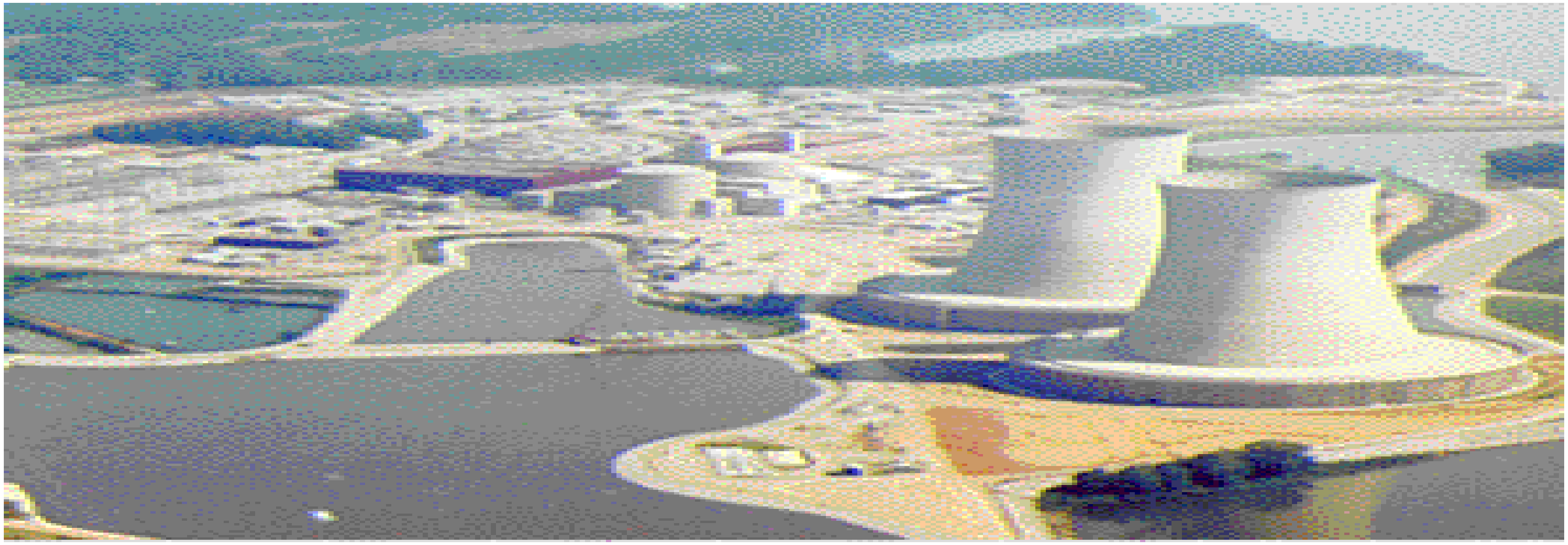
# MELCOR RN and Decay Heat



**Prepared by**
**MELCOR Development Team**



SAND2018-4259 PE

Sandia National Laboratories

# MELCOR RN and Decay Heat Overview of Presentation

- Describe relationship between RadioNuclide (RN) and Decay Heat (DCH) Packages
  - Emphasize significance of “reference” core
  - Discuss options to normalize “whole core” power
- Show example input
- Provide information necessary to add appropriate input to complete the input deck



Sandia National Laboratories

# MELCOR RN and Decay Heat Introduction

- MELCOR intended to capture feedback effects
  - Coupling of temperatures, release rates, decay heating
  - Relocation of heat sources, including deposition
- Impossible unless radionuclides are tracked
  - Simple models tie decay heat to $UO_2$ in fuel and debris
- If RN package is active
  - Decay heat package associates heat with RN classes
  - Heat delivered according to location of radioactive masses



Sandia National Laboratories

# MELCOR RN and Decay Heat Basic Approach

- **Define initial inventory of radioactive material**
  - Usually unreleased, within intact core
  - Can define elsewhere, including the debris in the cavity
- **Define specific decay power for RN classes**
  - Power, in W/kg, applied to class masses in each location
- **Define distribution of heat from radionuclides in various locations**
  - For unreleased, goes to core structures and/or debris
  - For airborne, part goes to surfaces
  - For deposited, part goes to fluids



Sandia National Laboratories

# MELCOR RN and Decay Heat "Reference" Core

- **Huge volumes of data associated with initial inventories and specific decay powers**
  - Depend on core design, operating power, point in refueling cycle, and (in principle) on operating history
  - Specific decay power depends on time since shutdown
- **MELCOR contains built-in data from ORIGEN calculations for two actual reactor cores**
  - 3412 MWt Westinghouse PWR
  - 3578 MWt General Electric BWR
  - Each at four points in equilibrium fuel cycle
  - Full details about assumptions in the code manuals
- **Initial inventory and decay power calculated from a constructed "reference" core**



Sandia National Laboratories

# MELCOR RN and Decay Heat "Reference" Core (2)

- Reference core normally defined by scaling built-in data, interpolating for point in cycle
  - Built-in data for the 29 "most important" elements
  - Built-in inventories normalized as $kg_{element}/W_{operating}$
    - Masses at time of shutdown
      - Appropriate to MELCOR treatment of classes
  - Total inventory calculated from operating power
    - Should be applicable to other cores of similar design
  - Built-in decay power for each element normalized as $W_{decay}/W_{operating}$ as function of (time- $t_{shutdown}$)
    - Each includes contribution of decay daughters
  - Scaled values should be applicable to similar cores
- User can also provide complete definition

# MELCOR RN and Decay Heat Class Decay Powers, Normalization

- **Class power defined from element powers**
  - **Recall default assignment of elements to classes**
- **"Whole-core" decay power in MELCOR is total power in the *reference* core**
- **Default for whole-core decay power is sum of the *default* class powers (from ORIGEN)**
  - **User input can modify default data for the reference core**
    - **Initial masses and/or decay curves for elements (change one of the 29 or add data for one or the others)**
    - **Assignment of elements to classes**
  - **If done, default is to normalize sum of *new* class powers to the *original* ORIGEN power**
  - **Otherwise, has no effect**



Sandia National Laboratories

# MELCOR RN and Decay Heat Normalization of Whole-Core Power

- **User can specify an alternate normalization**
  - — **ANS standard**
    - ✶ **Necessary parameters accessible through input or as sensitivity coefficients**
  - — **Tabular function of time**
  - — **Control function**
- **This defines the total power in the reference core, *not* the total power delivered to the radionuclides in a MELCOR calculation**
  - — ***If the inventories don't match, normalization won't help***

# MELCOR RN and Decay Heat Whole-Core Power for Uranium

- **Initial inventory of every class *except* Uranium defined by RN package input**
  - With normal care, inventory corresponds to reference core
- **Initial inventory of Uranium (class 10) inferred from $UO_2$ masses on COR and CAV**
  - Uranium mass, decremented by other fission products
  - *Will not correspond to reference core*
    - Concentration of unstable isotopes in total uranium depends on power density
- **Total decay powers won't match**
  - Normalization won't help
  - Only complete solution is to modify the reference core



Sandia National Laboratories

# MELCOR RN and Decay Heat Basic Whole-Core Power for Uranium (2)

- **Default will be to reconcile only class 10 (URANIUM)**
  - **This can be disabled, as we did in Exercise 5**

    ```
    RN1_DCHNORM      ! Disable reconciliation of UO2
    ```

  - **Other classes can be reconciled also (use with care)**

    ```
    RN1_DCHNORM 2 5 10 ! Reconcile classes 2, 5, 10
    ```

  - **Note that class mass represents *total* mass of *all* isotopes of *all* elements in the class, so as to calculate proper total aerosol mass and/or vapor density**



Sandia National Laboratories

# MELCOR RN and Decay Heat Decay Heat Package Input

- **Define Reactor Operating Power (only required input) if DCH is active.**

```
! Define reactor operating power (thermal)
DCH_OPW     3412.0E6
```



Sandia National Laboratories

# MELCOR RN and Decay Heat
# Decay Heat Package Input

- **Define reference core (all records optional)**

```
! Define reactor type
DCH_RCT   BWR     ! Options are BWR or PWR (default is PWR)
!
! Define point in refueling cycle (sensitivity coefficient)
DCH_SC 1
       1 3212 1.0 1 !Fraction of cycle elapsed (default 1.0)
!
! Define operating power (W) and split (optional)
!        U235     Pu239     U238      Total
DCH_FPW 2316.0E6 1111.4E6 150.6E6 ! 3578.0E6, default BWR
 . . .  2208.6E6 1059.8E6 143.6E6 ! 3412.0E6, default PWR
```

- **Define whole-core power (all records optional)**

```
DCH_DPW   ORIGEN   ! Options are ORIGEN (default), ANS,
!                    CF-nnn, and TF-nnn
! ANS option uses power split on DCH_FPW record
! Define operating time (s) for use in ANS option
DCH_OPT   5.05E7 ! 80% capacity for two years (default)
```



Sandia National Laboratories

# MELCOR RN and Decay Heat
# Decay Heat Package Input (2)

- Specify whether to normalize total power in reference core to whole-core power
  - Record is optional

```
!         RN Class Normalization Flag – Whole-core
DCH_NRM   YES        ! Options are YES (default) or NO
```

- Define reactor shutdown time (two options)

```
!         CF number, or negative to specify absolute time
DCH_SHT   CF ‘Scram’   ! Shutdown by LOGICAL CF ‘Scram’
!
DCH_SHT   TIME 1000.0 ! Shutdown at 1000.0 s (default is 0.0)
```

- Other options to define/redefine elements, elemental decay heats, class membership
  - New elements/classes to track trace materials in other models with standard definitions
  - Otherwise, only experts should attempt this method



Sandia National Laboratories

# MELCOR RN and Decay Heat Initial Inventories

- **Initial RN inventories are defined by user input**
  - **In most cases, they are unreleased masses in intact core**
  - **Can also reside in initial cavity debris, or as initial aerosols or vapors in a variety of locations**
  - ***Unless all class inventories in a MELCOR calculation match those in the reference core, the total decay heat* will not *match the whole core decay power***
- **Comparison Table, by class, in output file**

```
RADIOACTIVE MASS COMPARISON WITH DCH - MASSES IN KG

 CLS    DCH          RN1 INVENTORY
       REF CORE   INITIAL    CURRENT

  1 3.611E+02 4.333E+02 4.333E+02
  2 2.012E+02 2.415E+02 2.415E+02
  3 1.584E+02 1.901E+02 1.901E+02
. . .
```

This case contains 120% of reference core



Sandia National Laboratories

# MELCOR RN and Decay Heat Initial Inventories (2)

- **Unreleased fission products in intact core**
  - Total defined for each core cell, with three options
    - Gap inventory is *included* in this total
  - Easiest to define in terms of fractions of reference core
    - Fraction defined as product of radial and axial shapes
    - If shapes are normalized, initial inventory will contain 100% of reference core
  - Can also define by reference to another core cell
    - Multipliers allow different cell sizes
  - Third option is to specify absolute mass, class by class
    - Very tedious to reconcile with reference core



Sandia National Laboratories

# MELCOR RN and Decay Heat Input for Initial COR Cell Inventory

```
! Partial input for simple core
!   Fueled levels 4-7, relative powers 20%, 30%, 30%, 20%
!   Fueled rings 1-2, relative powers 60%, 20%
!      (fractions of power, *not* relative power densities)
!   Will define 100% of reference core since shapes normalized
!       Total Rows/Index
!       | Ring number (if>0) or Cavity input (if==0)
!       | | Axial Number/Cav Name
!       | | | Option flag: 0 or DH fraction of reference core
!       | | | |             (same fraction of all classes)
!       | | | |  First multiplier, typically axial fraction
!       | | | |  |     Second mult., typically radial fraction
!       | | | |  |     |
!       v | | |  |     |
RN1_FPN 1 v v v  vvvv  vvvv
        1 1 4 0  0.20  0.60  * 0.2*0.6 of total in cell 104
        2 1 5 0  0.30  0.60
. . . . . . . . . . . . . .
        5 2 4 0  0.20  0.40  * 0.2*0.4 of total in cell 204
        6 2 5 0  0.30  0.40
. . . . . . . . . . . . . .
```

# MELCOR RN and Decay Heat Input for Initial COR Cell Inventory (2)

- **More precise definition of distribution**

```
! Partial input for another core, cell by cell
!        Ring number (if>0) or Cavity input (if==0)
!        | Axial Number/Cav Name
!        | | Option flag: 0 or DH fraction of reference core
!        | | |             (same fraction of all classes)
!        | | |  Only product of multipliers is significant
!        V v v  VVVV  VVV
      n  1 4 0  0.13  1.0  ! 0.13 of total in cell 104
     n+1 1 5 0  0.17  1.0  ! 0.17 of total in cell 105
```

- **Other options (all input is additive)**

```
!       Core cell number
!       | | Option flag: 1 or Class - mass of individual class
!       | | |  Class Name (Option flag set to 1 activate
!       | | |  |           Class name input)
!       v v v  v   Mass and multiplier
     n  1 4 1 ‘Ag’ 50.0 1.0   ! 50 kg Class ‘Ag’ in cell 104
!           Option flag: -1 for use of reference cell
!           vv  Reference Cell input activated (IR IA)
    n+4 2 4 -1  1 4  0.66667  1.0  * 2/3 RN mass in cell 104
```



Sandia National Laboratories

# MELCOR RN and Decay Heat Initial Gap Inventories and Input

- **Gap inventory defined with two options**

```
! Class-by class input of cell fraction (default zero)
!        Table rows/index
!        |    Core cell number (IR IA)
!        |    |  Option flag:  1 or CLASS
!        |    |  |  Class name
!        |    |  |  |    Fraction of RN1_FPN in Gap
!        |    |  |  |    |      Ratio, total/radioactive
!        v    |  |  |    |      |    Required for class
RN1_GAP 12 !vvv  v vvvv  vvvvv  vvv
         1  1 4  1 'Cs'  0.05   1.0  * 5% cell Cs in gap
         . . .
! Multiplier on fractions defined for reference cell
!               Option flag: -1 or CELL for reference cell
!               |    Referenced Cell (IR IA)
!               |    |    Fraction multiplier
!               |    |    |        of reference cell
!               vvvv vvv  vvv
         n  1 5 CELL 1 4  1.0 * Use 1.0*fractions from 104
```

# MELCOR RN and Decay Heat Release Models

- Three basic release models, with options
  - CORSOR, fractional release rate = A exp(B T)
    - With or without correction for surface to volume ratio
    - Sensitivity coefficient arrays 7101, 7104, 7105
  - CORSOR-M, fractional release rate = $k_0$ exp(-Q/RT)
    - Extended in MELCOR 1.8.5 from the original form to include release of classes 7(Mo), 9(La), and 11 (Cd)
    - With or without correction for surface-to-volume ratio
    - Sensitivity coefficient arrays 7102, 7104, 7105
  - CORSOR-Booth, based on Cesium diffusion $D_0$ exp(-Q'/RT)
    - High- or low-burn-up fuel
    - Sensitivity coefficient arrays 7103, 7106, 7107
  - Modified CORSOR-Booth



Sandia National Laboratories

# MELCOR RN and Decay Heat Release Models (2)

- **Option to apply to structural materials**
  - **Not considered by default**
  - **Enabled by sensitivity coefficient array 7100**
- **Simple input specifies basic option for fuel**
  - **Various sensitivity coefficient arrays**

```
! Input record is RN_FP00, record is optional
!       Option default =-5
!       vv
RN_FP00  -2    * -1 for CORSOR with surface/volume correction
!                +1 for CORSOR without S/V correction
!                -2 for CORSOR-M with S/V correction (default)
!                +2 for CORSOR-M without S/V correction
!                -3 for CORSOR-Booth, high-burn-up fuel
!                +3 for CORSOR-Booth, low-burn-up fuel
!                -5 for Revised CORSOR-Booth, high-burn-up fuel
!                +5 for Revised CORSOR-Booth, low-burn-up fuel
```



Sandia National Laboratories

# MELCOR RN and Decay Heat
# Other Release Models

- **Gap release based on cladding temperature**
  - Failure temperature can be defined cell-by-cell
  - Inventory in entire ring release on failure in any level

```
!         Table row/index
!         |   Core cell (IR IA)
!         |   |    Failure temperature (K)
!         vv  |    |
RN1_GAP00 12  vvv  vvvvvv
           1  1 7  1200.0  * Default is 1173.0 K
```

- **Class combination on release**
  - Not default, but conventional for Cs + I → CsI
  - Described in earlier presentation

```
* [Recombination name] [acceptor class] [number of donors]
RN1_CLS 'Cs+I' 'CSI' 2
      1 'Cs'   1.0   * Cs Class - donor class
      2 'I2'   0.5   * I2 Class - donor class
! Molecular weights in sensitivity coefficient array 7120
```



Sandia National Laboratories

# MELCOR RN and Decay Heat Distribution of Power

- **Energy carried by fragments, neutrons, $\alpha$, $\beta$, and $\gamma$; each has a finite range**
- **Heat from unreleased radionuclides in fuel**
  - —Split among core components and materials in same cell
  - —Defaults based on detailed calculations for a specific core
  - —Splits are user-adjustable (SC arrays 1321, 1322)
- **Heat from radionuclides in pool goes to pool**
- **Heat from radionuclides in atmosphere**
  - —By default, 50% (typical $\gamma$) to pool and other surfaces in volume, 50% (balance) to atmosphere--but see next slide
  - —Splits can be modified
  - —Atmospheres and structures in other volumes can be included



Sandia National Laboratories

# MELCOR RN and Decay Heat Distribution of Power(2)

- Heat from radionuclides on structure surfaces
  - By default, 50% to surface, 25% (typical $\gamma$) to pool and other surfaces in volume, 25% (balance) to atmosphere
    - Splits can be modified
    - Atmospheres and structures in other volumes can be included
- Modification for small atmospheres
  - Range of $\beta$s may exceed volume dimensions, particularly for small volumes with low density atmospheres
  - Actual absorption modified, considering
    - Typical range of a $\beta$ (1.2 $kg/m^2$, in SC array 7002)
    - Typical distance in atmosphere ($volume^{1/3}$, modifiable)
- Won't discuss this further



Sandia National Laboratories

# MELCOR RN and Decay Heat Other Input

- **Almost everything is adjustable through input or sensitivity coefficients**
  - Definition and properties of elements
  - Definitions and properties of classes (molecular weight, vapor pressure, etc.)
  - Association of class numbers with chemical models
  - Coefficients in most models and correlations, including release rates (CORSOR)
- **There are few, if any, checks on changes**
  - It's easy to define things inappropriately
  - It's hard to determine the cause of the problem
- **In general, best to accept the defaults**
  - May not be possible in some cases, so *use great care*