

Activity Calculations

Presented by

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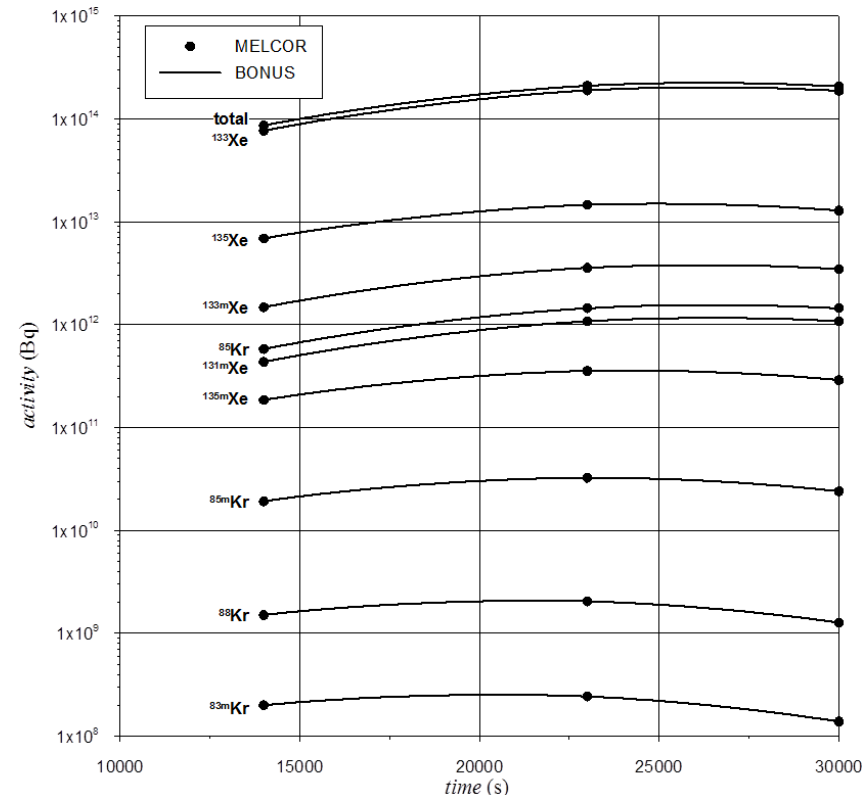
SAND2018-4221 C

Background

- MELCOR tracks RN class masses
 - Decay heat associated with mass determined by inventory of elements and DCH input
 - MELCOR does not track isotopes
 - MELCOR does not know anything about half-lives or decay energies
 - MELCOR does not track radioactive decay and transmutation
- Desirable to know activities
 - Curies or Bq released to atmosphere.
 - Additional isotopic information must be provided to generate estimates

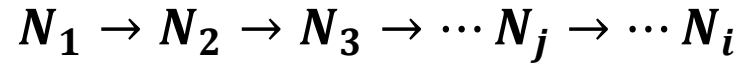
Radioactivity calculations

- For estimation of radiological impact activity values are required.
 - Hand calculations could be made
- BONUS code, developed at IBRAE was implemented into MELCOR to track activities
 - The component that provides calculations of FP evolution after reactor shutdown has been implemented in MELCOR 2.1.
 - Isotope properties and inventories must be defined by the user through separate library files



Bateman Equations

General Radioactive Decay Chain



Sources and losses

$$\frac{dN_i}{dt} = \sum_{j=1}^{i-1} \lambda_j N_j - \lambda_i N_i$$

Solution

$$N_i(t) = \lambda_1 \lambda_2 \cdots \lambda_{i-1} N_1(0) \sum_{j=1}^i \frac{e^{-\lambda_i t}}{\prod_{k \neq j} (\lambda_k - \lambda_j)}$$

- Isobaric β and γ decays of fission products are considered
- Thermal neutron capture also taken into account
- Daughter products defined in file Fpchains.in
 - Placement of chains is arbitrary
 - Coupled chains should follow each other

Model for activity calculations

The activity A_{ZA} (Bq) of isotope (Z, A) in the volume under interest is calculated as:

$$A_{ZA}(t) = \lambda_{ZA} N_{ZA}(t),$$

where N_{ZA} is the total number of atoms of isotope (Z, A) in the volume and λ_{ZA} is the decay constant (s^{-1}).

The variable $a_{CL,ZA}$ measures the relative contribution of isotope (Z, A) to the total activity A_{CL} of the class CL:

$$a_{CL,ZA}(t) \equiv \frac{A_{ZA}(t)}{A_{CL}} = \frac{A_{ZA}(t)}{\sum_{Z \in CL,A} A_{ZA}(t)} = \frac{\lambda_{ZA} N_{ZA}(t)}{\sum_{Z \in CL,A} \lambda_{ZA} N_{ZA}(t)}$$

Model for activity calculations

The total class activity A_{CL} (Bq) is calculated as

$$A_{CL}(t) = \frac{H_{CL}(t)}{\sum_{Z \in CL, A} E_{ZA} a_{CL, ZA}(t)} = \frac{M_{CL}(t)}{m_n \sum_{Z \in CL, A} \lambda_{ZA}^{-1} A a_{CL, ZA}(t)} = \frac{h_{CL}(t) \cdot M_{CL}(t)}{\sum_{Z \in CL, A} E_{ZA} a_{CL, ZA}(t)}$$

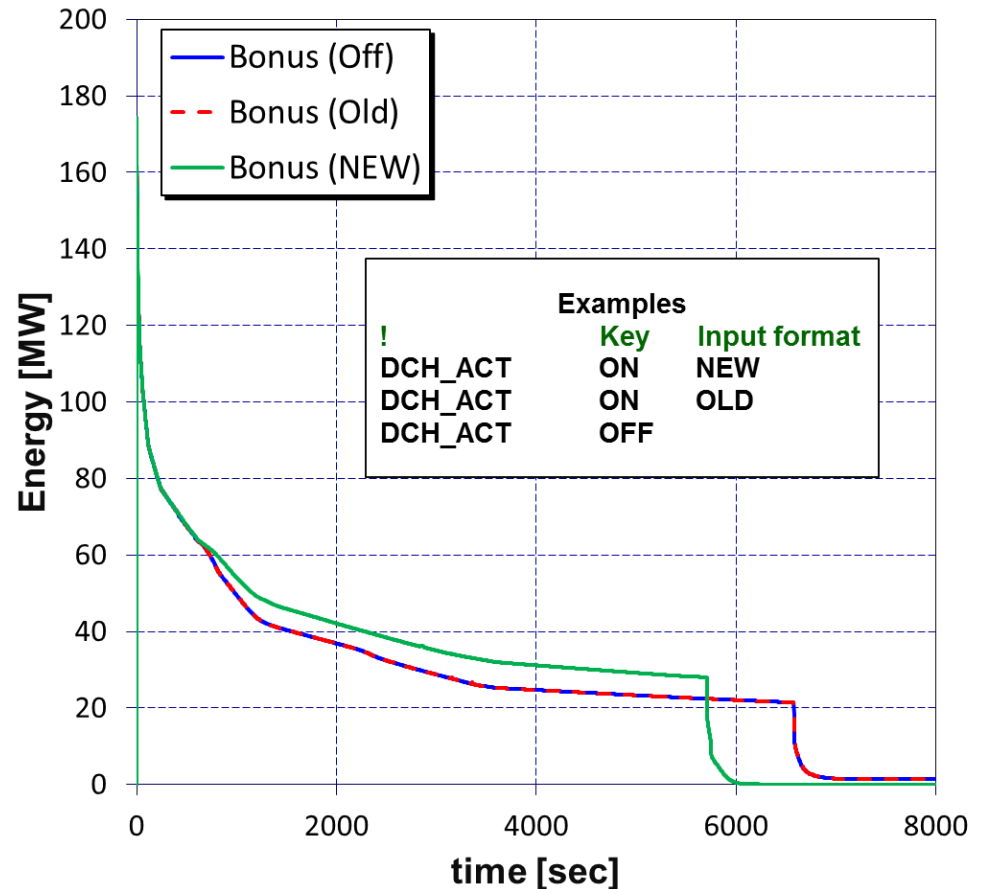
where m_n is the mass of nucleon (kg), A is a mass number, h_{CL} - the total specific decay heat of the class (J/kg/s), E_{ZA} - the decay energy of isotope (Z, A) (J) .

The activity of each isotope in the class:

$$A_{ZA}(t) = A_{CL}(t) a_{CL, ZA}(t).$$

Options for decay heat used in activity calculations

- Option 1 ('OLD')
 - Calculation uses original MELCOR decay heat table.
 - Calculation results not affected by BONUS libraries
- Option 2 ('NEW')
 - MELCOR determines decay heats from the isotopic inventories and isotope properties from the BONUS library.
 - Changes calculation results
 - User must have greater confidence in isotopic property libraries and inventories



Class Decay Heats

Decay Heat from BONUS

CLASS NUMBER	CLASS NAME	POWER/MASS W/KG	POWER W
1	XE	5.06165E+04	7.85076E+06
2	CS	1.56255E+05	1.45758E+07
3	BA	2.06496E+05	1.19187E+07
4	I2	1.95655E+06	1.42955E+07
5	TE	2.23732E+05	4.58827E+06
6	RU	1.94095E+04	2.31438E+06
7	MO	1.37669E+05	1.69848E+07
8	CE	5.51865E+04	2.63679E+07
9	LA	1.02658E+05	2.26019E+07
10	UO2	6.74759E+02	5.62400E+07
11	CD	4.24673E+08	5.55897E+06
12	AG	1.00162E+06	1.22336E+06
13	BO2	0.00000E+00	0.00000E+00
14	H2O	0.00000E+00	0.00000E+00
15	CON	0.00000E+00	0.00000E+00
16	CSI	1.03560E+06	0.00000E+00
17	CSM	1.51325E+05	0.00000E+00

TOTAL POWER FROM FISSION PRODUCT CLASSES =
1.84520E+08 W

Decay Heat from DCH

CLASS #	CLASS NAME	POWER/MASS W/KG	POWER W
1	XE	4.78564E+04	1.50816E+07
2	CS	1.57424E+05	2.76496E+07
3	BA	1.36364E+05	1.88520E+07
4	I2	1.55093E+06	2.10514E+07
5	TE	3.15909E+05	8.73476E+06
6	RU	1.91922E+04	3.73270E+06
7	MO	1.26027E+05	2.89064E+07
8	CE	3.12888E+04	1.26623E+07
9	LA	9.53138E+04	3.57874E+07
10	UO2	4.55673E+01	3.77040E+06
11	CD	7.32125E+06	6.72388E+06
12	AG	3.00602E+05	1.56786E+06
13	BO2	0.00000E+00	0.00000E+00
14	H2O	0.00000E+00	0.00000E+00
15	CON	0.00000E+00	0.00000E+00
16	CSI	8.38072E+05	0.00000E+00
17	CSM	1.49097E+05	0.00000E+00

TOTAL POWER FROM FISSION PRODUCT CLASSES =
1.84520E+08 W

DCH_FPW .2208E+10 0.1059E+10 0.1436E+09 ! Decay power U-235, Pu-239, U-238

Data Initialization

- For activity calculations it's necessary to specify isotopic composition at the time of reactor shutdown.
 - MELCOR does not explicitly treat isotopes. It works in terms of “elements” that are summed into RN classes.
- Capability to have multiple libraries for various reactor applications (reactor type, fuel type, etc.) to be used in practical calculations in combination with the total decay heats of elements.
- If the user utilizes the old MELCOR input file without providing any information about initial inventory, a default library is chosen.

Initial inventories

- User specifies masses of isotopes at reactor shutdown.
- Specified in File ' InitInventory.in' by default
 - File name can be changed by the user in input
 - Data can be specified for different reactor campaigns,
 - Block should start with REACTOR_XYZ line, where XYZ... is user-defined characters defining the campaign name
 - Example, REACTOR_PWR1Y, REACTOR_BWR_2Y).
 - The block name used in particular calculations is set on DCH_RCT record.
 - Tests confirm that properties ($T_{1/2}$, E_{α} , E_{β} , E_{γ}) of radionuclide are defined
 - Comments lines can begin with !

```

REACTOR_PWR
Se-80 4.06405E-01
Se-81 1.31432E-05
Br-81 6.81138E-01
Se-82 1.04052E+00
Se-83 1.77636E-05
Se*-83 7.74357E-07
Br-83 2.20323E-04
Kr*-83 1.67048E-04
Kr-83 1.63820E+00
Se-84 8.22949E-06
    
```

Optional 3rd field can specify γ energy (MeV) for dose calculation

R	E	A	C	T	O	R	_	P	W	R						
!	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	
S	e	-	8	0			4	.	0	6	E	-	0	1		
S	e	-	8	1			1	.	3	1	E	-	0	5		
B	r	-	8	1			6	.	8	1	E	-	0	1		
S	e	-	8	2			1	.	0	4	E	+	0	0		
S	e	-	8	3			1	.	7	8	E	-	0	5		
S	e	*	-	8	3			7	.	7	4	E	-	0	7	
B	r	-	8	3			2	.	2	0	E	-	0	4		
K	r	*	-	8	3			1	.	6	7	E	-	0	4	
K	r	-	8	3			1	.	6	4	E	+	0	0		
S	e	-	8	4			8	.	2	3	E	-	0	6		

Specifying Initial Mass Inventories

DCH_RCT – Reactor type for initial mass inventories

Optional

This record enables the user to specify the type of reactor or filename and data block with initial inventories.

If IACTIV = OFF or 0, the old format of DCH_RCT record must be used.

Examples

!	Reactor type	File name	Block name
DCH_RCT	PWR	“initInventory.in”	“REACTOR_PWR”
DCH_RCT	BWR	“initInventory.in”	“REACTOR_BWR”

Isotopes Associated with Each DCH Class

- MELGEN Output Shows All Isotopes Associated with Each DCH Class
 - Isotopes identified on library text files provided by user
 - Element names match short DCH element names

ISOTOPES ASSOCIATED WITH EACH RADIONUCLIDE CLASS

XE: Kr*83 Kr83 Kr84 Kr*85 Kr85 Kr86

Kr88 Kr89 Xe*131 Xe131 Xe132 Xe*133

Xe*135 Xe135 Xe136 Xe134 Xe137 Xe138

CS: Rb85 Rb87 Rb88 Rb89 Rb*90 Rb90

Cs133 Cs134 Cs135 Cs137 Cs*138 Cs138

Cs140 Cs141

...

Properties of fission products

- The isotopes database (half-life times, decay energies, etc.).
 - File 'FissProd.in' (properties of fission products)
 - Comment lines must begin with !
 - Half-life units seconds ('s','S'), minutes ('m','M'), hour('h','H'), day ('d','D'), year ('y','Y'), Stable ('e','E')
 - Any characters beyond 50 are ignored
 - E_gamma, E_beta, and E_alpha are summed to obtain a total transition energy

These columns are optional if DCH package is used to calculate decay heat

A	Name										t 1 / 2										E _ g a m m a										E _ b e t a										E _ a l p h a									
I	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	
6	6																																																	
6	6																																																	
6	6									0	.	2	3	s																																				
6	6									5	4	.	6	h															6	.	7	2	0	E	-	0	2													
6	6									5	.	1	0	m					8	.	4	7	0	E	-	0	2		1	.	0	7	0	E	+	0	0													
6	7																																																	
6	7									2	1	s																																						
6	7									2	.	5	8	0	d				1	.	1	5	0	E	-	0	1		1	.	5	5	0	E	-	0	1													
6	8																																																	
6	8																																																	
6	8									1	9	s																																						
6	8									3	.	7	9	m																																				
6	8									3	1	s																																						
6	8									s	t	a	b	l	e			0	.	0	0	0	E	+	0	0		0	.	0	0	0	E	+	0	0		0	.	0	0	0	E	+	0	0				

T.R.England, B.F.Rider. "Evaluation and Compilation of Fission Yields", ENDF-349, LA-UR-94-3106.

Isobaric chains

- The β - and γ -decays of FPs are taken into account in BONUS
 - no change in mass number and FP decay sequence represents the isobaric chain.
 - β -decay assumes one or two daughter nuclides
 - ground and isomeric states
- Thermal neutron capture also is taken into account,
 - produces one or two daughter nuclides with a mass number increased by 1
 - results in coupling of the current chain with the next one(s).
- Specified in File 'FPChains.in' (structure of isobaric chains)
- Comments lines can begin with !
 - Any heading lines must begin with !

		beta-decay		n-gamma		Branch_ratios								
		1-st	2-nd	1-st	2-nd	beta	neutron							

80														
Se														

81														
Se Br														
Br														

82														
		1-10		11-20		21-30		31-40		41-45				
!	2	3	4	5	6	7	8	9	0	1	2	3	4	5
! This is a comment														
80														
Se														

81														
Se			Br											
Br														

82														
Se														

83														
Se			Br											
! This is a comment														
Se*			Br											
Br			Kr*		Kr								. 9 9 9 7 5 4	
Kr*			Kr											
Kr														

151														
Nd			Pm											
Pm			S m											
S m			E u				S m							
E u							E u *		E u				. 3 3 7 4	

Input Files and Nuclear Data

FPchains.ini (IBRAE)

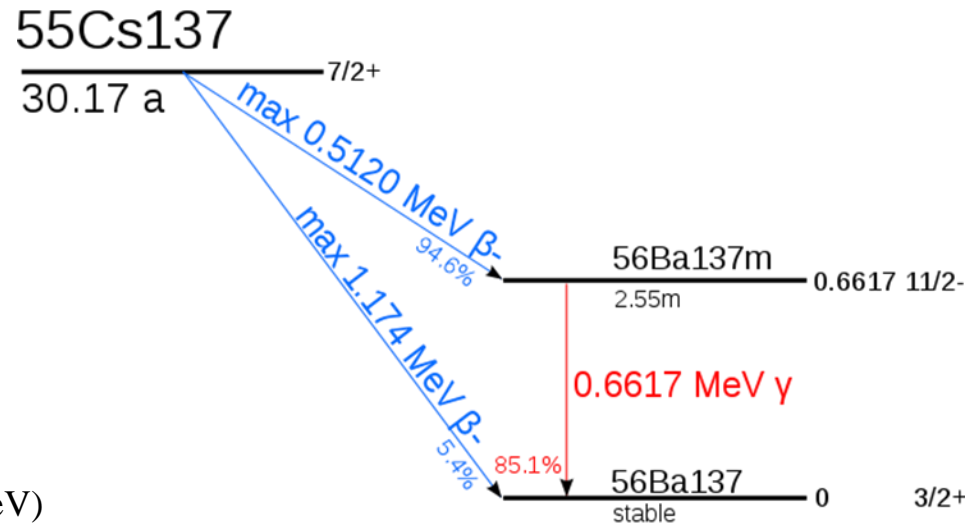
```

137
I Xe
Xe Cs
Cs Ba* Ba .945
Ba* Ba
Ba
    
```

Fissprod.ini (IBRAE)

!A	Name	t1/2	E_γ (MeV)	E_β (MeV)	E_α (MeV)
137	Sn				
137	Sb	0.478s			
137	Te	2.5 s	1.609	2.173	
137	I	24.5 s	1.23	2.03	
137	Xe	3.82 m	0.191	1.697	
137	Cs	30.17y		0.187	
137	Ba*	2.552m	5.960E-01	6.510E-02	
137	Ba	stable	0.000E+00	0.000E+00	0.000E+00

These columns are optional if DCH package is not used to calculate decay heat



**Cs-137 beta energy seems inconsistent!
Caution when allowing BONUS to
calculate activity**

Modifications of Output (1)

DCH_SUR – Output activity data

Optional. Allowed if IACTIV = ON on DCH_ACT record

Specifies the control volumes or heat structures sides for which isotope activities data will be printed to the output. If control volume is set, the data on isotopes activities will be summarized for control volume and heat structures associated with the corresponding control volume. By default isotopes activities will be printed for flow paths set on FL_MACCS record, different control volume types, and total problem inventory.

Examples

```
DCH_SUR 4 ! N TYPE      NAME      IKEY
      1 CVH  CORE-INLET   ALL
      2 LHS  INLET-FLOOR  ISOTOPE 'Cs-137' 'I-131'
      3 CVH  'CONTAINMENT' ALL
      4 LHS  'CORWALL6'   ISOTOPE 'Cs-137' 'I-131'
```

```
DCH_SUR 1 ! N TYPE      NAME      IKEY
      1 CVH  CV110-CORE  ALL
```


Modifications of output (2)

This output generated only for those CVs specified on the DCH_SUR record.

ACTIVITY (BQ) FOR CONTROL VOLUMES AND HEAT STRUCTURE SIDES DEFINED BY THE USER

```
          CUH
          CU110-CORE
Se-80      0.000000E+00
Se-81      0.159909E+17
Br-81      0.000000E+00
Se-82      0.804288E-03
Se-83      0.206375E+17
Se*-83     0.136319E+11
Br-83      0.818937E+17
```

This output generated for each CV type

ACTIVITY (BQ) FOR CONTROL VOLUMES OF THE SAME TYPE

ISOTOPE NAME	CORE	DRYWELL	WETWELL	CONTAINMENT	ENVIRONMENT	FILTERS
Se-80	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
Se-81	0.499953E+15	0.228914E+13	0.728978E+16	0.308654E+16	0.758805E+10	0.758044E+13
Br-81	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
Se-82	0.641286E-04	0.293627E-06	0.935055E-03	0.395908E-03	0.973314E-09	0.972339E-06
Se-83	0.756828E+15	0.346530E+13	0.110353E+17	0.467240E+16	0.114868E+11	0.114753E+14
Se*-83	0.404858E+03	0.185373E+01	0.590321E+04	0.249946E+04	0.614475E-02	0.613859E+01

Plot Variables

- BONUS-ISO.iso
 - Total activity of isotope, number iso, in Bq. This is the total activity inventory for the problem and includes all airborne, deposited, and unreleased isotopes. The isotope number is denoted in the MELGEN output.
- BONUS-ISOMASS.iso
 - Mass of isotope, number iso, in kg. This is the total activity inventory in the problem and includes all airborne, deposited, and unreleased isotopes. The isotope number is denoted in the MELGEN output.

Variable to be plotted

Select independent variable:

time [sec]
time [min]

Limit number of records read from plotfile

Select dependent variable:

BONUS-ISO (1/S)
BONUS-ISOMASS (KG)

Description

Sort Alphabetically
 Show added variables

Next
Back

Select Variables

Filter List: *.83

Additional Variables Done

Available Variables to Plot:

BONUS-ISOMASS.5	Isotope = Se-83,
BONUS-ISOMASS.6	Isotope = Se*-83,
BONUS-ISOMASS.7	Isotope = Br-83,
BONUS-ISOMASS.8	Isotope = Kr*-83,
BONUS-ISOMASS.9	Isotope = Kr-83,

Add -->

-->Remove

Selected Variables to Plot:

Allow Multi-select
 Apply Filters

Show full (strict) variable name on legend
 Show only the user-defined object name

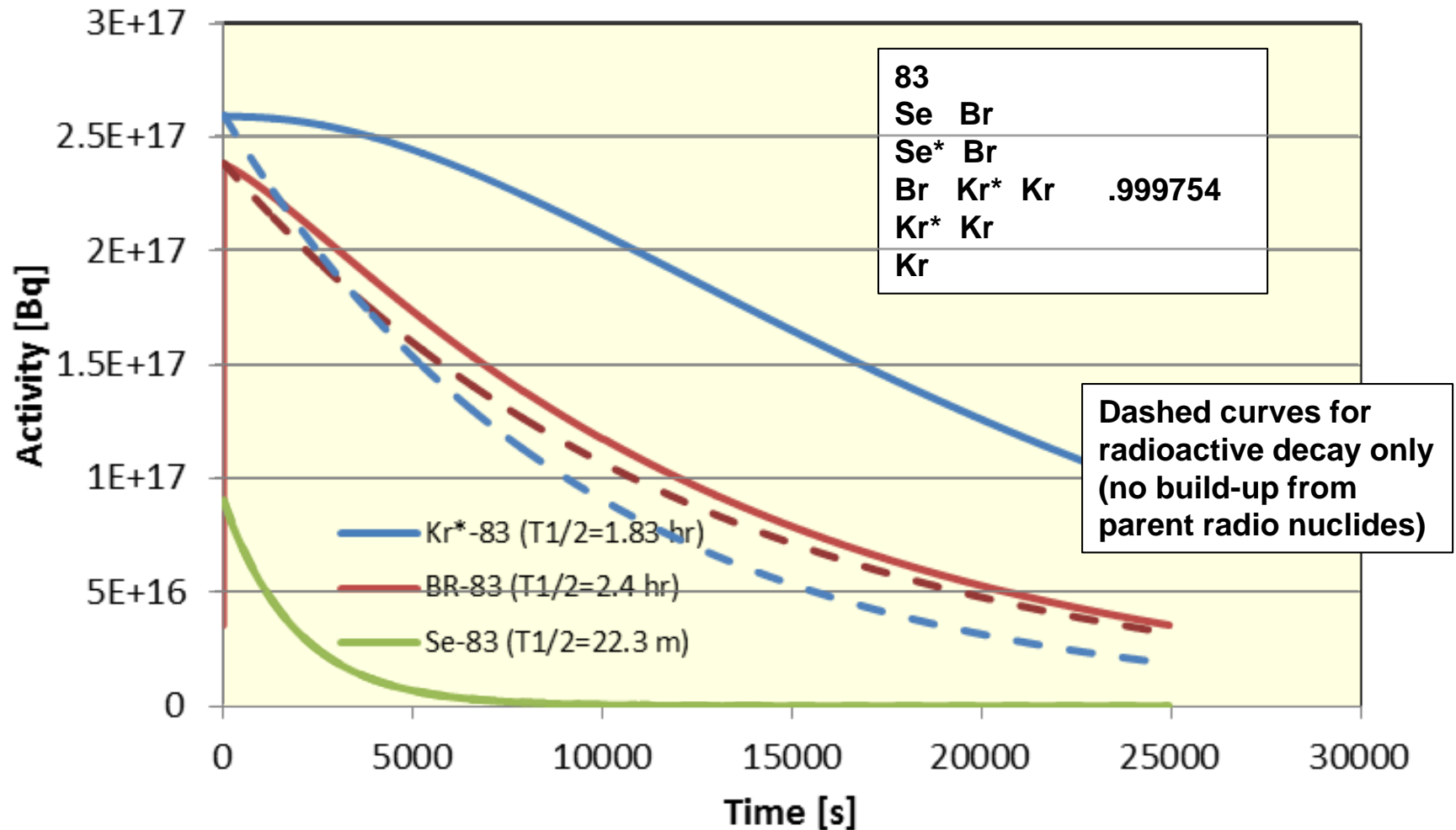
Decay Heat from DCH

XE Class (DCH Mass = 315.142600, DCH Decay Heat = 0.150816E+08)				XE Class (DCH Mass = 315.142600, DCH Decay Heat = 0.702507E+06)			
ISOTOPE	Decay Lambda	Total Mass Bonus	Total Activity	ISOTOPE	Decay Lambda	Total Mass Bonus	Total Activity
Kr*-83	0.105214E-03	0.339315E-03	0.259066E+18	Kr*-83	0.105214E-03	0.122818E-03	0.937714E+17
Kr-83	0.000000E+00	0.333220E+01	0.000000E+00	Kr-83	0.000000E+00	0.333241E+01	0.000000E+00
Kr-84	0.000000E+00	0.623771E+01	0.000000E+00	Kr-84	0.000000E+00	0.623710E+01	0.000000E+00
Kr*-85	0.429779E-04	0.169861E-02	0.517288E+18	Kr*-85	0.429779E-04	0.587421E-03	0.178891E+18
Kr-85	0.204686E-08	0.219438E+01	0.318268E+17	Kr-85	0.204686E-08	0.219421E+01	0.318245E+17
Kr-86	0.000000E+00	0.103014E+02	0.000000E+00	Kr-86	0.000000E+00	0.103001E+02	0.000000E+00
Kr-87	0.151607E-03	0.100779E-02	0.105775E+19	Kr-87	0.151607E-03	0.231600E-04	0.243081E+17
Kr-88	0.677961E-04	0.318997E-02	0.148020E+19	Kr-88	0.677961E-04	0.587633E-03	0.272672E+18
Kr-89	0.366744E-02	0.737554E-04	0.183054E+19	Kr-89	0.366744E-02	0.134285E-43	0.333283E-21
Xe*-131	0.674163E-06	0.772095E-02	0.239319E+17	Xe*-131	0.674163E-06	0.772146E-02	0.239335E+17
Xe-131	0.000000E+00	0.351506E+02	0.000000E+00	Xe-131	0.000000E+00	0.351582E+02	0.000000E+00
Xe-132	0.000000E+00	0.568912E+02	0.000000E+00	Xe-132	0.000000E+00	0.569028E+02	0.000000E+00
Xe*-133	0.366326E-05	0.833050E-02	0.138197E+18	Xe*-133	0.366326E-05	0.760188E-02	0.126110E+18
Xe-133	0.153014E-05	0.666440E+00	0.461800E+19	Xe-133	0.153014E-05	0.664231E+00	0.460269E+19
Xe*-135	0.755062E-03	0.296647E-03	0.999313E+18	Xe*-135	0.755062E-03	0.100374E-03	0.338128E+18
Xe-135	0.211583E-04	0.633931E-02	0.598415E+18	Xe-135	0.211583E-04	0.161629E-01	0.152574E+19
Xe-136	0.000000E+00	0.110328E+03	0.000000E+00	Xe-136	0.000000E+00	0.110314E+03	0.000000E+00
Xe-134	0.000000E+00	0.900100E+02	0.000000E+00	Xe-134	0.000000E+00	0.900065E+02	0.000000E+00
Xe-137	0.302420E-02	0.302742E-03	0.402510E+19	Xe-137	0.302420E-02	0.541146E-36	0.719478E-14
Xe-138	0.819323E-03	0.101591E-02	0.363284E+19	Xe-138	0.819323E-03	0.134518E-11	0.481027E+10
Xe-139	0.174596E-01	0.337284E-04	0.255169E+19	Xe-139	0.174596E-01	0.218215E-193	0.165089E-170
TOTAL		315.142600	0.217642E+20	TOTAL		315.142600	0.721807E+19

$$M_{Xe137}(t) = M_{Xe137}(0)e^{-\lambda_{Xe137} \cdot t}$$

$$0.541146 \cdot 10^{-36} = 0.302742 \cdot 10^{-3} e^{-.0030242 \cdot 24950sec}$$

Decay and Build-up (A=83)



Estimate dose given MELCOR-supplied activities throughout plant

One possible method

- **Gamma dose rate in air**

$$\dot{D}_i^\gamma = (5.77 \times 10^{-5}) \phi_i E_i \left(\frac{\mu_{a,i}}{\rho} \right)_{air}$$

Where

\dot{D}_i^γ - gamma dose rate of the i^{th} isotope [Rad/hr]

ϕ_i - gamma flux of the i^{th} isotope [1/(cm² s)]

E_i - gamma energy of the i^{th} isotope [MeV]

$\left(\frac{\mu_a}{\rho} \right)_{air}$ - mass absorption coefficient for air at E_i [cm²/g]

- **Assume mono-energetic gammas for each isotope**

- In reality, gammas interactive with matter before reaching detector, creating an energy spectrum

- **For each isotope of interest, this approach amounts to estimating the gamma flux at a detector**

Flux estimations for dose calculation

- **In general, a 3-D particle transport calculation is necessary for high accuracy calculation of energetic particle flux at a radiation detector**
 - Depends on the detector design, 3-D arrangement of obstructions in the plant region interest (metal and concrete between source and detector)
 - Scattering, absorption, and secondary particles can affect flux by orders of magnitude
 - Time-dependent thermal-hydraulics and radionuclide transport
 - Requires external coupling to another code
- **For first order approximations using only MELCOR, implement simple user-specified model for particle flux**
 - Assume a geometric distribution of activity in the MELCOR control volume(s) of interest
 - May consider airborne activity, activity in liquid pools, activity deposited on the floor, and activity plated out on vertical heat structures
 - User choice to neglect/include various contributions to total flux

Un-collided gamma flux, spherical distribution of gamma-emitting radionuclides

- **For a uniform and spherical distribution of activity with a detector located at the center of the sphere:**

$$\phi_i = (3.7 \times 10^{10}) \frac{A_i}{V \rho_{air} \left(\frac{\mu_s}{\rho} \right)_{air}} \left(1 - e^{-\rho_{air} R \left(\frac{\mu_s}{\rho} \right)_{air}} \right)$$

- Where

A_i = activity for the i^{th} isotope (Ci),

R = equivalent spherical radius of volume V (cm^3),

ρ_{air} = density of air (g/cm^3),

$\left(\frac{\mu_s}{\rho_{air}} \right)$ = total attenuation coefficient of air at E_i (cm^2/g),

and V = volume of MELCOR control volume(s) of interest (cm^3).

- **Assumptions:**

– Mono-energetic flux

– Mono-energetic gamma particles from each isotope reach the detector

– attenuation coefficient: consider energy dependence or treat as a constant

Attenuation coefficient – function of energy

$$\left(\frac{\mu_a}{\rho}\right)_{air} = a + bE + c[\ln(E)]^2 + d\sqrt{E} + e[\ln(E)]$$

$$\left(\frac{\mu_s}{\rho}\right)_{air} = a + bE^c$$

fit coefficient	mass absorption coefficient for air	mass attenuation coefficient for air
a	0.0	-0.037274
b	-5.2588E-04	0.101714
c	-5.2077E-03	-0.274123
d	2.8172E-02	--
e	-1.7809E-02	--

Simplest approach: energy is the initial energy of the emitted gamma for each isotope (effectively giving each isotope its own distinct attenuation coefficients).

Un-collided gamma flux due to activity on control volume floor

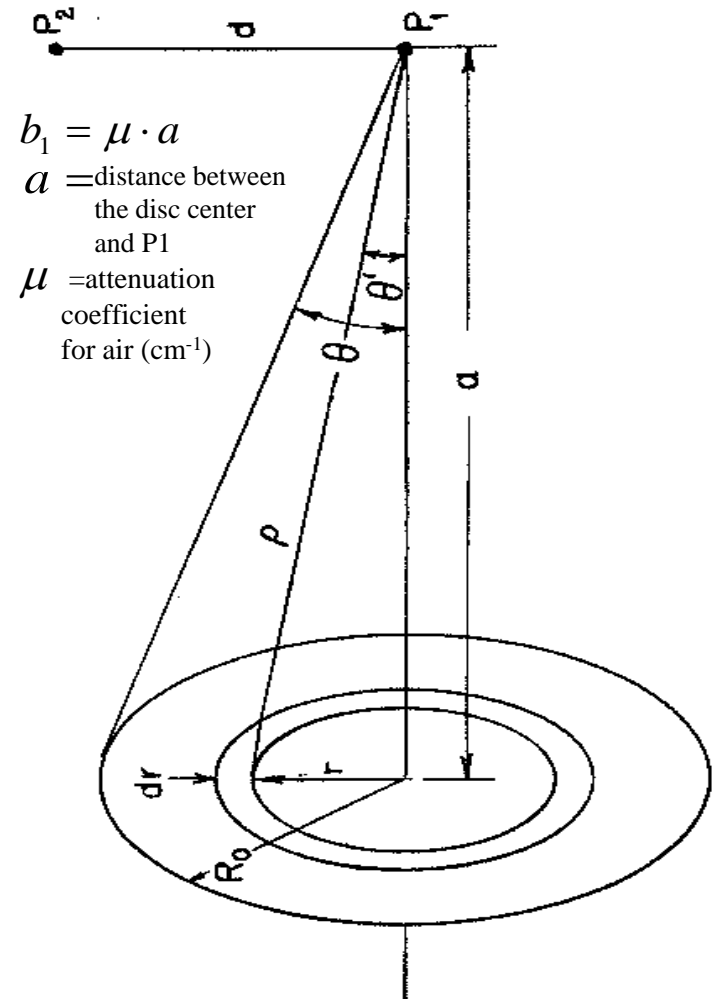
- Simplest case: detector at centerline

$$\phi_i = \frac{A_i}{2 \cdot \pi \cdot R_o^2} [E_1(b_1) - E_1(b_1 \sec \theta)]$$

$$E_n(b) = b^{n-1} \int_{b_n}^{\infty} \frac{e^{-t}}{t^n} dt \quad \text{(Exponential integral)}$$

- **Numerous other analytical and computational models available to estimate un-collided flux, some more complicated than others...**

- Sources in pools
- Sources on horizontal slabs
- Cylindrical sources in pipes
- Detectors in complicated orientations with source



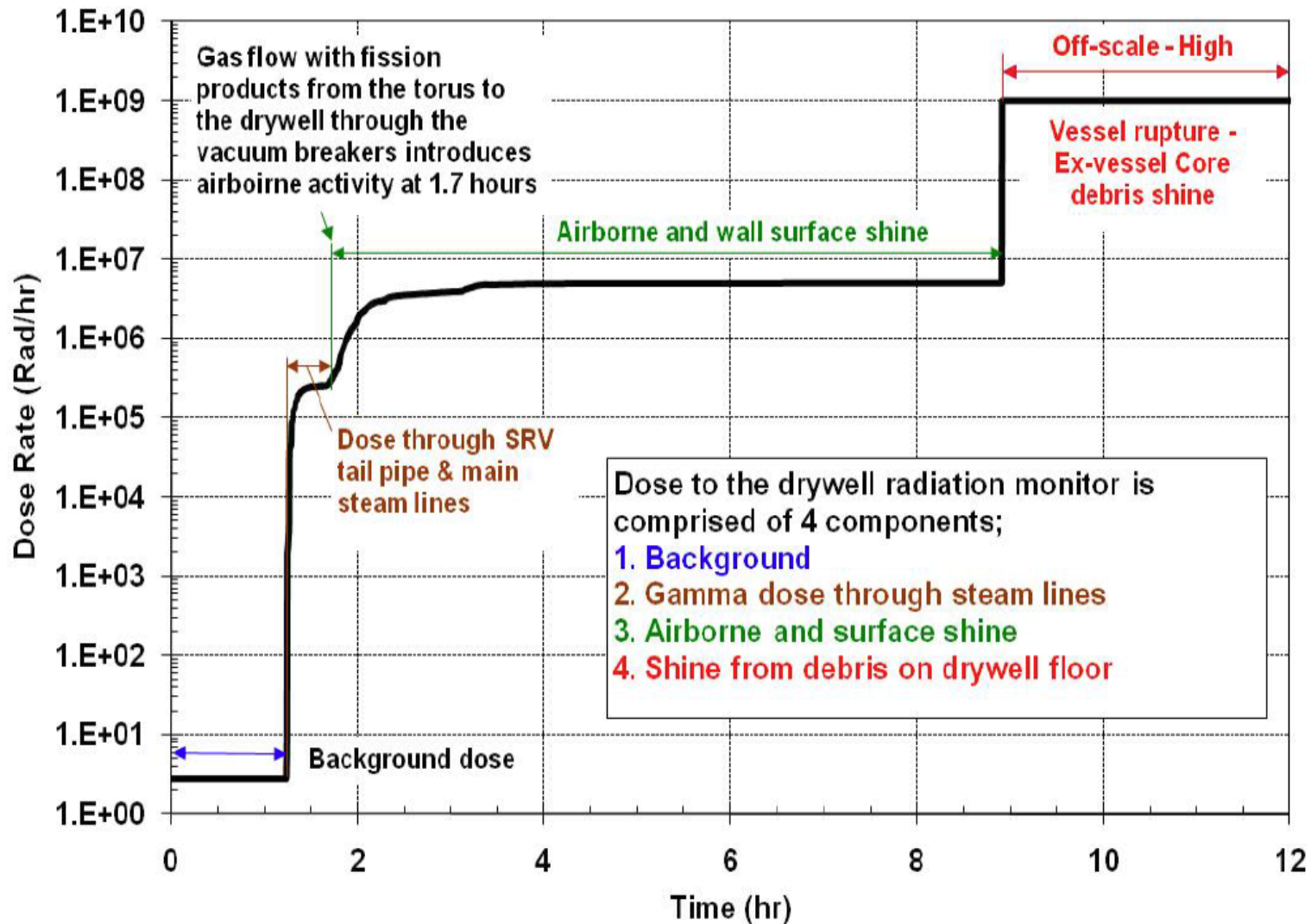
Dose Plot Variable

- Plot variables for dose estimate recently added (April 2018)
 - Doses calculated for each surface or volumes in DCH_SUR table
 - BONUS-DOSE.isur (Rad/hr)
 - isur corresponds to table entry in DCH_SUR table
 - Optional characteristic length, CHARL, provided by user (in red)
 - Real value for word 4 indicates characteristic length.
 - Otherwise, 4th word should be KEY.
 - For CVOLUME – CHARL = radius of volume used by flux calculation
 - » Default is calculated from atmospheric volume assuming spherical volume
 - For HS surface – CHARL = orthogonal distance from surface to dose ‘detector’
 - » Default is 1 m from surface

Example				
DCH_SUR	4	! N TYPE	NAME	CHARL IKEY
1	CVH	CORE-INLET		ALL
2	LHS	INLET-FLOOR	1.25	ISOTOPE 'Cs-137' 'I-131'
3	CVH	'CONTAINMENT'	0.9	ALL
4	LHS	'CORWALL6'		ISOTOPE 'Cs-137' 'I-131'

- Gamma energy from user files
 - 1st uses gamma energy from FissProd.in file
 - Overwrites with any gamma energy on 3rd field in inventory file.

BWR SBO: drywell dose rate



MELCOR dose work at Sandia

- **Preliminary investigations by Raymond Jun**

R. Jun, “Application of MELCOR to Containment Dose Analysis,” *Proceedings of CSARP 2010*, Bethesda, MD, September 16-17, 2010.

- **Proposed Equipment Dose Calculation Method for the Regulatory Guide 1.89 Update by Donald Kalinich**

D. Kalinich, et al., “Proposed Equipment Dose Calculation Method for the Regulatory Guide 1.89 Update,” DRAFT, 2012.

- **Regulatory Guide 1.89, Revision 1, “Environmental Qualification of Certain Electrical Equipment Important to Safety for Nuclear Power Plants”**

Questions