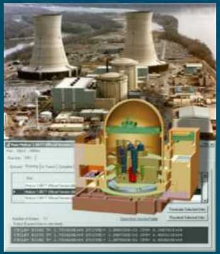
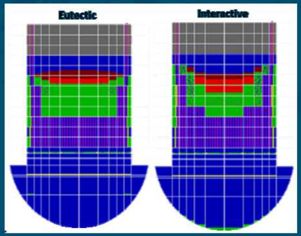
SAND2019-13345PE

MELCOR
New Modeling
SQA
Utilities

Radiation Enclosure Model

PRESENTED BY

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Multi HS Radiation Enclosure Model

Previous HS radiation model

- Radiation defined only for surface pairs
- Radiation to gas performed independently for each surface
  - Does not account for transmissivity of gas
    - Radiation between surfaces is calculated even for optically opaque gases
  - Does not account for reflection among surfaces

New enclosure model

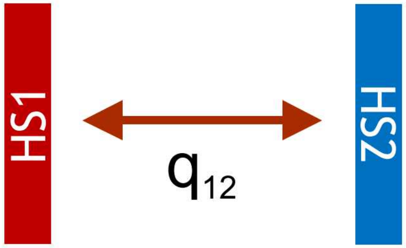
- Multiple enclosure networks, each with multiple heat structures defined by the user.
  - Memory dynamically allocated
- User defines all surfaces exchanging radiant heat
  - Matrix of view factors connecting surfaces
  - View factors can be control functions
  - Accounts for surface submerged below pool
- Participating gas
  - Transmissivity accounts for reduction in radiation between surfaces
  - Only 1 CV associated with all surfaces
    - Does not account for rising pool in CV (yet)
  - User supplies beam length (similar to COR package)

Structure-to-Structure Radiation Input
(Previous HS Radiation Model)

Basic input for each surface pair

```
HS_RD     2
      !  first surface        side        second surface       side     view factor
   1         HS1             LEFT             HS2             LEFT        0.15
   2         HS1             RIGHT            HS2             RIGHT       0.075

! left side of HS1 sees left of HS2
! right side of HS1 sees right of HS2
```



- **To override built-in emissivity model**

```
HS_RD   1
   1    'HS1'     LEFT     'HS2'      LEFT     0.15        NO              CFemissivity
```

'NO' means that the emissivity as a function of temperature is determined by core

CFemissivity: control function whose value is the emissivity of surface 2.

Radiation to Fluids
(Not to be used with enclosure network)

Radiation between surface and gases

- Calculated only if input record HS_LBR or HS_RBR included
- Two options, "equivalent band model" and "gray" gas

HS_LBR	0.9	gray-gas-a	0.1
	wall emissivity of surface		radiation path length

- This should not be active when radiation enclosure model is used because radiation to gas is already in enclosure model.

Emissivity is constant for the transient

Radiation to H2O, CO, and CO2.

Not to other non-condensible gases

Not to aerosols

Mechanistic model is used for radiation on film covered surfaces

Gray Gas Model
Beam Length

Equivalent path length representing the average contribution of different beam lengths from the gas body to the surface.

Geometry:	L
Sphere: internal radiation	0.65 x D
Hemisphere: Radiating to element at center of base	0.5 x D
Circular cylinder of infinite height: Internal radiation	0.95 D
Circular cylinder of semi-infinite height	
Element at center of base	0.9 D
Entire base	0.65 D
Circular cylinder of height equal to two diameters radiating to:	
Plane end	0.43 D
Cylindrical surface	0.46 D
Entire surface	0.45 D
Cube radiating to any face	0.6 x edge
Gas volume outside infinite bank of tubes radiating to a single tube (P = pitch)	
Equilateral-triangle array:	
P=2D	3.0(P-D)
P=3D	3.8x(S-D)
Square Array	3.5x(S-D)
Arbitrary shape of volume V	3.6 V/A

Multi HS Radiation Enclosure Model

The space between surfaces may or may not be filled with a participating medium,

- Participating gas may absorb, emit, and scatter radiation emitted by the surfaces.

Each surface is assumed to be isothermal, opaque, diffuse, and gray, and are characterized by uniform radiosity.

- The absorptivity (a) of a surface is equal to the emissivity (e) and the sum of the absorptivity and reflectivity (r) is 1.0

$$\varepsilon_i = \alpha_i = 1 - \rho_i$$

Reciprocity is also assumed between surface pairs

It is assumed the sum of the view factors from a surface to all surfaces in the enclosure network, is equal to 1.0.

- a surface may also radiate to itself.

$$\sum_{i=1}^{N} VF_{i,j} = 1.0$$

The surface radiosity is defined as the total heat flux that departs from an area (reflected and emitted)

$$J_i = \rho_i \cdot G_i + \varepsilon_i E_{b,i}$$

where

G_i= radiation flux incident on surface I from radiation from all other surfaces,

E_{bi}= blackbody emissive power of surface i, σT_i^4

$$J_i = (1-\varepsilon_i) \cdot \sum_j^N \left[F_{ij} \cdot \tau_{ji} \cdot J_j\right] + \varepsilon_i \cdot \sigma \cdot T_i^4 + \rho_i \varepsilon_m E_{bm}$$

$$G_i = \sum_j^N \left[A_j \cdot F_{ji} \cdot \tau_{ji} \cdot J_j\right] / A_i + \varepsilon_m E_{bm}$$

$$q_i = A_i (J_i - G_i)$$

$\tau_{j,i}$ is the transmissivity through gas

Radiation Enclosure Input HS_RAD Record

HS_RAD –Radiation Enclosure
Optional

(1) NUMBERHS
Number of heat structure surfaces in the network.
(type = integer, default = none, units = none)

(2) NetworkName
User specified network name
(type = character*16, default = none, units = none)

(2) NetworkNumber
User specified network number
(type = integer, default = none, units = none)

Next data are input as a table with number or rows = NUMBERHS:

(1) i
Index for HS in network.
(type = integer, default = none, units = none)

(2) IHSRDi
Name of heat structure i.
(type = character*16,default = none)

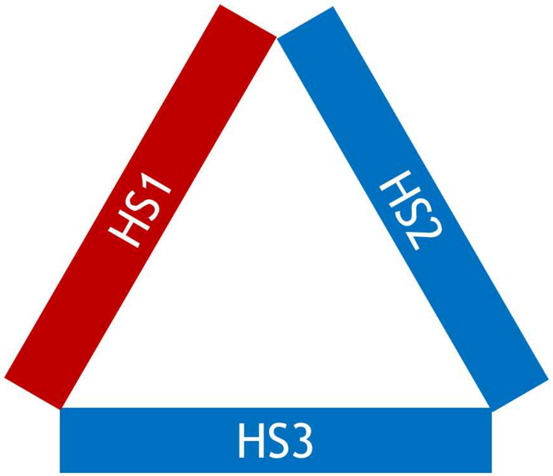
(3) LRBNDi
Option to identify the side of surface IHSRDi.
-1 or LEFT
Left side surface of the given heat structure.
1 or RIGHT
Right side surface of the given heat structure.
(type = integer / character*5, default = none, units = none)

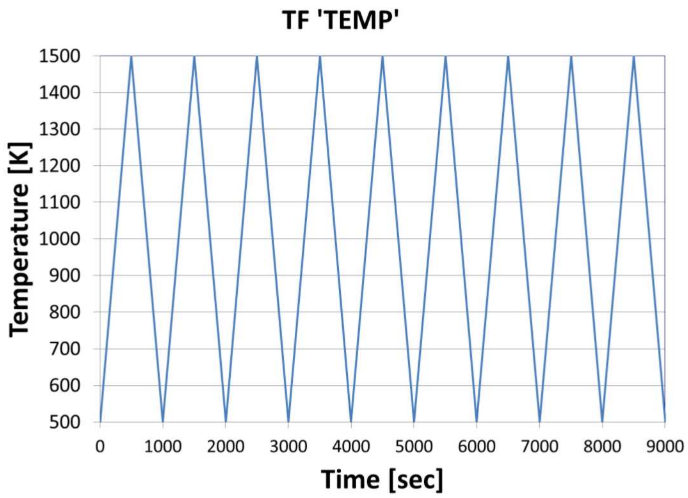
(4) ICFRDi
Optional constant value for emissivity of the surface (real) or real-valued control function name (character*16) whose value is the emissivity of the surface. If neither is specified, MELCOR calculates the emissivity using the COR package relation for oxidized steel surfaces.
(type = real or character*16, default = '-', units = none)

(5) BEAMLi
Radiation path length for the boundary gas associated with the surface i. If the beam length is zero, then the gas is non-participating.
(type = real, default =0.0, units = m)

(5+ NUMBERHS) $VIEW_{i,NUMBERHS}$
View factor between surface i and surface NUMBERHS, which must lie in the range of 0.0 to 1.0. If '-' is entered and i<>NUMBERHS, then the viewfactor is calculated by reciprocity from $VIEW_{NUMBERHS,i}$
(type = real or character*16, default = none, units = none)

Exercise 8-1

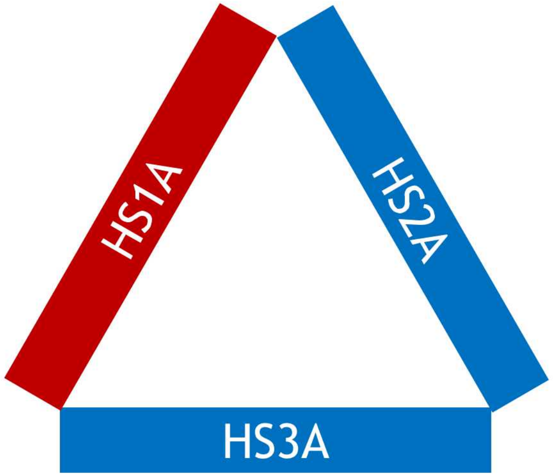





```
HS_ID 'HS1'  10001
HS_LB CalcCoefHS        'resevoir'   NO
HS_LBR  0.1  2  0.5
HS_RB TempTimeTF        'TEMP'
HS_ID 'HS2'  10002
HS_LB CalcCoefHS        'resevoir'
HS_LBR  0.1  2  0.5
HS_RB Symmetry
HS_ID 'HS3'  10003
HS_LB CalcCoefHS        'resevoir'   NO
HS_LBR  0.1  2  0.5
HS_RB Symmetry

HS_RD     3 !( n
        1 'HS1'  LEFT 'HS2'   LEFT  0.4    EM1    EM1
        2 'HS1'  LEFT 'HS3'   LEFT  0.5    EM1    EM1
        3 'HS2'  LEFT 'HS3'   LEFT  0.5    EM1    EM1
```

Exercise 8-1



Identical HS definition

- HS1 and HS1A
  - Use TF 'TEMP'
- HS2 and HS2A adiabatic BC
- HS3 and HS3A adiabatic BC
- Emissivity = 0.1 = EM1

```
HS_ID 'HS1A'  10011
HS_LB CalcCoefHS        'resevoir'   NO
~~HS_LBR 0.1 2 100.5~~
HS_RB TempTimeTF         'TEMP'
HS_ID 'HS2A'  10012
HS_LB CalcCoefHS        'resevoir'
~~HS_LBR 0.1 2 0.5~~
HS_RB Symmetry
HS_ID 'HS3A'  10013
HS_LB CalcCoefHS        'resevoir'   NO
~~HS_LBR 0.1 2 0.5~~
HS_RB Symmetry
```

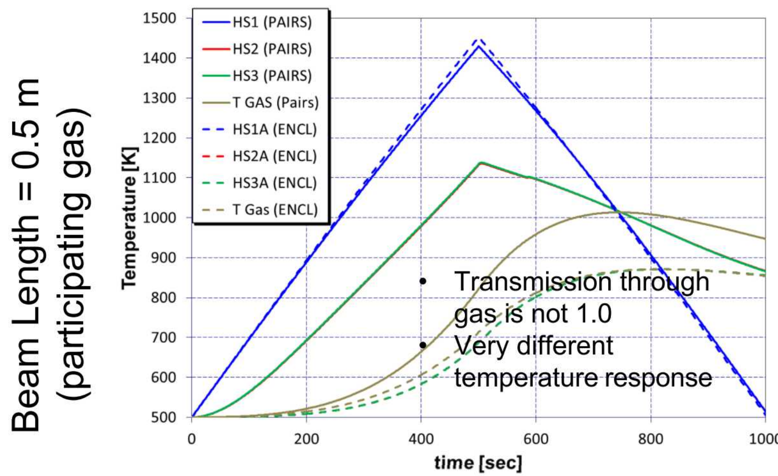
Assignment: Add a radiation enclosure network using the appropriate surface for these three heat structures.

```
HS_RAD
  1 HS1A
  2 HS2A
  3 HS3A
```

Exercise 8-1

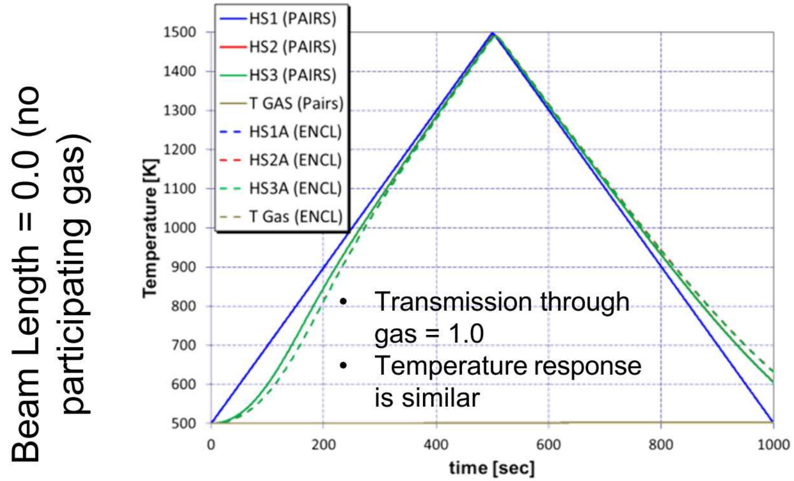
Compare Enclosure model with Radiation surface pairs

- Add enclosure model to test deck
- Run MELGEN
  - Check diagnostic file for any warnings related to enclosure model (expect to find one) and correct the problem(s)
- Run MELCOR
- Examine the plot file
  - Temperature for gas
  - Temperature for each HS



Change the beam length in the gas to 0.0 (both for radiation enclosure & radiation surface pairs)

- Examine the plot file
  - Temperature for gas
  - Temperature for each HS
  - Is the energy transferred to the gas zero?



Exercise 8-1
Compare Text Output

- **BL=0.5**
  - **MELGEN**

RADIATION ENCLOSURE MODEL INPUT
NUMBER OF NETWORKS ENTERED= 1

RADIATION ENCLOSURE NETWORK: NET2

	HS NAME	SURFACE	BEAM L	VIEW FAC		
1	HS1A	LEFT	0.500E+00	0.100	0.400	0.500
2	HS2A	LEFT	0.500E+00	0.400	0.100	0.500
3	HS3A	LEFT	0.500E+00	0.500	0.500	0.000

  - **MELCOR**

RADIATION ENCLOSURE MODEL

The following table provides the surface emissivity, gas emissivity, gas, transmissivity, the net heat removed from surface (W), and the net heat to the gas (W).

RADIATION ENCLOSURE NETWORK: NET2 [Q-GAS = 0.119E+03]

	HS NAME	EMISS	EM-GAS	TRANS	Q-SURF
1	HS1A	0.100	0.982	0.018	0.124E+03
2	HS2A	0.100	0.982	0.018	-0.209E+01
3	HS3A	0.100	0.982	0.018	-0.326E+01

- **BL=0.0**
  - **MELGEN**

RADIATION ENCLOSURE MODEL INPUT
NUMBER OF NETWORKS ENTERED= 1

RADIATION ENCLOSURE NETWORK: NET2

	HS NAME	SURFACE	BEAM L	VIEW FAC		
1	HS1A	LEFT	0.000E+00	0.100	0.400	0.500
2	HS2A	LEFT	0.000E+00	0.400	0.100	0.500
3	HS3A	LEFT	0.000E+00	0.500	0.500	0.000

  - **MELCOR**

RADIATION ENCLOSURE MODEL

The following table provides the surface emissivity, gas emissivity, gas, transmissivity, the net heat removed from surface (W), and the net heat to the gas (W).

RADIATION ENCLOSURE NETWORK: NET2 [Q-GAS = 0.0]

	HS NAME	EMISS	EM-GAS	TRANS	Q-SURF
1	HS1A	0.100	0.000	1.000	0.814E+02
2	HS2A	0.100	0.000	1.000	-0.404E+02
3	HS3A	0.100	0.000	1.000	-0.409E+02

Exercise 8-1
Try using placeholder in view factor input

- The radiation enclosure model allows the user to specify a placeholder '-' for a view factor if that missing view factor can be calculated implicitly by reciprocity

$$V_{i,j} A_i = V_{j,I} A_j$$

- The sum of view factors from a surface to all other surfaces in the network is equal to 1.0. If it sums to something less, the difference is accounted for by adjusting the self-radiation term.

MELGEN Input:

```
HS_RAD 7 NET3  3!
!n                         B   1  2  3  4  5    6    7
 1  HS1B   LEFT 'EM3' 0.  -    0.   0.   0.   0.   0.50   0.20      !Area = 10.0
 2  HS2B   LEFT 'EM3' 0.  0.   -    0.   0.   0.   0.50   0.20      !Area = 10.0
 3  HS3B   LEFT 'EM3' 0.  0.   0.   -    0.   0.   0.50   0.20      !Area = 10.0
 4  HS4B   LEFT 'EM3' 0.  0.   0.   0.   -    0.   0.50   0.20      !Area = 10.0
 5  HS5B   LEFT 'EM3' 0.  0.   0.   0.   0.   -    0.50   0.20      !Area = 10.0
 6  HS6B   LEFT 'EM3' 0.  -    -    -    -    -     -     0.0       !Area = 150.0
 7  HS7B   LEFT 'EM3' 0.  -    -    -    -    -    0.0     -        !Area = 100.0
```

MELCOR Output:

RADIATION ENCLOSURE NETWORK: NET3

$VF_{7,1}=VF_{1,7}*A_1/A_7$

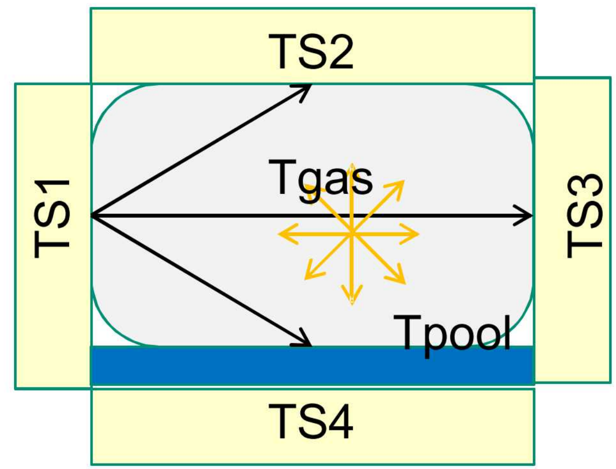
0.02=0.2*10.0/100.0

HS	NAME	SURFACE	BEAM L	VIEW FAC						
1	HS1B	LEFT	0.000E+00	0.300	0.000	0.000	0.000	0.000	0.500	0.200
2	HS2B	LEFT	0.000E+00	0.000	0.300	0.000	0.000	0.000	0.500	0.200
3	HS3B	LEFT	0.000E+00	0.000	0.000	0.300	0.000	0.000	0.500	0.200
4	HS4B	LEFT	0.000E+00	0.000	0.000	0.000	0.300	0.000	0.500	0.200
5	HS5B	LEFT	0.000E+00	0.000	0.000	0.000	0.000	0.300	0.500	0.200
6	HS6B	LEFT	0.000E+00	0.033	0.033	0.033	0.033	0.033	0.833	0.000
7	HS7B	LEFT	0.000E+00	0.020	0.020	0.020	0.020	0.020	0.000	0.900

Multi HS Radiation Enclosure Model
(Recent improvements)

Recent model improvements

- Continuation of view factor records onto new line
- View factors can now be control functions.
  - Sum of view factors for a surface cannot exceed 1.0
- Radiation to pool surface
  - When pool covers a participating surface on a HS, the pool surface replaces that HS surface in the enclosure network.




```
HS_Rad 4  NET3      !EM     BeamL   VF
  1  HS1C     RIGHT  EM1    0.5     0.0  0.2  0.4   &
                                    'MyLongNamedCF'
  2  HS2C     LEFT   EM2    0.5     0.2  0.0  0.3  0.5
  3  HS3C     LEFT    -     0.5     0.4  0.3  0.2  0.1
  4  HS4C     RIGHT   -     0.5     0.4  0.5  0.1  0.0
```

Aerosol Radiation Model
(New in 2019 Code Release)

Aerosol cloud emissivity derived per Pilat and Ensor

$$\alpha_{\lambda m} = 4000 C_{\lambda m} f_m$$

Where $C_{\lambda m}$ is the user defined parameter kmx,

- Input as part of the radiation enclosure model.
- f_m is the total aerosol mass concentration (kg/m^3) calculated by the code.

$C_{\lambda m}$ in this equation is provided to allow the user to account for the effects of wavelength, index of refraction, particle size distribution, and aerosol particle material density.

$C_{\lambda m} = 1$, corresponds to soot-like particles with a density of 2000 kg/m^3.

```
! #HS  NetName  #Net  NotUsed   KMX
HS_RAD  5  NET2 1  IGNOREPOOL -  0.25
  1 'top head'    LEFT  EM1     20.3   0.05  0.3   0.15   0.5   0.0
  2 'walls-edge'  LEFT  EM1     7.62   0.1    -      -    0.3    -
  3 'vert-int'    LEFT  EM1     3.81   -     0.9   0.0     -    0.0
  4 'floor'       LEFT  0.65    20.3   0.0   0.25  0.25   0.0   0.5
  5 'horiz-int'   LEFT  EM1     3.81   0.0   0.5   0.0    0.5   0.0
```

M. J. Pilat and D. S. Ensor, "Plume Opacity and Particulate Mass Concentration," *Atmospheric Environment,* Vol. 4, pp. 163-173, 1970.