APPENDIX D

CRITICALITY MODEL INPUT DECKS

Intentionally Blank

The input decks for the three types of TMI-2 canister, a DSC loaded with 12 *knockout* canisters in the MP187, and a DSC loaded with 12 *knockout* canisters in an HSM are provided below.

Extensive annotated input is provided in lieu of sketches of the models. Where input is redundant from one model to the next, descriptive text is not repeated.

Fuel Canister Model

```
=csas2x
```
Indicates that the control module CSAS2X (which uses the functional modules BONAMI-S, NITAWL-II, and XSDRNPM-S) will be called.
```
single fuel canister model'
```
Title card.
```
44groupndf5 latticecell
```
Indicates that the 44 group cross section library will be used and that the lattice cell fuel region geometry will be used.
```
uo2  1 0.91075 293 92235 2.98 92238 97.02 end
```
The standard composition component name uo2 is used, the volume fraction is 0.91075, the temperature used is 20 Celsius, 2.98 w/o uranium-235 and 97.02 w/o uranium-238 was specified.
```
o      2 0 2.942-6    293 end
h      2 0 5.884-6    293 end
```
The number densities of oxygen and hydrogen corresponding to 8.8E-05 grams/cc are entered individually since a density for a standard composition component with multiple elemental constituents cannot be readily specified.
```
ss304  4   1.0        293 end
```
The standard composition component name ss304 is used for stainless steel with a volume fraction of 1.0.
```
h2o    9    0.29      293 end
```
The standard composition component h2o was used to specify water at 0.9982 grams/cc occupying 29% of the low density concrete.
```
o     9 0 1.1855-2    293 end
na    9 0 1.4380-4    293 end
mg    9 0 3.5859-5    293 end
al    9 0 2.8385-3    293 end
si    9 0 8.7196-4    293 end
ca    9 0 1.3101-3    293 end
fe    9 0 1.3576-5    293 end
```
The other elements contained in the LDC were specified by atomic number densities.
```
b-10 11 0 5.2650-3    293 end
b-11 11 0 2.9198-2    293 end
al   11 0 4.1548-2    293 end
```

The elemental composition of the borated aluminum sheet was specified based on 75% of the B-10 used in the 125-B SAR and 100% of the other components.

```
end comp
```

Ends the composition data input.

```
triangpitch 0.93904 0.93904 1 2 end
```

Specified a triangular pitch with the pitch equal to the diameter of the fuel lump, thus making a close packed fuel cell for geometric and resonance self shielding as well as other calculations.

```
fuel canister model
```

Title card.

```
read para
  tme=800.0  gen=515  npg=500  run=yes  flx=no  fdn=no
  far=no  plt=no  nsk=15
end para
```

Maximum problem run time, number of generations, number of neutrons per generation, number of skipped generations and output options are specified.

```
read geom
global
  unit  2
    com=" fuel canister inside storage sleeve "
    cuboid   500 1 4p11.59  381.00  -0.0
```

Mixture 500 is specified for the fuel area inside the fuel canister. The maximum shell outer diameter is 14.093" (3.18) and the nominal thickness is 0.25" (3.18). Using these bounding dimensions, a conservative fuel region is calculated by assuming that the poison shroud is the maximum size which can fit inside the canister shell. The following assumptions are made: inner stainless steel skin is 0.04" thick, the borated aluminum is 0.130" thick, the outer skin is 0.080" thick and the borated aluminum is continuous in the shroud. As such, the maximum fuel area would be bounded by an area 23.18 cm by 23.18 cm and is represented by a 4p11.59, 381 cm high cuboid.

```
    cuboid    4  1 4p11.69  381.00  -0.0
    cuboid   11  1 4p12.02  381.00  -0.0
    cuboid    4  1 4p12.22  381.00  -0.0
```

The three cuboids above represent the inner skin, the borated aluminum, and the outer poison skin.

```
    cylinder  9  1 17.29    381.00  -0.0
```

This cylinder represents the LDC (slightly oversized).

```
    cylinder  4  1 17.78    381.00  -0.0
```

This cylinder represents the canister shell (slightly undersized).

```
    com="infinite void to isolate one canister"
    cylinder  0  1 200.000  500.0000  -50.0000
end geom
end data
end
```

This input gives output results of 0.26057 + OR - 0.00055.

Knockout Canister Model

```
=csas2x
single knockout canister model'
44groupndf5 latticecell
uo2  1 0.91075 293 92235 2.98 92238 97.02 end
o      2 0 2.942-6    293 end
h      2 0 5.884-6    293 end
ss304  4   1.0        293 end
b-10 12 0 9.525-3     293 end
b-11 12 0 5.08-2      293 end
c    12 0 1.58-2      293 end
end comp
triangpitch 0.93904 0.93904 1 2 end
knockout canister model
read para
  tme=800.0  gen=515  npg=500  run=yes  flx=no  fdn=no
  far=no  plt=no  nsk=15
end para
read geom
unit  3
    com="displaced center poison tube"
    cylinder  12  1  2.5337  360.680  -0.0
    com="ss b4c liner"
    cylinder  4  1  2.6988  360.680  -0.0
    com="void annulus"
    cylinder 0 1  2.8575  360.680  -0.0
    com="structural ss center poison tube"
    cylinder  4  1  3.6513  360.680  -0.0
```

Unit 3 provides the dimensions of the center poison tube used in the model

```
  unit  4
    com=" radial poison 75% B-10 for ko can"
    cylinder  12  1  1.0351  360.680  -0.0
    cylinder  4  1  1.6701  360.680  -0.0
```

Unit 4 provides the dimensions of the radial poison tubes used in the model

```
global
  unit  5
    com="fuel inside can id"
    cylinder 500 1 17.263  381.000  -0.0
    com="insert center poison tube, 1in displ"
      hole   3   0.0   2.54  0.0
    com="inserting four (small) poison tubes, 1in displ"
      hole   4   6.35  8.89  0.0
      hole   4  -6.35  8.89  0.0
      hole   4  -6.35 -3.81  0.0
      hole   4   6.35 -3.81  0.0
    com="canister od"
```

```
    cylinder  4 1 17.78  381.000 -0.0
```
Unit 5 provides the fuel area, the offset locations of the five poison tubes, and the canister shell. The poison tubes are modeled as 8” shorter than the height of the fuel region.
```
end geom
end data
end
```
This input gives output results of 0.26174 + OR - 0.00055.

Filter Canister Model

```
=csas2x
single filter canister'
44groupndf5 latticecell
uo2  1 0.91075 293 92235 2.98 92238 97.02 end
o      2 0 2.942-6    293 end
h      2 0 5.884-6    293 end
o      3 0 2.942-6    293 end
h      3 0 5.884-6    293 end
ss304  4   1.0        293 end
b-10 12 0 9.525-3     293 end
b-11 12 0 5.08-2      293 end
c    12 0 1.58-2      293 end
end comp
triangpitch 8.5-4 8.5-4 1 2 end
filter canister
read para
  tme=800.0  gen=515  npg=500  run=yes  flx=no  fdn=no
  far=no  plt=yes  nsk=15
end para
read geom
 unit 6
  com="filter canister"
  com="drain tube fuel cell"
  cylinder 500 1 2.2225 351.00 -0.0
  cylinder 4   1 2.54   351.00 -0.0
```
Unit 6 is the single drain tube in the canister
```
 unit 7
  com="tie rod"
  cylinder 4 1 .9525 381.00 -0.0
```
Unit 7 is the tie rods
```
  unit  8
    com="filter elements for filter can"
    cylinder  500  1  1.1938  351.00  -0.0
    cylinder  4  1  1.8161  351.00  -0.0
```
Unit 8 is the tube portion of the filter element. The tubes are modeled 30cm shorter than the fuel region. The filter media is conservatively assumed to not exist.
```
  unit  9
```

```
    com="poison tube"
    cylinder   12 1  2.54  378.00  -0.0
    com="ss b4c liner"
    cylinder  4  1  2.69875  378.00  -0.0
    com="void annulus"
    cylinder 0 1  2.8575  378.00  -0.0
    com="ss center poison tube"
    cylinder  4  1  3.175  378.00  -0.0
```
Unit 9 is the central poison tube, one inch shorter than the fuel region.
```
GLOBAL
  unit 10
    com="fuel inside can id"
    cylinder 500 1 17.2631  381.00  -0.0
    com="inserting filter tubes"
    hole 8 6.59 -5.49 0.0
    hole 8 -0.23 -9.91 0.0
    hole 8 -6.16 -6.16 0.0
    hole 8 -5.26 -1.18 0.0
    hole 8 -1.68 2.28 0.0
    hole 8 5.64 0.16 0.0
    hole 8 12.58 -5.56 0.0
    hole 8 9.57 -9.57 0.0
    hole 8 3.52 -13.20 0.0
    hole 6 -4.59 -13.59 0.0
    hole 8 -9.18 -10.13 0.0
    hole 8 -12.25 -6.05 0.0
    hole 8 -13.65 -1.30 0.0
    hole 8 -9.51 1.56 0.0
    hole 8 -12.53 5.57 0.0
    hole 8 11.58 7.34 0.0
    hole 8 9.95 2.61 0.0
    hole 8 13.75 -0.66 0.0
    hole 9 0.55 -3.64 0.0
    hole 7 9.11 -2.19 0.0
    hole 7 5.42 -9.46 0.0
    hole 7 -4.70 -10.07 0.0
    hole 7 -9.12 -3.25 0.0
    hole 7 -5.77 3.51 0.0
    hole 7 6.21 4.24 0.0
    com="canister od"
    cylinder  4  1 17.7800  381.00  -0.0
```
Unit 10 generates the complete canister. The tie rods, drain tube, filter tubes, and poison tube are slumped to one side.
```
end geom
end data
end
```
This input gives output results of 0.24641 + OR - 0.00051.

DSC WITH 12 KNOCKOUT CANISTERS IN THE MP187

```
=csas2x
mp187 with 12 knockout canisters'
44groupndf5 latticecell
uo2  1 0.91075 293 92235 2.98 92238 97.02 end
o      2 0 2.942-6    293 end
h      2 0 5.888-5    293 end
o      3 0 2.942-6    293 end
h      3 0 5.884-6    293 end
ss304  4   1.0        293 end
carbonsteel 5 1.0        293 end
pb     7    1.0        293 end
h2o    9    0.29       293 end
o      9 0 1.1855-2    293 end
na     9 0 1.4380-4    293 end
mg     9 0 3.5859-5    293 end
al     9 0 2.8385-3    293 end
si     9 0 8.7196-4    293 end
ca     9 0 1.3101-3    293 end
fe     9 0 1.3576-5    293 end
b-10 12 0 9.525-3     293 end
b-11 12 0 5.08-2      293 end
c    12 0 1.58-2      293 end
o     15 0 3.7793-2   293 end
c     15 0 8.2505-3   293 end
h     15 0 5.0996-2   293 end
al    15 0 7.0275-3   293 end
si    15 0 1.2680-3   293 end
ca    15 0 1.4835-3   293 end
fe    15 0 1.0628-4   293 end
end comp
triangpitch 0.93904 0.93904 1 2 end
mp187 with 12 knockout canisters
read para
  tme=800.0  gen=515  npg=500  run=yes  flx=no  fdn=no
  far=no  plt=yes  nsk=15
end para
read geom
unit  3
    com="displaced center poison tube"
    cylinder  12  1  2.5337  360.680  -0.0
    com="ss b4c liner"
    cylinder  4  1  2.6988  360.680  -0.0
    com="void annulus"
    cylinder 0 1  2.8575  360.680  -0.0
    com="ss center poison tube"
    cylinder  4  1  3.6513  360.680  -0.0
```

```
  unit  4
    com=" radial poison 75% B-10 for ko can"
    cylinder  12  1  1.0351  360.680  -0.0
    cylinder  4  1  1.6701  360.680  -0.0
  unit  5
    com="knockout canister"
    com="fuel inside can id"
    cylinder 500 1 17.2631  381.000  -0.0
    com="insert center poison tube, 1in displ"
      hole   3   0.0   2.54  0.0
    com="inserting four (small) poison tubes, 1in displ"
      hole   4   6.35  8.89  0.0
      hole   4  -6.35  8.89  0.0
      hole   4  -6.35 -3.81  0.0
      hole   4   6.35 -3.81  0.0
    com="canister od"
    cylinder  4 1 17.78  381.000 -0.0
 unit 11
  cylinder  3  1 80.7438  381.00 -0.0
  hole 5    0.000         0.0    0.0
  hole 5   35.56          0.0    0.0
  hole 5  -35.56          0.0    0.0
  hole 5   53.35         30.80   0.0
  hole 5   17.78         30.80   0.0
  hole 5  -17.78         30.80   0.0
  hole 5  -53.35         30.80   0.0
  hole 5    0.0          61.62   0.0
  hole 5   53.35        -30.80   0.0
  hole 5   17.78        -30.80   0.0
  hole 5  -17.78        -30.80   0.0
  hole 5  -53.35        -30.80   0.0
```

Unit 11 places the TMI-2 knockout canisters into a close packed array.

```
 unit  12
        cylinder 3 1 83.743801 474.98 0.0
        hole 11 0.0 3.0 0.0
        cylinder 5 1 85.3313 474.98 0.0
        cylinder 0 1 86.3600 474.98 0.0
        cylinder 4 1 89.5350 474.98 0.0
        cylinder 7 1 99.6950 474.98 0.0
        cylinder 4 1 106.045 474.98 0.0
        cylinder 0 1 117.005 474.98 0.0
        cylinder 4 1 117.483 474.98 0.0
        cuboid 0 1 4p117.484 474.98 0.0
```

Unit 12 generates the mist moderator inside the DSC, places the close packed TMI-2 canisters into the DSC, and generates the carbon steel DSC shell, the gap between the DSC and the MP187, the inner shell of the MP187, the lead shield, the outside shield wall, void where neutron shield material is, and outermost stainless steel shell.

```
  unit  13
        cylinder 4 1 117.483 15.24 0.0
        cuboid 0 1 4p117.484 15.24 0.0
```
Unit 13 generates the top and bottom MP187 lids
```
  global
  unit  14
        array  1  0.0 0.0 0.0
end geom
read array
        com='MP187 (187" long with 6" steel lid and
bottom)'
        ara=1   nux=1 nuy=1 nuz=3
        fill 13 12 13 end fill
end array
```
The array builds the MP187 with a full DSC in it and top and bottom lids
```
read bounds
   all=mirror
end bounds
```
Provides infinite lattice of MP187 casks
```
end geom
end data
end
```
This input gives output results of 0.54881 + OR - 0.00062.

DSC WITH 12 KNOCKOUT CANISTERS IN AN HSM

```
=csas2x
hsm with 12 knockout canisters'
44groupndf5 latticecell
uo2  1 0.91075 293 92235 2.98 92238 97.02 end
o      2 0 2.942-6    293 end
h      2 0 5.888-5    293 end
```
The number density for hydrogen includes hydrogen from the mist water moderator and hydrogen generated by radiolysis.
```
o      3 0 2.942-6    293 end
h      3 0 5.884-6    293 end
ss304  4   1.0        293 end
carbonsteel 5 1.0     293 end
orconcrete 6.0 1.0    293 end
pb     7    1.0       293 end
h2o    9    0.29      293 end
o      9 0 1.1855-2   293 end
na     9 0 1.4380-4   293 end
mg     9 0 3.5859-5   293 end
al     9 0 2.8385-3   293 end
si     9 0 8.7196-4   293 end
ca     9 0 1.3101-3   293 end
```

```
fe     9 0 1.3576-5    293 end
b-10 12 0 9.525-3     293 end
b-11 12 0 5.08-2      293 end
c    12 0 1.58-2      293 end
o     15 0 3.7793-2   293 end
c     15 0 8.2505-3   293 end
h     15 0 5.0996-2   293 end
al    15 0 7.0275-3   293 end
si    15 0 1.2680-3   293 end
ca    15 0 1.4835-3   293 end
fe    15 0 1.0628-4   293 end
end comp
triangpitch 0.93904 0.93904 1 2 end
hsm with 12 knockout canisters
read para
  tme=800.0  gen=515  npg=500  run=yes  flx=no  fdn=no
  far=no  plt=yes  nsk=15
end para
read geom
unit  3
    com="displaced center poison tube"
    cylinder  12  1  2.5337  360.680  -0.0
    com="ss b4c liner"
    cylinder  4  1  2.6988  360.680  -0.0
    com="fuel annulus"
    cylinder 500 1  2.8575  360.680  -0.0
    com="ss center poison tube"
    cylinder  4  1  3.6513  360.680  -0.0
  unit  4
    com=" radial poison 75% B-10 for ko can"
    cylinder  12  1  1.0351  360.680  -0.0
    cylinder  4  1  1.6701  360.680  -0.0
  unit  5
    com="knockout canister"
    com="fuel inside can id"
    cylinder 500 1 17.2250  381.000  -0.0
    com="insert center poison tube, 1in displ"
      hole   3   0.0   2.54  0.0
    com="inserting four (small) poison tubes, 1in displ"
      hole   4   6.35  8.89  0.0
      hole   4  -6.35  8.89  0.0
      hole   4  -6.35 -3.81  0.0
      hole   4   6.35 -3.81  0.0
    com="canister od"
    cylinder  4 1 17.78  381.000 -0.0
 unit 11
  cylinder  3  1 80.7438  381.00 -0.0
  hole 5   0.000         0.0    0.0
```

```
  hole 5  35.56          0.0    0.0
  hole 5 -35.56          0.0    0.0
  hole 5  53.35         30.80   0.0
  hole 5  17.78         30.80   0.0
  hole 5 -17.78         30.80   0.0
  hole 5 -53.35         30.80   0.0
  hole 5   0.0          61.62   0.0
  hole 5  53.35        -30.80   0.0
  hole 5  17.78        -30.80   0.0
  hole 5 -17.78        -30.80   0.0
  hole 5 -53.35        -30.80   0.0
 unit  12
        cylinder 3 1 83.743801 474.98 0.0
        hole 11 0.0 3.0 0.0
        cylinder 5 1 85.3313 474.98 0.0
        cylinder 6 1 147.00  474.98 0.0
        cuboid 0 1 4p147.00  474.98 0.0
```

Unit 12 has a two foot thick cylinder of concrete to approximate the HSM.

```
  unit  13
        cuboid 6 1 4p147.00 60.96 0.0
```

Unit 13 generates two foot thick HSM end walls.

```
  global
  unit  14
        array  1  0.0 0.0 0.0
end geom
read array
        com='HSM (2 foot cylinder of concrete and 2 foot
lid and bottom)'
        ara=1   nux=1 nuy=1 nuz=3
        fill 13 12 13 end fill
end array
read bounds
   all=mirror
end bounds
end geom
end data
end
```

This input gives output results of 0.54051   + OR - 0.00082.

Discussion of Criticality Modeling/Analysis

The expected composition of the canister contents includes slightly depleted fuel, cladding, control rod debris, and some residual soluble absorber material. The fuel may have been degraded to less dense oxides. No credit is taken for these realistic conditions because, while real and present, qualification of these conditions is extremely difficult. Therefore, the actual condition of the fuel in the canisters provide an additional, albeit un-quantified, margin of safety from those conditions as described below.

Control Parameter	**Controls/Barriers**
Mass	It is not possible to increase the mass in the canisters above the theoretical triangular close packed columns of whole fuel pellets assumed in the models.
Enrichment	No burnup credit is taken. The maximum initial enrichment (batch 3 average plus 2 sigma). There are no mechanisms possible to increase the enrichment above the 2.98 w/o U-235 assumed in the models.
Geometry	1) Worst case TMI-2 canister poison displacements from original manufacturer's drop testing were used in the evaluation. 2) No structural credit is taken for the DSC basket and hence the TMI-2 canisters are assumed to be close packed. 3) Whole fuel pellets are used in the models and shown to remain subcritical. 4) Fuel pitch is minimized for triangular pitch columns of cylindrical fuel pellets. 5) No credible mechanisms exists for fuel to escape from the TMI-2 canisters to the DSC.
Reflection	The DSC has been modeled essentially fully reflected by concrete in the HSM and reflected by the MP187 in the cask model. No significant additional reactivity can be added via external reflection over that shown to be subcritical in this analysis.

Interaction	1) The DSC has been shown subcritical with twelve canisters loaded to the theoretical maximum payload which exceeds that measured for any of the TMI-2 canisters. 2) The canisters are not over moderated or isolated neutronically from each other. No increase in interaction is physically possible in the DSC.
Absorbers	1) The boron carbide and borated aluminum absorbers were fabricated, tested and verified by the original manufacturer. Degradation of the absorbers is not credible due to the materials of construction and methods used to isolated them from the external environment. 2) Only 75% of the minimum specified B-10 was used in the models. 3) Under the conditions of storage system, the poisons provide little negative reactivity since the fuel region is not moderated and the system multiplication factor would remain far subcritical without the absorbers.
Moderator	The TMI-2 canister contents are dried prior to loading into the DSC. No credible mechanism exists which could introduce water into the system.
Natural Phenomena	1) The DSC is located well above the flood plain preventing water from reaching the DSC or the vent system filters. 2) If water was used to fight a fire in or near the ISFSI, no direct path exists which would allow for impingement of the water

stream on the system filters.

3) Seismic events could not relocate the fuel from the TMI-2 canisters to other locations in the system.

Second Criticality Evaluation

The input decks for a DSC loaded with 12 *knockout* canisters in an HSM is provided below.

Extensive annotated input is provided in lieu of sketches of the models.

DSC WITH 12 KNOCKOUT CANISTERS IN AN HSM

```
=CSASIX
```

Indicates that the control module CSASIX (which uses the functional modules BONAMI-S, NITAWL-II, XSDRNPM-S, ICE, and WAX) will be called.

```
DSC420  1908lb fuel, 1.35cm pitch, 8l water, fuel above,
upside down cask vf=0.6
```

Title card.

```
27GROUPNDF4 LATTICECELL
```

Indicates that the 27 group cross section library will be used and that the lattice cell fuel region geometry will be used.

```
U-238   1 0  2.18749-2  293 END
U-235   1 0  6.81347-4  293 END
O       1 0  4.51125-2  293 END
```

The fuel region number densities at 20 Celsius are specified.

```
H2O     2    1.0        293 END
```

Full density water for the moderator region is specified.

```
END COMP
```

Ends the composition data input for the wet fuel region.

```
TRIANGPITCH 1.35 0.93904 1 2 END
```

Specifies a triangular 1.35 cm pitch (optimal) with a 0.93904 cm diameter fuel lump, thus making a fuel cell for geometric and resonance self shielding as well as other calculations.

```
END
```

Ends (temporarily) the CSAS input to the file.

```
=WAX
0$$ 12 2
1$$ 1  1T
2$$ 2 1 2T
3$$ 500
4$$ 500  3T
END
```

The WAX portion of the input. Mixes the fuel/moderator region, and names it region 500.

```
=CSASIX
DSC420  1908lb fuel, 1.35cm pitch, 8l water, fuel above,
upside down cask vf=0.6
27GROUPNDF4 LATTICECELL
U-238   1 0  2.18749-2  293 END
U-235   1 0  6.81347-4  293 END
O       1 0  4.51125-2  293 END
```

Back into the CSAS input to the file, and specifies the number densities for the dry fuel region. The densities are the same as for the wet fuel region since it is the same fuel.

```
H2O     7  0.6   293 END
```

Specifies region 7, which is the region between the TMI canisters, as 0.6 volume fraction water (optimal).

```
H2O     8  1.0   293 END
```

Specifies region 8, which is used to represent the boron carbide poison columns in the canisters, as full density water.

```
ORCONCRETE 5 1.0 293 END
```

The standard composition component used to specify region 5 as ordinary concrete. Not used in this calculation.

```
CARBONSTEEL 6 1.0 293 END
```

The standard composition component used to specify region 6 as steel. Used to represent the shell of the DSC.

```
C       9 0  1.6000-3   293 END
O       9 0  3.9700-2   293 END
NA      9 0  5.5000-4   293 END
AL      9 0  1.6000-3   293 END
SI      9 0  1.5200-2   293 END
S       9 0  5.0000-5   293 END
CA      9 0  3.1000-3   293 END
FE      9 0  3.8000-4   293 END
H2O     9  0.114        293 END
```

The number densities for region 9, modeled as INTEC concrete. Used to represent the HSM.

```
PB      3 0   3.2988-2       END
```

The number density for region 3, modeled as lead. Not used in this calculation.

```
END COMP
```

Ends the composition data input for the dry fuel region, and for the other components of the system.

```
TRIANGPITCH 0.93904 0.93904 1 2 END
```

Specifies a triangular pitch with the pitch equal to the diameter of the fuel lump, thus making a close packed fuel cell for geometric and resonance self shielding as well as other calculations for the dry fuel region.

```
END
```

Ends the CSAS input to the file.

```
=WAX
0$$ 4 2
1$$ 2  1T
2$$ 12 1 2T
3$$ 500
4$$ 501   3T
2$$ 2 8 2T
3$$ 3 4 5 6 7 8 9 500
4$$ 3 4 5 6 7 8 9 502  3T
END
```

Back into WAX, mixes fuel and void for the dry fuel region and names it region 502. Renames the wet fuel region (previously 500) as region 501.

```
=KENOV
```

Starts the KENO portion of the input.

```
DSC420  1908lb fuel, 1.35cm pitch, 81 water, fuel above,
upside down cask vf=0.6
```

Title card.

```
READ PARA
  TME=800.0  GEN=215  NPG=1200  RUN=YES  FLX=YES  FDN=NO
  FAR=NO  PLT=YES  NSK=15  LIB=4
END PARA
```

Maximum problem run time, number of generations, number of neutrons per generation, number of skipped generations and output options are specified.

```
READ MIXT
  MIX=3 3 1.0  MIX=4 4 1.0  MIX=5 5 1.0
  MIX=6 6 1.0  MIX=7 7 1.0  MIX=8 8 1.0
  MIX=9 9 1.0  MIX=501 501 1.0  MIX=502 502 1.0
END MIXT
```

Specifies full density for each of the mixtures specified in the composition data

```
READ GEOM
  UNIT  2
    COM=* KNOCKOUT CANISTER INSIDE STORAGE SLEEVE -(1289)
LOWER CASK *
    CYLINDER    8  1  2.5337      0.353   0.0
    CYLINDER    4  1  2.6988      0.353   0.0
    CYLINDER  501  1  2.8575      0.353   0.0
    CYLINDER    4  1  3.6513      6.703   0.0
    CYLINDER  501  1 17.2250     15.593   0.0
    CYLINDER    4  1 17.7800     20.673   0.0
```

Unit 2 models the top portion of the canister and central poison tube. The poison is modeled as full density water, stainless steel is used to represent the structural regions, and the wet fuel is used to fill all other spaces. Only the water mixed with the fuel is considered when calculating the limiting water volume per canister.

```
  UNIT  3
    COM=* RADIAL POISON TUBE WITHOUT POISON  - (1289) 1st
layer  *
    CYLINDER    8  1  1.0351     96.666   0.0
    CYLINDER    4  1  1.6702     98.888   0.0
```

Unit 3 provides the dimensions of the radial poison tubes used in the middle portion of the canister model.

```
UNIT  4
    COM=* KNOCKOUT CANISTER INSIDE STORAGE SLEEVE -(1289)
LOWER CASK *
    CYLINDER    8  1  2.5337    101.71    0.0
    CYLINDER    4  1  2.6988    101.71    0.0
    CYLINDER  502  1  2.8575    101.71    0.0
```

```
    CYLINDER     4   1   3.6513     101.71     0.0
    CYLINDER   502  1  17.2250     101.71     0.0
      HOLE    3    6.35   6.35   0.0
      HOLE    3    6.35  -6.35   0.0
      HOLE    3   -6.35   6.35   0.0
      HOLE    3   -6.35  -6.35   0.0
    CYLINDER     4   1  17.7800     101.71     0.0
```

Unit 4 models the middle portion of the canister and central poison tube. The radial poison tubes are placed in the region as holes. The dry fuel is used to fill all other spaces.

```
UNIT  5
    COM=* RADIAL POISON TUBE WITHOUT POISON  - (1289) 1st
layer  *
    CYLINDER     8   1   1.0351     231.947   0.0
    CYLINDER     4   1   1.6701     231.947   0.0
```

Unit 5 provides the dimensions of the radial poison tubes used in the bottom portion of the canister model.

```
UNIT  6
    COM=* KNOCKOUT CANISTER INSIDE STORAGE SLEEVE -(1289)
LOWER CASK *
    CYLINDER     8   1   2.5337     231.947   0.0
    CYLINDER     4   1   2.6988     231.947   0.0
    CYLINDER     8   1   2.8575     231.947   0.0
    CYLINDER     4   1   3.6513     231.947   0.0
    CYLINDER     0   1  17.2250     231.947   0.0
      HOLE    5    6.35   6.35   0.0
      HOLE    5    6.35  -6.35   0.0
      HOLE    5   -6.35   6.35   0.0
      HOLE    5   -6.35  -6.35   0.0
    CYLINDER     4   1  17.2250     231.947  -6.35
    CYLINDER     8   1  17.2250     231.947  -8.89
    CYLINDER     4   1  17.7800     231.947  -9.53
```

Unit 6 models the bottom portion of the canister and central poison tube. The radial poison tubes are placed in the region as holes. Full density water is modeled between the two stainless steel tubes of the central poison tube, and in the bottom inch of the canister. Neither of these water volumes is counted in the calculation for the water limit per canister. Void is used to fill all other spaces.

```
GLOBAL
  UNIT  7
    COM=* SILO *
    CYLINDER     7   1    79.400001  474.98  0.0
    HOLE    6           0.0        0.0      9.5301
    HOLE    6          35.56       0.0      9.5301
    HOLE    6         -35.56       0.0      9.5301
    HOLE    6          53.35     30.80      9.5301
    HOLE    6         -53.35     30.80      9.5301
    HOLE    6          53.35    -30.80      9.5301
    HOLE    6         -53.35    -30.80      9.5301
```

```
     HOLE   6           17.78    30.80    9.5301
     HOLE   6          -17.78    30.80    9.5301
     HOLE   6           17.78   -30.80    9.5301
     HOLE   6          -17.78   -30.80    9.5301
     HOLE   6            0.0     61.62    9.5301
     HOLE   4            0.0      0.0   241.4772
     HOLE   4           35.56     0.0   241.4772
     HOLE   4          -35.56     0.0   241.4772
     HOLE   4           53.35    30.80  241.4772
     HOLE   4          -53.35    30.80  241.4772
     HOLE   4           53.35   -30.80  241.4772
     HOLE   4          -53.35   -30.80  241.4772
     HOLE   4           17.78    30.80  241.4772
     HOLE   4          -17.78    30.80  241.4772
     HOLE   4           17.78   -30.80  241.4772
     HOLE   4          -17.78   -30.80  241.4772
     HOLE   4            0.0     61.62  241.4772
     HOLE   2            0.0      0.0   343.1873
     HOLE   2           35.56     0.0   343.1873
     HOLE   2          -35.56     0.0   343.1873
     HOLE   2           53.35    30.80  343.1873
     HOLE   2          -53.35    30.80  343.1873
     HOLE   2           53.35   -30.80  343.1873
     HOLE   2          -53.35   -30.80  343.1873
     HOLE   2           17.78    30.80  343.1873
     HOLE   2          -17.78    30.80  343.1873
     HOLE   2           17.78   -30.80  343.1873
     HOLE   2          -17.78   -30.80  343.1873
     HOLE   2            0.0     61.62  343.1873
     CYLINDER    6  1   80.9875    474.98   0.0
     CUBOID      9  1 4P142.0      534.98  -60.0
END GEOM
```

Unit 7 places the TMI-2 knockout canisters into a close packed array inside of the DSC, and surrounds the DSC with concrete. The space between the canisters is filled with 0.6 volume fraction water, which is not counted in the calculation of the limiting water volume per canister.

```
READ PLOT
  PIC=MIX  TTL=* X-Y THRU TUBES *
  NCH=' X-C.*SL'
    XUL=0.0     YUL=38.2   ZUL=148.0
    XLR=38.2    YLR=0.0    ZLR=148.0
    UAX=1.0  VDN=-1.0  NAX=130     END
END PLOT
END DATA
END
```

End of the KENO input, and a function to plot the geometry in the output to assure the system has been modeled correctly. This input gives output results of 0.91112 + OR - 0.00118. This becomes 0.9235 with the addition of the 1% bias and two standard deviations of the statistical uncertainty.

Discussion of Criticality Modeling/Analysis

The expected composition of the canister contents includes slightly depleted fuel, cladding, control rod debris, and some residual soluble absorber material. The fuel may have been degraded to less dense oxides. No credit is taken for these realistic conditions because, while real and present, qualification of these conditions is extremely difficult. Therefore, the actual condition of the fuel in the canisters provide an additional, albeit un-quantified, margin of safety from those conditions as described below.

Control Parameter	**Controls/Barriers**
Mass	The payload of the heaviest canister is assumed to consist completely of UO2, and this canister is modeled in all positions. This is a conservative assumption since there are other materials (zirconium clad, etc.) mixed with the fuel.
Enrichment	No burnup credit is taken. The maximum initial enrichment (batch 3 average plus 2 sigma). There are no mechanisms possible to increase the enrichment above the 2.98 w/o U-235 assumed in the models.
Geometry	1) No structural credit is taken for the DSC basket and hence the TMI-2 canisters are assumed to be close packed. 2) Whole fuel pellets are used in the models and shown to remain subcritical. 3) Fuel pitch is optimized for triangular pitch columns of cylindrical fuel pellets. 4) No credible mechanism exists for fuel to

escape from the TMI-2 canisters to the DSC.

Reflection	The DSC has been modeled essentially fully reflected by concrete in the HSM. No significant additional reactivity can be added via external reflection over that shown to be subcritical in this analysis.
Interaction	1) The DSC has been shown subcritical with twelve canisters maximum loaded payload which equals or exceeds that measured for any of the TMI-2 canisters.
	2) The canisters are not over moderated or isolated neutronically from each other. No increase in interaction is physically possible in the DSC.
Absorbers	1) The boron carbide and borated aluminum absorbers were fabricated, tested and verified by the original manufacturer. Degradation of the absorbers is not credible due to the materials of construction and methods used to isolated them from the external environment.
	2) The boron carbide was modeled as full density water.
Moderator	A volume limit of 8.0 liters of water per canister is imposed by the results of the analysis. The TMI-2 canister contents are dried prior to loading into the DSC, leaving much less than the 8.0 liter limit. No credible mechanism exists which could introduce water into the system.
Natural Phenomena	1) The DSC is located well above the flood plain preventing water from reaching the DSC or the vent system filters.

2) If water was used to fight a fire in or near the ISFSI, no direct path exists which would allow for impingement of the water stream on the system filters.

3) Seismic events could not relocate the fuel from the TMI-2 canisters to other locations in the system.

Intentionally Blank