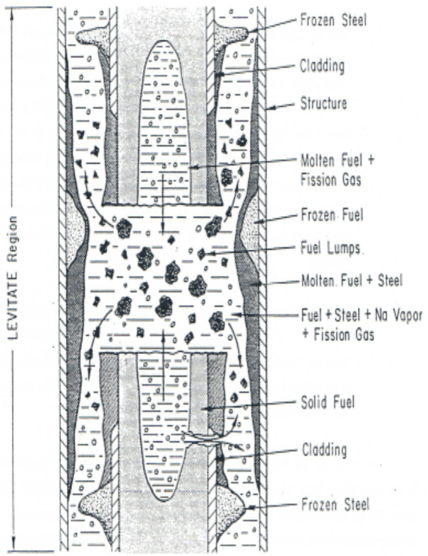
- Overpressure or other mechanical failure of cladding
- Clad melt from outside or eutectic thinning from inside
- Gross in-pin molten fuel migration upward to pin plenum
- Varying degrees of disruption are possible depending on scenario

Severe Accident Response









Array of degradation modes must be considered

Localized failures in otherwise intact fuel geometry

- Candling and reverse candling may deposit conglomerate on intact cladding or assembly duct
- Molten fuel expulsion may break-up to generate small particulates or may candle and refreeze

Large scale disruptions that obliterate previously intact fuel geometry

- Chunks of frozen fuel and clad explode into coolant channels
- Smaller fuel and clad particulates eject or form after ejection
- Conglomerate formed by refreezing of molten films/rivulets
- Conglomerate also possibly formed by expulsion of molten material into/across channel

Reactivity Phenomena

Fuel point kinetics – Derived from standard PRKEs and solved similarly

- Feedback models
  - User-specified external input
  - Doppler
  - Fuel and moderator density
  - Flow reactivity feedback effects integrated into the equation set

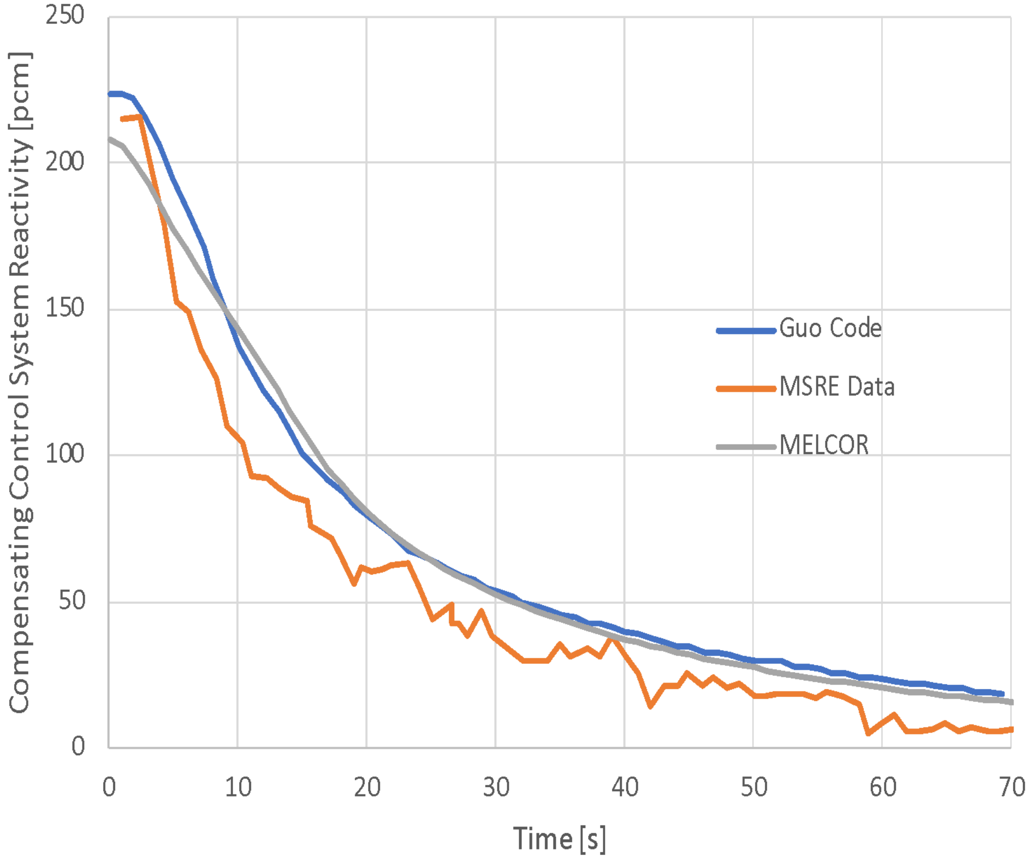
$$\frac{dP(t)}{dt} = \left(\frac{\rho(t) - \beta_{eff}}{\Lambda}\right) P(t) + \sum_{i=1}^{6} \lambda_i C_i^C(t) + S_0$$

$$\frac{dC_i^C(t)}{dt} = \left(\frac{\beta_i}{\Lambda}\right) P(t) - \left(\lambda_i + {}^{2}/_{\tau_C}\right) C_i^C(t) + \left(\frac{V_L}{V_C}\right)\left(\lambda_i + {}^{2}/_{\tau_L}\right) C_i^L(t),$$
$$i = 1 \ldots 6$$

$$\frac{dC_i^L(t)}{dt} = \left(\frac{V_C}{\tau_C V_L}\right) C_i^C(t) - \left(\lambda_i + {}^{1}/_{\tau_L}\right) C_i^L(t),$$
$$i = 1 \ldots 6$$

Transmutation modeling (under development)

- Coupling with ORIGEN



Thermal Hydraulics Phenomena

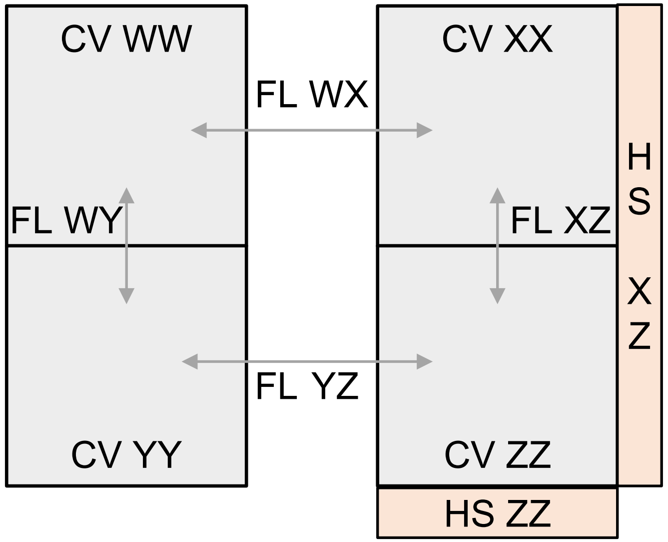
Generalized EOS – Equations of state for multiple working fluids are presently available in MELCOR including water, sodium, and FLiBe.

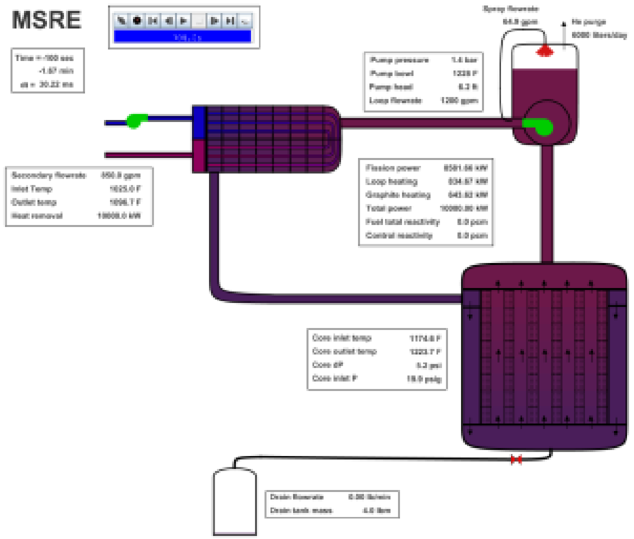
Thermal hydraulics – CVH/FL Packages

- The CVH package defines control volumes (CV)
- The FL package defines flow paths (FL)

Heat Transfer – HS/CVH/COR Packages

- The HS package defines heat structures (HS) that model radiative and conductive heat losses
- The CVH package manages convective heat losses
- The COR package controls heat losses of heat bearing and other core structures





MELCOR Generalized Radionuclide Transport and Retention (GRTR) Model

U.S.NRC
Oak Ridge National Laboratory
Sandia National Laboratories

Model Scope

Define radionuclide forms in liquid pool

Define transitions between forms in liquid pool based on thermochemical equilibrium

Transitions between forms in liquid pool influence potential to evolve out of pool

Evaluation of thermochemical state

- Gibbs Energy Minimization with Thermochimica
- Provides solubilities and vapor pressures

Thermodynamic database

- Generalized approach to utilize any thermodynamic database

Radionuclides grouped into forms found in the Molten Salt Reactor Experiment

Fission Product Forms	Soluble FPs (salt-seeking) **Form 1**	Insoluble FP suspension **Form 2**	Salt liq./gas Interface **Form 3**	Insoluble FP deposits on structures **Form 4**	FPs Vapor/NCG **Form 5**
Equilibrium	Soluble & Volatile FP	Insoluble FP suspension			Gas Bubbles
Transport within GRTR	Soluble & Volatile FP	Insoluble FP suspension	Salt gas/liq. Interface	Deposits on heat structures Deposits on core	Gas Bubble Rise
Gas space Release	Volatile Vapor and Eventual Aerosol	No Release	Bubble Film Rupture Aerosol	No Release	Gas Release (Kr, Xe, T)

MELCOR Generalized Radionuclide Transport and Retention (GRTR) Model

GRTR Initial State

- Radionuclide mass in (or released to) liquid pool
- Chemical speciation
- Pressure
- Temperature

GRTR Computation

- Soluble radionuclide form mass
- Colloidal radionuclide form mass
- Deposited radionuclide form mass
- Gaseous radionuclide mass

MELCOR Calculations

- Advection of radionuclides in liquid pool or atmosphere
- Decay of radionuclides in hydrodynamic control volume

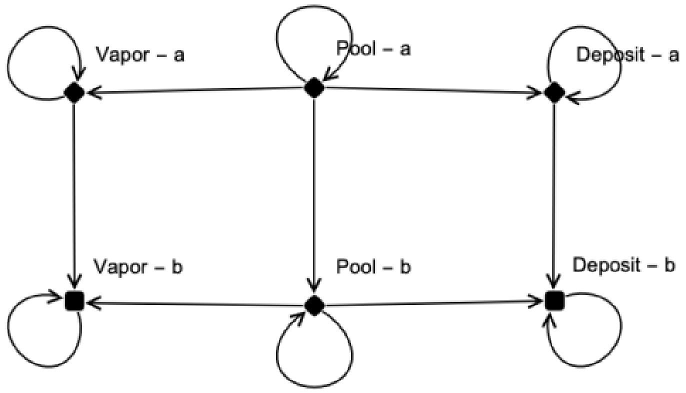
For Each Timestep

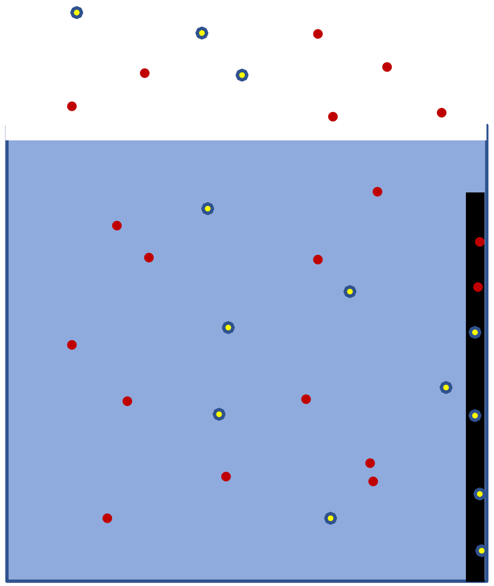
MELCOR Generalized Radionuclide Transport and Retention (GRTR) – States and State Transitions

Fission products characterized by discrete state degrees of freedom

- Isotopic state
- Space volume
- Physico-chemical states

Single Control Volume Example





Isotopic state

- Neutronic state transitions treated locally volume

Space volume

- Hydrodynamic flows moving fission produ system

Chemical state

- Transitions between thermodynamic states within volumes
- E.g., deposition on structures, vaporization from pools

Note: MELCOR considers soluble, bulk colloid, interfacial colloid, and vapors as distinct chemical states

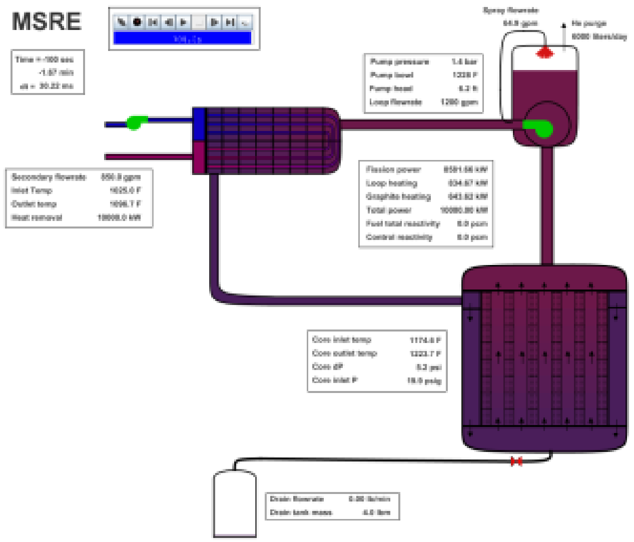
MSRE – Overall Plant Model for Demonstration

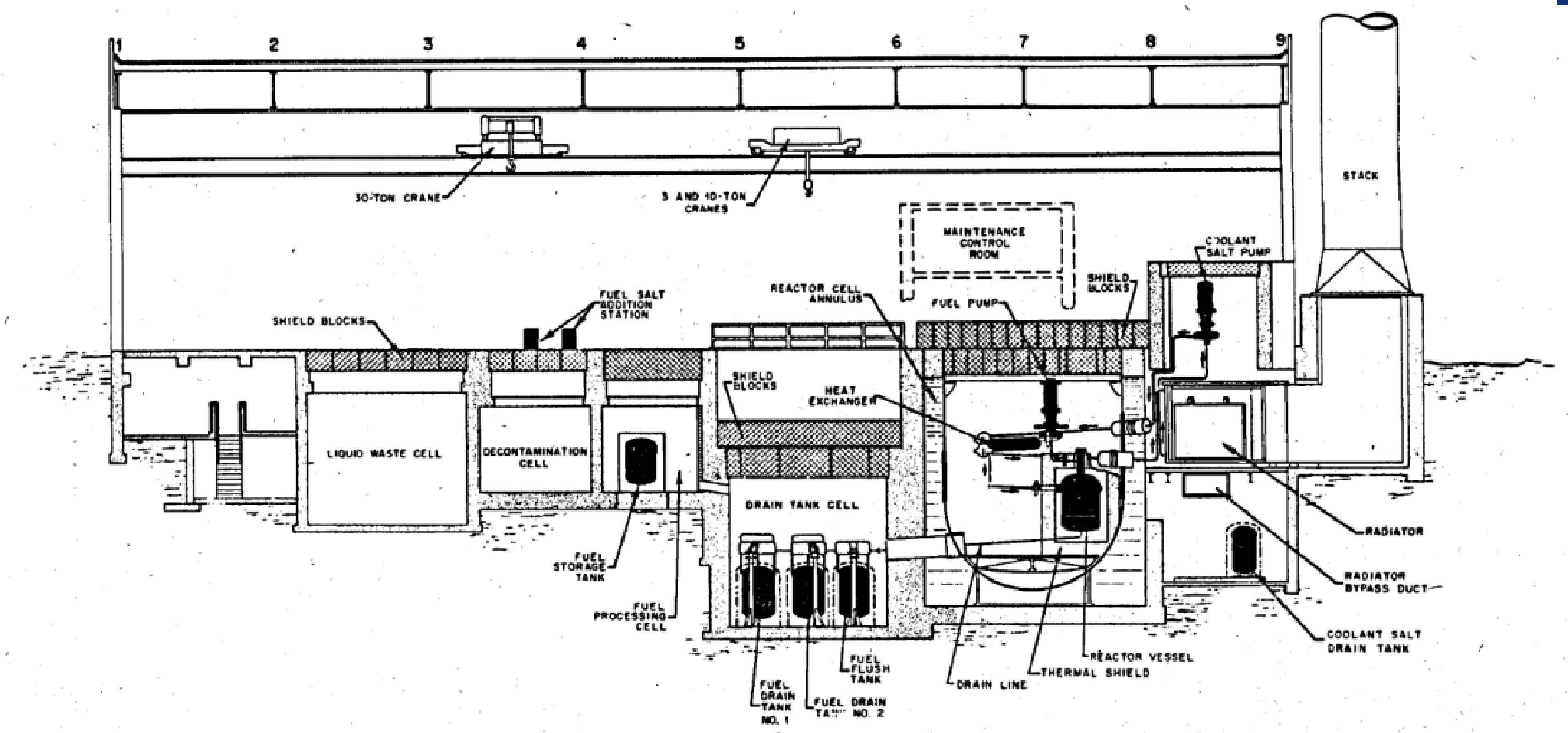
Reactor vessel contained within Reactor Cell

Reactor Vessel can drain to drain tanks in Drain Tank Cell

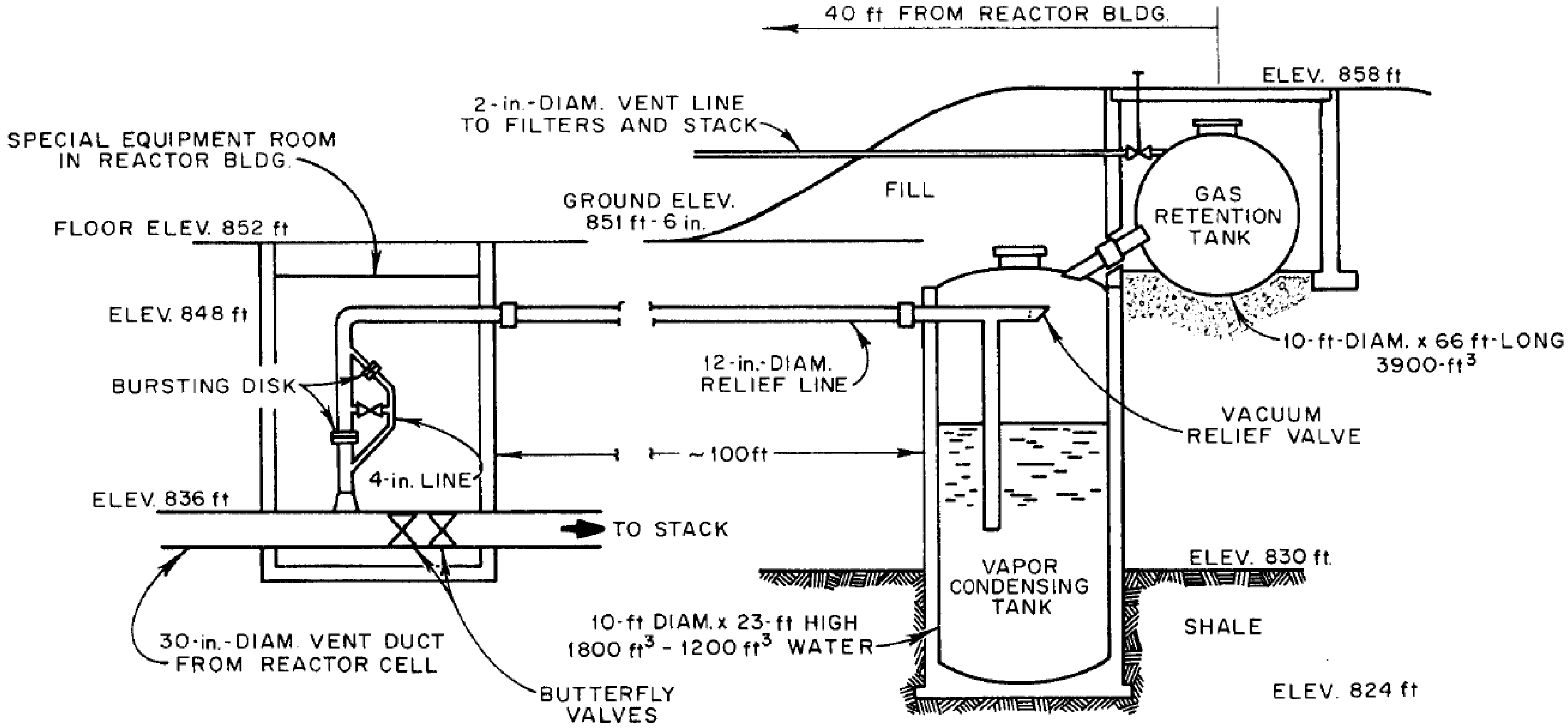
Reactor Cell pressure transients accommodated by relief into Vapor-Condensing System through 12” and 30” lines

Vapor-Condensing System discharges vented via Stack





Representation of Reactor Enclosure Response



Representation of Off-Gas System

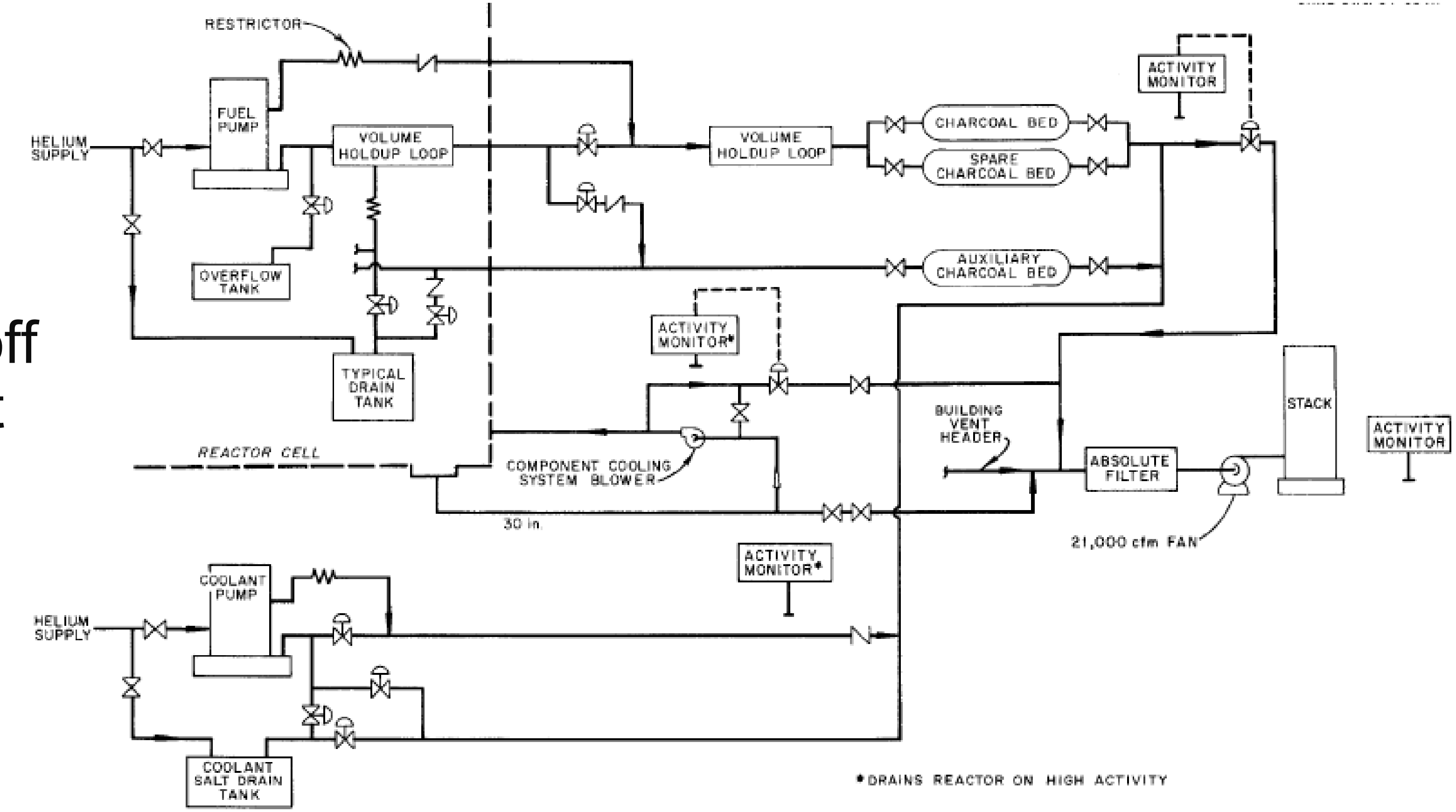
Off-Gas System components include

- Volume holdup tanks
- Charcoal bed filters
- Release to environment via stack

Study focuses primarily on off-gas system iodine transport

Assumed decontamination factor for iodine in charcoal beds

- DF of 100 assumed



Questions?