Nuclear Engineering Laboratory
M O N T E C U C C O L I N O
technical report
Nuclear Reactor Physics
Department of Energy and Nuclear Engineering
and of Environmental Control (DIENCA)
University of Bologna

Doc. ID: LIN-R07.2007
Subject: ELSY criticality analysis
Date: November 09, 2007

Author: Giacomo Grasso
Phone: +39-051-6441708
e-mail: giacomo.grasso@mail.ing.unibo.it

ELSY criticality analysis with MCNP - A preliminary study

The development of an European Gen-IV reactor is one of the main object of interest in the European research framework. An European Lead cooled SYstem (ELSY) is therefore under investigation on a joint research committee where the National Agency for the New Technologies, Energy and Environment (ENEA) plays the role of neutronic designer for the so-called *square open* hypothesis of the core.
Some preliminary Monte Carlo criticality calculations of the square open ELSY core model are therefore here presented: they have been produced in order to verify the main deterministic calculations performed with ERANOS and to give an easier, detailed analysis of the neutronic performances of the system. The latest versions of the core are here presented for the modeling with MCNP5 (whose input files are presented in appendices) and discussed.

The Author
Giacomo Grasso

The Supervisor
prof. Marco Sumini

Revisions List:

Date	Author

ELSY criticality analysis with MCNP - A preliminary study

Giacomo Grasso

November 09, 2007

Abstract

The development of an European Gen-IV reactor is one of the main object of interest in the European research framework. An European Lead cooled SYstem (ELSY) is therefore under investigation on a joint research committee where the National Agency for the New Technologies, Energy and Environment (ENEA) plays the role of neutronic designer for the so-called *square open* hypothesis of the core.
Some preliminary Monte Carlo criticality calculations of the square open ELSY core model are therefore here presented: they have been produced in order to verify the main deterministic calculations performed with ERANOS and to give an easier, detailed analysis of the neutronic performances of the system. The latest versions of the core are here presented for the modeling with MCNP5 (whose input files are presented in appendices) and discussed.

Contents

1 Introduction

The world-wide renewed interest in nuclear power has found the European Commission in agree with the need to bring out new researches in the Generation-IV nuclear reactors field.

The aim at designing new systems under the main specifications of [1]

- *Sustainability - 1* Generation IV nuclear energy systems will have to provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production.
- *Sustainability - 2* Generation IV nuclear energy systems will have to minimize and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.
- *Economics - 1* Generation IV nuclear energy systems must have a clear life-cycle cost advantage over other energy sources.
- *Economics - 2* Generation IV nuclear energy systems must have a level of financial risk comparable to other energy projects.
- *Safety and Reliability - 1* Generation IV nuclear energy systems operations must excel in safety and reliability.
- *Safety and Reliability - 2* Generation IV nuclear energy systems must have a very low likelihood and degree of reactor core damage.
- *Safety and Reliability - 3* Generation IV nuclear energy systems must eliminate the need for offsite emergency response.
- *Proliferation Resistance and Physical Protection* Generation IV nuclear energy systems will have to increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.

is intended to relaunch the nuclear image beyond the shadows induced in the population by the Chernobyl disaster.

In particular, within the VI European Framework Programme Euratom, a working task has been instituted to investigate several possible solutions about the joint development of an European Gen-IV nuclear reactor: the Working Party 2 for Core Design. Among all the strategic solutions under investigation:

Gas-Cooled Fast Reactor (GFR) featuring a fast-neutron-spectrum, helium-cooled reactor and closed fuel cycle;

Very-High-Temperature Reactor (VHTR) a graphite-moderated, helium-cooled reactor with a once-through uranium fuel cycle;

Supercritical-Water-Cooled Reactor (SCWR) a high-temperature, high-pressure water-cooled reactor that operates above the thermodynamic critical point of water;

Sodium-Cooled Fast Reactor (SFR) featuring a fast-spectrum, sodium-cooled reactor and closed fuel cycle for efficient management of actinides and conversion of fertile uranium;

Lead-Cooled Fast Reactor (LFR) featuring a fast-spectrum lead or lead/bismuth eutectic liquid-metal-cooled reactor and a closed fuel cycle for efficient conversion of fertile uranium and management of actinides;

Molten Salt Reactor (MSR) producing fission power in a circulating molten salt fuel mixture with an epithermal-spectrum reactor and a full actinide recycle fuel cycle;

ENEA, together with SCK-CEN, is studying the neutronic design of an European LFR system (ELSY [2]).

LFR systems are Pb or Pb-Bi alloy-cooled reactors with a fast-neutron spectrum and full actinide closed fuel cycle. The fuel is metal or nitride-based, containing fertile uranium and transuranics. The LFR is cooled by natural convection with a reactor outlet coolant temperature of 550 °C, possibly ranging up to 800 °C with advanced materials.

The technologies employed are extensions of those currently available from the Russian Alpha class submarine Pb-Bi alloy-cooled reactors, from the Integral Fast Reactor metal alloy fuel recycle and refabrication development, and from the ALMR passive safety and modular design approach. Existing ferritic stainless steel and metal alloy fuel, which are already significantly developed for sodium fast reactors, are adaptable to Pb-Bi cooled reactors at reactor outlet temperatures of 550 °C.

Applicability options include a range of plant ratings, including a long refueling interval battery ranging from 50–150 MWe, a modular system from 300–400 MWe, and a large monolithic plant at 1200 MWe. These options also provide a range of energy products. The options in the LFR class may provide a time-phased development path: the nearer-term options focus on electricity production and rely on more easily developed fuel, clad, and coolant combinations and their associated fuel recycle and refabrication technologies; the longer-term option seeks to further exploit the inherently safe properties of Pb and raise the coolant outlet temperature sufficiently high to enter markets for hydrogen and process heat, possibly as merchant plants.

The assurance of reliable and effective thermostructural reactivity feedback is key to the passive safety/passive load following design strategy and will require coordinated neutronics/ thermal-hydraulics/structural design of the core.

Regarding the ELSY neutronic design, the investigated core configurations are the square open (ENEA) and the hexagonal closed (SCK-CEN). Following the square open philosophy, the latest solutions are here presented and discussed, and then modeled for preliminary MCNP [3] calculations intended to assist the ERANOS [4] deterministic design of the reactor under development [5].

2 The ELSY core

The two different core designs (square open and hexagonal closed) are developed independently under common assumptions compiled by the WP2 [6] as desirable goals and constructional constraints.

The main features of the square open core (for the hexagonal closed design more references can be found in [7]), are:

- despite the worser thermo hydraulics, the open configuration achieves a better neutronics due to the absence of the absorbing steel box;

- despite the less compact configuration due to the square lattice (with respect to the triangular one implemented in the hexagonal solution) which implies more fissile material immobilized within the core, the square configuration let an easier engineering because of the already available technological solutions which imply reduced construction times and costs.

The fuel assembly element developed at ENEA is a 17x17 pin array, made of 5 structural pins (the four corners and the central pin) and the remaining 284 fuel rods, as shown in Figure 1. 272 assemblies are needed for criticality (the breeding ratio which about equals 1 let the system be slightly critical, i.e. $k_{eff} \sim 1$), organized to make up a pseudo-cylindrical core (Figure 2). To achieve a flatter neutronic flux for better performances, the core has been segmented into three concentric regions with different Pu contents (different colors in Figure 2).

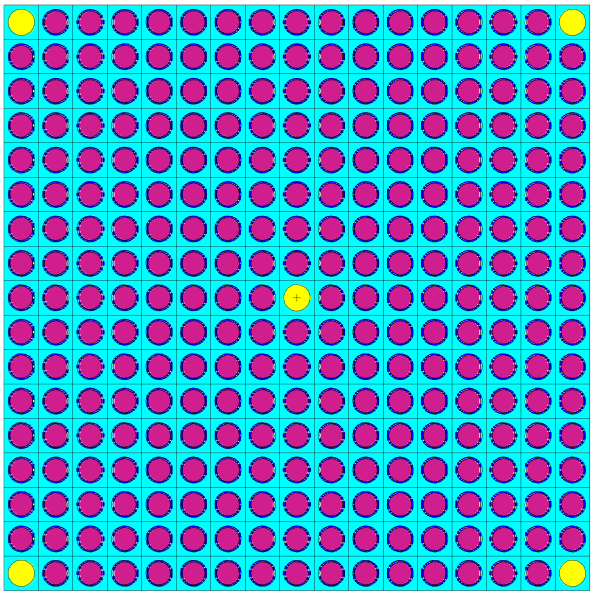

Figure 1: Axial view of a generic fuel assembly with 17x17 fuel pins lattice.

The control rods (absorbers with 70% in mass of B_4C) are organized in 12 assemblies radially distributed between the second and the third fuel regions, to achieve the -5000 pcm reactivity required by the constraints of [6]. The criticality tuning during the cycle is obtained by means of a mobile control cloak (B_4C at about 15% of mass content) superposed the active region, sliding within a fully Pb inundated chamber. Such a control device grants a maximum reactivity counter reaction of about -1000 pcm.

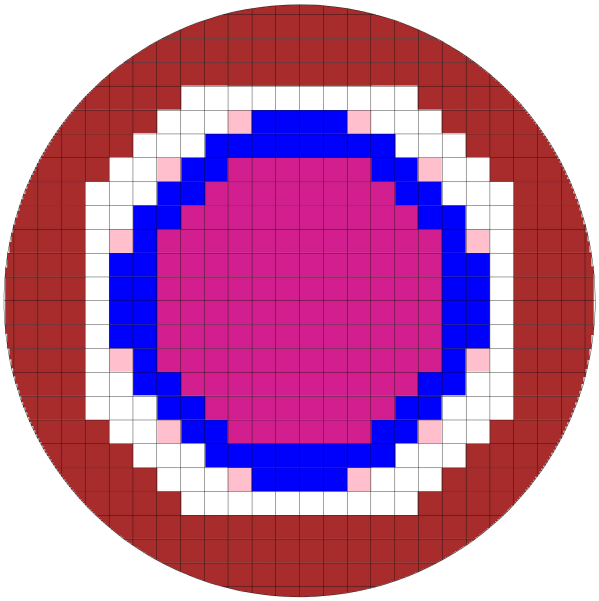

Figure 2: Axial view of the schematic ELSY core with both the fuel (white, purple and blue), the control (pink) and the coolant pseudo- (dark red) assemblies.

3 The MCNP model

The preliminary MCNP model built for Monte Carlo simulation of the ELSY neutronics is a simplified assembly description of the real core. Such a model is more detailed then the pseudo-cylindrical one used for the deterministic preliminary studies on the reactor; this choice follows the need to obtain some first prompt responses from an investigated core design, such as criticality, geometrical behavior of the neutronic flux and reactor performances, to get an approximated but significant suggestion for the design process.

Both the system geometries and the homogenized materials composition have been obtained from the ERANOS model for results consistency with the latter.

3.1 Main features

In the present, preliminary assembly-level scheme, the core is modeled as a cylindrical-like arrangement of assembly boxes in a square lattice [8, 9], with different filling universes depending on the specific core region: the three fuel zones and the absorbers assemblies. In general, each fuel assembly has been modeled as a stack of different materials. From the bottom of the core to the top they are:

1. Bottom assembly;
2. Fuel plenum;
3. Active region;

4. Top assembly;
5. Lead chamber for Control cloak movement;
6. Control cloak.

The active region description varies depending on the specific configuration the core is modeled with.

The control assemblies are modeled in the same way, but the materials composition is:

1. Bottom assembly;
2. Lower lead chamber for control rods movement;
3. Control rods;
4. Upper lead chamber for Control cloak movement.

The cylindrical equivalent cross section is shown in Figure 3 for different regions quotation.

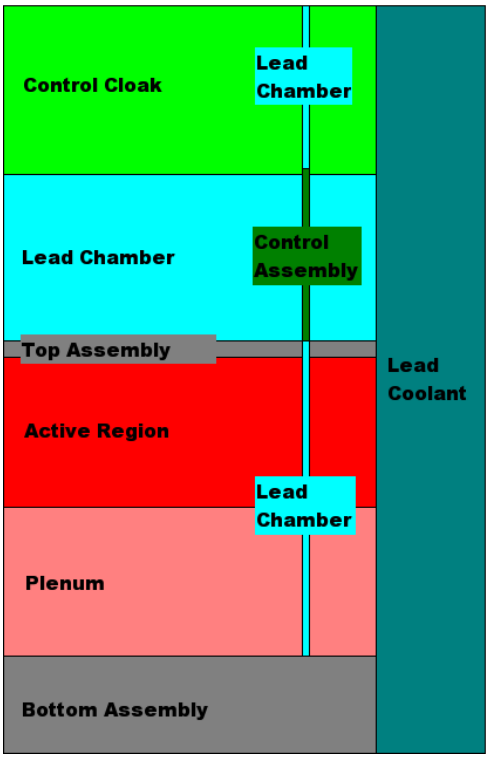

Figure 3: Schematic view of the cylindrical model of the ELSY core.

The structurals are SST91, whose composition is presented in Table 1. The working temperature is 440 °C for the assemblies structures and 480 °C for the cladding.

Element	Fraction
C	4.604268E-03
Fe	8.744541E-01
Cr	9.573146E-02
Ni	3.770166E-03
Mn	5.033134E-03
Mo	5.764173E-03
Si	7.876242E-03
V	2.171199E-03
Nb	5.952451E-04

Table 1: Stainless steel SST91 element composition.

The fuel, MOX with a Minor Actinides (MAs) content chosen to achieve the stationarity of MAs concentration during the cycle, has three different isotopic compositions for the three different fuel regions depending on the core design. The common operative temperature is 950 °C.

All the cross sections needed for the simulation have been taken from the JEFF2.2 database, automatically reprocessed [10] with the NJoy99.259 [11] code.

3.1.1 First standard model

The earliest core model designed (the first case study of the present work) with the control cloak mechanism was characterized by two thin axial blankets made of Natural Uranium (NU) pellets at the top and bottom ends of the fuel rods; the fuel Pu contents, for the three zones, of - respectively - 14%, 15% and 18% were needed for system's criticality, resulting in the fuels isotopic compositions of Table 2.

	Inner	Middle	Outer
Isotope	Fraction		
O	6.610164E-01	6.610163E-01	6.610163E-01
Pu^{238}	1.153088E-03	1.234957E-03	1.480167E-03
Pu^{239}	2.799172E-02	2.997912E-02	3.593172E-02
Pu^{240}	1.323192E-02	1.417137E-02	1.698521E-02
Pu^{241}	2.979275E-03	3.190803E-03	3.824362E-03
Pu^{242}	3.739302E-03	4.004789E-03	4.799971E-03
U^{234}	8.845185E-06	8.738833E-06	8.420272E-06
U^{235}	1.186068E-03	1.171807E-03	1.129091E-03
U^{236}	2.923351E-05	2.888201E-05	2.782917E-05
U^{238}	2.886641E-01	2.851933E-01	2.747969E-01

Table 2: MOX fuels isotopic composition.

The exact scheme is shown in Figure 4. The corresponding MCNP input file is presented in Appendix A.1.

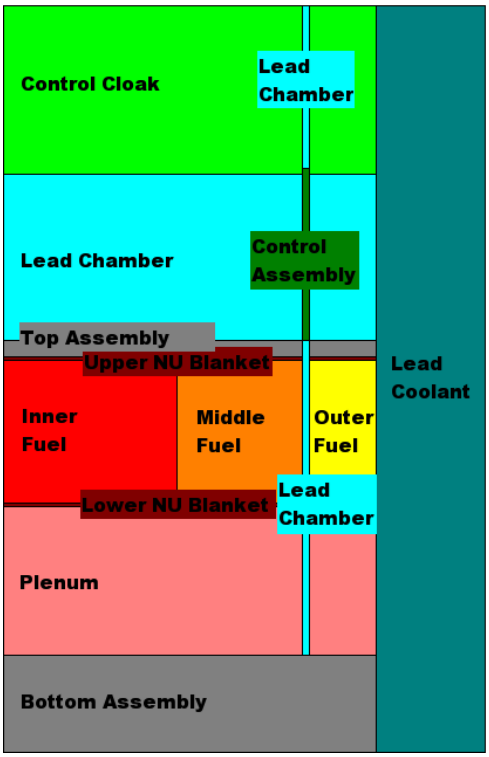

Figure 4: Schematic view of the first cylindrical model of the ELSY core.

3.1.2 Latest standard model

The actual core configuration is presented in Figure 5, in which the two NU blankets have been removed.

This choice implies a slight modify in the Pu content of the inner fuel region to gain the criticality lack due to the removal of the blanket: it therefore switches from 14% to 17%. The resulting fuels isotopic composition are given in Table 3. The corresponding MCNP input file is documented in Appendix A.2.

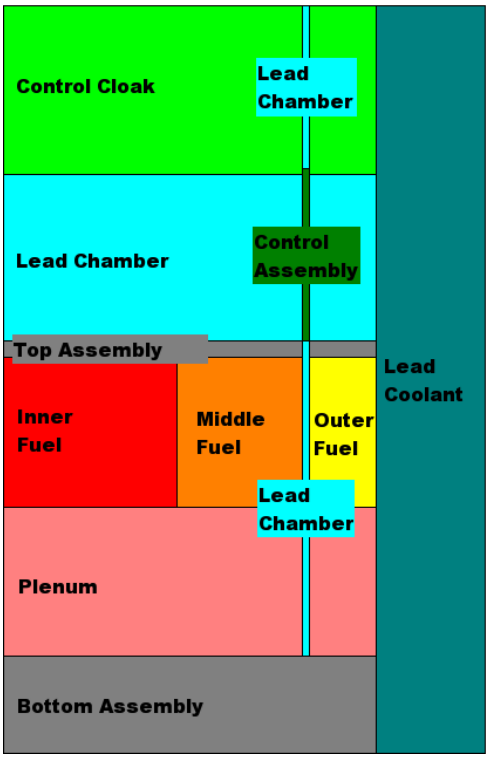

Figure 5: Schematic view of the latest cylindrical model of the ELSY core.

	Inner	Middle	Outer
Isotope	Fraction		
O	6.610164E-01	6.610163E-01	6.610163E-01
Pu^{238}	1.112130E-03	1.234957E-03	1.480167E-03
Pu^{239}	2.699745E-02	2.997912E-02	3.593172E-02
Pu^{240}	1.276191E-02	1.417137E-02	1.698521E-02
Pu^{241}	2.873451E-03	3.190803E-03	3.824362E-03
Pu^{242}	3.606480E-03	4.004789E-03	4.799971E-03
U^{234}	8.898397E-06	8.738833E-06	8.420272E-06
U^{235}	1.193204E-03	1.171807E-03	1.129091E-03
U^{236}	2.940937E-05	2.888201E-05	2.782917E-05
U^{238}	2.904007E-01	2.851933E-01	2.747969E-01

Table 3: MOX fuels isotopic composition.

4 Results

The preliminary results obtained for Monte Carlo criticality analysis of the two designs of the ELSY reactor are here presented. They have been obtained with MCNP5 v.1.22 compiled for OpenMP support and executed on an Intel Core 2 Duo 2.66 MHz with 2 GB RAM commodity workstation at ENEA. All the simulations have been run with 250 cycles (200 active) of 10000 particles per cycle, after a preliminary fast run for neutron source definition of 110 cycles of 1000 particles per cycle.

For the earliest design, the NU blanket lets the inner fuel low enrichment be sufficient for criticality of the system: a $k_{eff} = 0.99864$ (stddev = 18 pcm) was found to slightly undergo the ERANOS deterministic results ($k_{eff} = 1.00145$).

The latest design simulation was found to achieve quite the same criticality ($k_{eff} = 0.99852$) (stddev = 19 pcm) due to the correction in the inner fuel composition after the NU blanket removal. Again, the result was found to undergo the ERANOS deterministic results $k_{eff} = 1.00122$.

5 Concluding remarks

The preliminary criticality calculation of the ELSY core has been carried out by Monte Carlo calculations with MCNP5.

Besides the importance of the specific results (which - even if slightly undergoing the ERANOS ones, as it would been expected by the different nature of the computations - confirm the deterministic ones for neutronic design of the core), all the preliminary activities for MCNP simulation have been successfully completed and the system has been fully modeled for further investigations.

A MCNP input

The two MCNP input files used for the preliminary ELSY criticality analysis are here presented.

A.1 First standard model

```
c ELSY - European Lead cooled SYstem
c
c   Created on 17/10/2007
c
c
c ------------- CELL CARDS ------------------------------------------------
c
c --- Internal Assembly
c Foot Assembly
   1   6   3.566993E-02   -8               u=5         imp:n=1  TMP=6.1460E-08
c Plenum
   2   4   2.402454E-02    8  -9           u=5         imp:n=1  TMP=6.1460E-08
c Lower NU Breeder
   3   5   4.290006E-02    9 -10           u=5         imp:n=1  TMP=1.0541E-07
c Fuel
   4   1   4.256536E-02   10 -11           u=5         imp:n=1  TMP=1.0541E-07
c Upper NU Breeder
   5   5   4.290006E-02   11 -12           u=5         imp:n=1  TMP=1.0541E-07
c Top Assembly
   6   6   3.566993E-02   12 -13           u=5         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
   7   8   2.402455E-02   13 -14           u=5         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
   8   7   4.396166E-02   14               u=5         imp:n=1  TMP=6.1460E-08
c
c --- Intermediate Assembly
c Foot Assembly
  11   like 1 but                          u=6         imp:n=1  TMP=6.1460E-08
c Plenum
  12   like 2 but                          u=6         imp:n=1  TMP=6.1460E-08
c Lower NU Breeder
  13   like 3 but                          u=6         imp:n=1  TMP=1.0541E-07
c Fuel
  14   like 4 but   mat=2 rho=4.257397E-02  u=6         imp:n=1  TMP=1.0541E-07
c Upper NU Breeder
  15   like 5 but                          u=6         imp:n=1  TMP=1.0541E-07
c Top Assembly
  16   like 6 but                          u=6         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
  17   like 7 but                          u=6         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
  18   like 8 but                          u=6         imp:n=1  TMP=6.1460E-08
c
c --- External Assembly
c Foot Assembly
  21   like 1 but                          u=7         imp:n=1  TMP=6.1460E-08
c Plenum
```

```
  22   like 2 but                            u=7         imp:n=1  TMP=6.1460E-08
c Lower NU Breeder
  23   like 3 but                            u=7         imp:n=1  TMP=1.0541E-07
c Fuel
  24   like 4 but   mat=3 rho=4.259982E-02   u=7         imp:n=1  TMP=1.0541E-07
c Upper NU Breeder
  25   like 5 but                            u=7         imp:n=1  TMP=1.0541E-07
c Top Assembly
  26   like 6 but                            u=7         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
  27   like 7 but                            u=7         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
  28   like 8 but                            u=7         imp:n=1  TMP=6.1460E-08
c
c --- Control Assembly
c Foot Assembly
  31   like 1 but                            u=4         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Assembly movement)
  32   8   2.402455E-02    8 -12             u=4         imp:n=1  TMP=6.1460E-08
c B4C_70% Control Assembly
  33   9   1.017630E-01   12 -15             u=4         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Assembly movement)
  34   8   2.402455E-02   15                 u=4         imp:n=1  TMP=6.1460E-08
c
c --- Assembly Lattice Cell
  19  10   2.34276243E-02  1  -2   3  -4    u=9  lat=1
           fill=-12:13 -12:13 0:0
     9 25r
     9 25r
     9 25r
     9 25r
     9 7r 7 9r 9 7r
     9 6r 7 2r 4 6 3r 4 7 2r 9 6r
     9 5r 7 2r 6 7r 7 2r 9 5r
     9 4r 7 7 4 6 6 5 5r 6 6 4 7 7 9 4r
     9 3r 7 2r 6 6 5 7r 6 6 7 2r 9 3r
     9 3r 7 7 6 6 5 9r 6 6 7 7 9 3r
     9 3r 7 4 6 5 11r 6 4 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 4 6 5 11r 6 4 7 9 3r
     9 3r 7 7 6 6 5 9r 6 6 7 7 9 3r
     9 3r 7 2r 6 6 5 7r 6 6 7 2r 9 3r
     9 4r 7 7 4 6 6 5 5r 6 6 4 7 7 9 4r
     9 5r 7 2r 6 7r 7 2r 9 5r
     9 6r 7 2r 4 6 3r 4 7 2r 9 6r
     9 7r 7 9r 9 7r
     9 25r
     9 25r
     9 25r
     9 25r
c
c The explicit geometry follows for clarity
```

```
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-13
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-12
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-11
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-10
c    9 9 9 9 9 9 9 9 7 7 7 7 7 7 7 7 7 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= -9
c    9 9 9 9 9 9 9 7 7 7 4 6 6 6 6 4 7 7 7 9 9 9 9 9 9 9 9 $x=-13:12,y= -8
c    9 9 9 9 9 9 7 7 7 6 6 6 6 6 6 6 6 7 7 7 9 9 9 9 9 9 9 $x=-13:12,y= -7
c    9 9 9 9 9 7 7 4 6 6 5 5 5 5 5 5 6 6 4 7 7 9 9 9 9 9 9 $x=-13:12,y= -6
c    9 9 9 9 7 7 7 6 6 5 5 5 5 5 5 5 5 6 6 7 7 7 9 9 9 9 9 $x=-13:12,y= -5
c    9 9 9 9 7 7 6 6 5 5 5 5 5 5 5 5 5 5 6 6 7 7 9 9 9 9 9 $x=-13:12,y= -4
c    9 9 9 9 7 4 6 5 5 5 5 5 5 5 5 5 5 5 5 6 4 7 9 9 9 9 9 $x=-13:12,y= -3
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y= -2
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y= -1
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y=  0
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y=  1
c    9 9 9 9 7 4 6 5 5 5 5 5 5 5 5 5 5 5 5 6 4 7 9 9 9 9 9 $x=-13:12,y=  2
c    9 9 9 9 7 7 6 6 5 5 5 5 5 5 5 5 5 5 5 6 6 7 7 9 9 9 9 $x=-13:12,y=  3
c    9 9 9 9 7 7 7 6 6 5 5 5 5 5 5 5 5 5 5 6 6 7 7 7 9 9 9 $x=-13:12,y=  4
c    9 9 9 9 9 7 7 4 6 6 5 5 5 5 5 5 5 6 6 4 7 7 9 9 9 9 9 $x=-13:12,y=  5
c    9 9 9 9 9 9 7 7 7 6 6 6 6 6 6 6 6 7 7 7 9 9 9 9 9 9 9 $x=-13:12,y=  6
c    9 9 9 9 9 9 9 7 7 7 4 6 6 6 6 4 7 7 7 9 9 9 9 9 9 9 9 $x=-13:12,y=  7
c    9 9 9 9 9 9 9 9 7 7 7 7 7 7 7 7 7 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=  8
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=  9
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 10
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 11
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 12
c
                                                          imp:n=1  TMP=6.1460E-08
c
c --- Fuel Region
c
  29   0                7 -16 -17         fill=9        imp:n=1  TMP=6.1460E-08
c --- Universe
  20   0               -7:16:17                        imp:n=0

c
c
c ------------- SURFACE CARDS -----------------------------------------
c
c Lattice 2 (Assembly) Elementary cell surfaces
   1 px -11.896274325
   2 px  11.896274325
   3 py -11.896274325
   4 py  11.896274325
   7 pz   0.0       $ Core lower limit
   8 pz  59.10138   $ End Foot Assembly, Start Plenum
   9 pz 150.02658   $ End Plenum, Start Lower NU
  10 pz 151.542     $ End Lower NU, Start Fuel
  11 pz 242.4672    $ End Fuel, Start Upper NU
  12 pz 243.98262   $ End Upper NU, Start Top Assembly & Control Assembly
  13 pz 252.57      $ End Top Assembly, Start Lead Chamber
  14 pz 353.598     $ End Lead Chamber, Start Control Cloak
  15 pz 358.6494    $ End Control Assembly, Start Lead Channel
  16 pz 454.626     $ Core Upper Limit
  17 c/z -11.896274325 -11.896274325 290.5858
```

```
c 304.07687245 304.07687245
c
c

c
c
c ------------- TALLY CARDS ------------------------------------------
c
c ---  MATERIALS CARDS ---
c
c MOX - Internal Region Composition
m1   47109.24c  2.320736E-30
     95241.24c  1.048464E-25
     95242.24c  1.044120E-25
     95242.25c  1.044120E-25
     95243.24c  1.039820E-25
     56138.24c  1.832709E-30
     6000.23c   3.690961E-05
     48111.24c  2.278906E-30
     48112.24c  2.258561E-30
     48113.24c  2.238536E-30
     48114.24c  2.218903E-30
     58140.24c  1.806510E-30
     58141.24c  1.793651E-30
     58142.24c  1.780998E-30
     58144.24c  1.756186E-30
     96242.24c  1.043985E-25
     96243.24c  1.039820E-25
     96244.24c  1.035551E-25
     96245.24c  1.031317E-25
     96246.24c  1.027117E-25
     96247.24c  1.022948E-25
     96248.24c  1.018816E-25
     24050.23c  3.443016E-05
     24052.23c  6.434114E-04
     24053.23c  7.197369E-05
     24054.23c  1.760502E-05
     55133.24c  1.901657E-30
     55134.24c  1.887427E-30
     55135.24c  1.873450E-30
     55137.24c  1.846069E-30
     63153.24c  1.652747E-30
     63154.24c  1.641988E-30
     63155.24c  1.631389E-30
     26054.23c  4.223727E-04
     26056.23c  6.414723E-03
     26057.23c  1.505714E-04
     26058.23c  2.229801E-05
     64156.24c  1.620937E-30
     64157.24c  1.610586E-30
     49115.24c  1.991582E-30
     57139.24c  1.819502E-30
     57140.24c  1.806458E-30
     25055.23c  4.034754E-05
     42000.23c  4.620784E-05
```

```
c     42100.24c  2.529737E-30
      42095.24c  2.663058E-30
      42097.24c  2.608091E-30
      42098.24c  2.581469E-30
      42099.24c  2.555309E-30
      41093.23c  4.771713E-06
      41095.24c  2.663031E-30
      60143.24c  1.768524E-30
      60144.24c  1.756234E-30
      60145.24c  1.744079E-30
      60146.24c  1.732126E-30
      60147.24c  1.720301E-30
      60148.24c  1.708659E-30
      60150.24c  1.685830E-30
      28058.23c  2.077680E-05
      28060.23c  7.767107E-06
      28061.23c  3.638069E-07
      28062.23c  1.038003E-06
      28064.23c  2.773887E-07
      93237.24c  1.066196E-25
      93239.24c  1.057254E-25
c     8000.24c   1.419939E-02
      8016.24c   1.419398E-02
      8017.24c   5.406852E-06
      82000.22c  1.306782E-02
      46105.24c  2.409224E-30
      46106.24c  2.386537E-30
      46107.24c  2.364152E-30
      46108.24c  2.342264E-30
      46110.24c  2.299620E-30
      61147.24c  1.720313E-30
      61148.24m  1.708659E-30
      61149.24c  1.697173E-30
      59141.24c  1.793651E-30
      59143.24c  1.768499E-30
      94238.24c  2.476965E-05
      94239.24c  6.012943E-04
      94240.24c  2.842367E-04
      94241.24c  6.399825E-05
      94242.24c  8.032450E-05
      94243.24c  1.039816E-25
      94244.24c  1.035547E-25
c     37085.24c  2.976497E-30
c     37087.24c  2.908089E-30
      45103.24c  2.456025E-30
      45105.24c  2.409201E-30
      44101.24c  2.504704E-30
      44102.24c  2.480174E-30
      44103.24c  2.456025E-30
      44104.24c  2.432411E-30
      44106.24c  2.386431E-30
      51121.24c  2.090416E-30
      51125.24c  2.023455E-30
      14000.23c  6.313903E-05
      62147.24c  1.720313E-30
```

```
     62149.24c  1.697185E-30
     62150.24c  1.685864E-30
     62151.24c  1.674660E-30
     62152.24c  1.663637E-30
     62154.24c  1.641998E-30
     38090.24c  2.811102E-30
     65159.24c  1.590308E-30
     43099.24c  2.555345E-30
     52128.24c  1.976011E-30
     52130.24c  1.945558E-30
     92234.24c  1.900047E-07
     92235.24c  2.547811E-05
     92236.24c  6.279692E-07
     92238.24c  6.200836E-03
     23000.23c  1.740517E-05
     39089.24c  2.842780E-30
     39091.24c  2.780191E-30
     40091.24c  2.780243E-30
     40092.24c  2.750011E-30
     40093.24c  2.720367E-30
     40094.24c  2.691403E-30
     40095.24c  2.662997E-30
     40096.24c  2.635223E-30
c
c MOX - Intermediate Region Composition
m2   47109.24c  2.486503E-30
     95241.24c  1.123355E-25
     95242.24c  1.118700E-25
     95242.25c  1.118700E-25
     95243.24c  1.114093E-25
     56138.24c  1.963617E-30
     6000.23c   3.690961E-05
     48111.24c  2.441685E-30
     48112.24c  2.419887E-30
     48113.24c  2.398432E-30
     48114.24c  2.377396E-30
     58140.24c  1.935547E-30
     58141.24c  1.921769E-30
     58142.24c  1.908213E-30
     58144.24c  1.881628E-30
     96242.24c  1.118556E-25
     96243.24c  1.114093E-25
     96244.24c  1.109520E-25
     96245.24c  1.104982E-25
     96246.24c  1.100483E-25
     96247.24c  1.096015E-25
     96248.24c  1.091589E-25
     24050.23c  3.443016E-05
     24052.23c  6.434113E-04
     24053.23c  7.197368E-05
     24054.23c  1.760502E-05
     55133.24c  2.037490E-30
     55134.24c  2.022244E-30
     55135.24c  2.007268E-30
     55137.24c  1.977931E-30
```

```
     63153.24c  1.770800E-30
     63154.24c  1.759273E-30
     63155.24c  1.747918E-30
     26054.23c  4.223729E-04
     26056.23c  6.414722E-03
     26057.23c  1.505714E-04
     26058.23c  2.229802E-05
     64156.24c  1.736718E-30
     64157.24c  1.725629E-30
     49115.24c  2.133838E-30
     57139.24c  1.949467E-30
     57140.24c  1.935491E-30
     25055.23c  4.034755E-05
     42000.23c  4.620783E-05
c     42100.24c  2.710433E-30
     42095.24c  2.853278E-30
     42097.24c  2.794384E-30
     42098.24c  2.765860E-30
     42099.24c  2.737832E-30
     41093.23c  4.771714E-06
     41095.24c  2.853248E-30
     60143.24c  1.894847E-30
     60144.24c  1.881680E-30
     60145.24c  1.868656E-30
     60146.24c  1.855850E-30
     60147.24c  1.843180E-30
     60148.24c  1.830706E-30
     60150.24c  1.806246E-30
     28058.23c  2.077681E-05
     28060.23c  7.767106E-06
     28061.23c  3.638069E-07
     28062.23c  1.038003E-06
     28064.23c  2.773886E-07
     93237.24c  1.142353E-25
     93239.24c  1.132772E-25
c    8000.24c   1.420508E-02
     8016.24c   1.419967E-02
     8017.24c   5.409019E-06
     82000.22c  1.306782E-02
     46105.24c  2.581313E-30
     46106.24c  2.557004E-30
     46107.24c  2.533021E-30
     46108.24c  2.509569E-30
     46110.24c  2.463879E-30
     61147.24c  1.843193E-30
     61148.24m  1.830706E-30
     61149.24c  1.818401E-30
     59141.24c  1.921769E-30
     59143.24c  1.894820E-30
     94238.24c  2.653892E-05
     94239.24c  6.442440E-04
     94240.24c  3.045393E-04
     94241.24c  6.856958E-05
     94242.24c  8.606194E-05
     94243.24c  1.114089E-25
```

```
     94244.24c  1.109515E-25
c     37085.24c  3.189105E-30
c     37087.24c  3.115811E-30
     45103.24c  2.631456E-30
     45105.24c  2.581288E-30
     44101.24c  2.683612E-30
     44102.24c  2.657330E-30
     44103.24c  2.631456E-30
     44104.24c  2.606155E-30
     44106.24c  2.556891E-30
     51121.24c  2.239732E-30
     51125.24c  2.167988E-30
     14000.23c  6.313901E-05
     62147.24c  1.843193E-30
     62149.24c  1.818413E-30
     62150.24c  1.806284E-30
     62151.24c  1.794279E-30
     62152.24c  1.782468E-30
     62154.24c  1.759285E-30
     38090.24c  3.011896E-30
     65159.24c  1.703902E-30
     43099.24c  2.737870E-30
     52128.24c  2.117155E-30
     52130.24c  2.084527E-30
     92234.24c  1.877954E-07
     92235.24c  2.518185E-05
     92236.24c  6.206673E-07
     92238.24c  6.128734E-03
     23000.23c  1.740517E-05
     39089.24c  3.045837E-30
     39091.24c  2.978777E-30
     40091.24c  2.978833E-30
     40092.24c  2.946441E-30
     40093.24c  2.914679E-30
     40094.24c  2.883647E-30
     40095.24c  2.853212E-30
     40096.24c  2.823454E-30
c
c MOX - External Region Composition
m3   47109.24c  2.983803E-30
     95241.24c  1.348026E-25
     95242.24c  1.342439E-25
     95242.25c  1.342439E-25
     95243.24c  1.336911E-25
     56138.24c  2.356339E-30
     6000.23c   3.690960E-05
     48111.24c  2.930021E-30
     48112.24c  2.903863E-30
     48113.24c  2.878119E-30
     48114.24c  2.852874E-30
     58140.24c  2.322655E-30
     58141.24c  2.306122E-30
     58142.24c  2.289855E-30
     58144.24c  2.257953E-30
     96242.24c  1.342267E-25
```

```
     96243.24c  1.336911E-25
     96244.24c  1.331423E-25
     96245.24c  1.325978E-25
     96246.24c  1.320579E-25
     96247.24c  1.315218E-25
     96248.24c  1.309906E-25
     24050.23c  3.443016E-05
     24052.23c  6.434113E-04
     24053.23c  7.197371E-05
     24054.23c  1.760502E-05
     55133.24c  2.444989E-30
     55134.24c  2.426692E-30
     55135.24c  2.408721E-30
     55137.24c  2.373516E-30
     63153.24c  2.124960E-30
     63154.24c  2.111127E-30
     63155.24c  2.097501E-30
     26054.23c  4.223726E-04
     26056.23c  6.414723E-03
     26057.23c  1.505714E-04
     26058.23c  2.229802E-05
     64156.24c  2.084062E-30
     64157.24c  2.070754E-30
     49115.24c  2.560605E-30
     57139.24c  2.339359E-30
     57140.24c  2.322588E-30
     25055.23c  4.034754E-05
     42000.23c  4.620784E-05
c     42100.24c  3.252519E-30
     42095.24c  3.423932E-30
     42097.24c  3.353261E-30
     42098.24c  3.319031E-30
     42099.24c  3.285397E-30
     41093.23c  4.771713E-06
     41095.24c  3.423898E-30
     60143.24c  2.273816E-30
     60144.24c  2.258015E-30
     60145.24c  2.242387E-30
     60146.24c  2.227019E-30
     60147.24c  2.211816E-30
     60148.24c  2.196847E-30
     60150.24c  2.167495E-30
     28058.23c  2.077681E-05
     28060.23c  7.767106E-06
     28061.23c  3.638069E-07
     28062.23c  1.038003E-06
     28064.23c  2.773887E-07
     93237.24c  1.370823E-25
     93239.24c  1.359326E-25
c    8000.24c   1.422217E-02
     8016.24c   1.421675E-02
     8017.24c   5.415526E-06
     82000.22c  1.306782E-02
     46105.24c  3.097574E-30
     46106.24c  3.068404E-30
```

```
     46107.24c  3.039624E-30
     46108.24c  3.011482E-30
     46110.24c  2.956653E-30
     61147.24c  2.211830E-30
     61148.24m  2.196847E-30
     61149.24c  2.182081E-30
     59141.24c  2.306122E-30
     59143.24c  2.273784E-30
     94238.24c  3.184670E-05
     94239.24c  7.730928E-04
     94240.24c  3.654472E-04
     94241.24c  8.228349E-05
     94242.24c  1.032743E-04
     94243.24c  1.336906E-25
     94244.24c  1.331417E-25
c     37085.24c  3.826925E-30
c     37087.24c  3.738971E-30
     45103.24c  3.157746E-30
     45105.24c  3.097544E-30
     44101.24c  3.220334E-30
     44102.24c  3.188795E-30
     44103.24c  3.157746E-30
     44104.24c  3.127385E-30
     44106.24c  3.068267E-30
     51121.24c  2.687678E-30
     51125.24c  2.601585E-30
     14000.23c  6.313904E-05
     62147.24c  2.211830E-30
     62149.24c  2.182094E-30
     62150.24c  2.167540E-30
     62151.24c  2.153134E-30
     62152.24c  2.138961E-30
     62154.24c  2.111141E-30
     38090.24c  3.614273E-30
     65159.24c  2.044681E-30
     43099.24c  3.285443E-30
     52128.24c  2.540585E-30
     52130.24c  2.501432E-30
     92234.24c  1.811673E-07
     92235.24c  2.429308E-05
     92236.24c  5.987616E-07
     92238.24c  5.912423E-03
     23000.23c  1.740517E-05
     39089.24c  3.655004E-30
     39091.24c  3.574531E-30
     40091.24c  3.574599E-30
     40092.24c  3.535727E-30
     40093.24c  3.497614E-30
     40094.24c  3.460375E-30
     40095.24c  3.423853E-30
     40096.24c  3.388143E-30
c
c Fuel Plenum
m4   6000.22c   3.816259E-06
     26054.22c  4.367113E-05
```

```
     26056.22c  6.632484E-04
     26057.22c  1.556829E-05
     26058.22c  2.305499E-06
     24050.22c  3.559898E-06
     24052.22c  6.652538E-05
     24053.22c  7.441701E-06
     24054.22c  1.820267E-06
     28058.22c  2.148213E-06
     28060.22c  8.030779E-07
     28061.22c  3.761572E-08
     28062.22c  1.073241E-07
     28064.22c  2.868055E-08
     25055.22c  4.171725E-06
     42000.22c  4.777649E-06
     14000.22c  6.528243E-06
     23000.22c  1.799603E-06
     41093.22c  4.933701E-07
     82000.22c  2.319569E-02
c
c Natural Uranium Breeder
m5   95241.24c  3.090376E-21
     95242.24c  3.090375E-21
     95242.25c  3.090375E-21
     95243.24c  3.090376E-21
     6000.22c   4.037692E-05
     96242.24c  3.089965E-21
     96243.24c  3.090376E-21
     96244.24c  3.090377E-21
     96245.24c  3.090375E-21
     96246.24c  3.090376E-21
     96247.24c  3.090375E-21
     96248.24c  3.090377E-21
     24050.22c  3.766455E-05
     24052.22c  7.038540E-04
     24053.22c  7.873496E-05
     24054.22c  1.925884E-05
     26054.22c  4.620507E-04
     26056.22c  7.017326E-03
     26057.22c  1.647162E-04
     26058.22c  2.439272E-05
     25055.22c  4.413781E-05
     42000.22c  5.054863E-05
     41093.22c  5.219971E-06
     28058.22c  2.272860E-05
     28060.22c  8.496754E-06
     28061.22c  3.979831E-07
     28062.22c  1.135514E-06
     28064.22c  3.034467E-07
     93237.24c  3.090375E-21
     93239.24c  3.090376E-21
c    8000.24c   1.436324E-02
     8016.24c   1.435777E-02
     8017.24c   5.469243E-06
     82000.22c  1.258575E-02
     94238.24c  3.090375E-21
```

```
     94239.24c  3.090375E-21
     94240.24c  3.090377E-21
     94241.24c  3.090376E-21
     94242.24c  3.090376E-21
     94243.24c  3.090376E-21
     94244.24c  3.090376E-21
     14000.22c  6.907035E-05
     92234.24c  4.018106E-07
     92235.24c  5.236424E-05
     92236.24c  3.090376E-21
     92238.24c  7.128854E-03
     23000.22c  1.904022E-05
c
c Assembly Foot and Top Plates
m6   6000.22c   7.861494E-05
     26054.22c  8.996254E-04
     26056.22c  1.366292E-02
     26057.22c  3.207068E-04
     26058.22c  4.749327E-05
     24050.22c  7.333390E-05
     24052.22c  1.370423E-03
     24053.22c  1.532991E-04
     24054.22c  3.749750E-05
     28058.22c  4.425319E-05
     28060.22c  1.654340E-05
     28061.22c  7.748840E-07
     28062.22c  2.210877E-06
     28064.22c  5.908192E-07
     25055.22c  8.593754E-05
     42000.22c  9.841957E-05
     14000.22c  1.344818E-04
     23000.22c  3.707183E-05
     41093.22c  1.016343E-05
     82000.22c  1.859557E-02
c
c Control Cloak (B4C_15%)
m7   6000.22c   3.894658E-03
     5010.22c   1.388338E-02
     5011.22c   1.542598E-03
     26054.22c  4.367114E-04
     26056.22c  6.632485E-03
     26057.22c  1.556829E-04
     26058.22c  2.305499E-05
     24050.22c  3.559898E-05
     24052.22c  6.652538E-04
     24053.22c  7.441702E-05
     24054.22c  1.820267E-05
     28058.22c  2.148213E-05
     28060.22c  8.030779E-06
     28061.22c  3.761573E-07
     28062.22c  1.073241E-06
     28064.22c  2.868055E-07
     25055.22c  4.171725E-05
     42000.22c  4.777649E-05
     14000.22c  6.528243E-05
```

```
     23000.22c  1.799603E-05
     41093.22c  4.933702E-06
     82000.22c  1.639066E-02
c
c Control Assembly Plenum
m8   6000.22c   3.816259E-06
     26054.22c  4.367113E-05
     26056.22c  6.632484E-04
     26057.22c  1.556829E-05
     26058.22c  2.305499E-06
     24050.22c  3.559898E-06
     24052.22c  6.652538E-05
     24053.22c  7.441701E-06
     24054.22c  1.820267E-06
     28058.22c  2.148213E-06
     28060.22c  8.030779E-07
     28061.22c  3.761572E-08
     28062.22c  1.073241E-07
     28064.22c  2.868055E-08
     25055.22c  4.171725E-06
     42000.22c  4.777649E-06
     14000.22c  6.528243E-06
     23000.22c  1.799603E-06
     41093.22c  4.933701E-07
     82000.22c  2.319569E-02
c
c Control Assembly (B4C_70%)
m9   6000.22c   1.803514E-02
     5010.22c   6.478912E-02
     5011.22c   7.198791E-03
     26054.22c  4.367114E-04
     26056.22c  6.632485E-03
     26057.22c  1.556829E-04
     26058.22c  2.305499E-05
     24050.22c  3.559898E-05
     24052.22c  6.652538E-04
     24053.22c  7.441702E-05
     24054.22c  1.820267E-05
     28058.22c  2.148213E-05
     28060.22c  8.030779E-06
     28061.22c  3.761573E-07
     28062.22c  1.073241E-06
     28064.22c  2.868055E-07
     25055.22c  4.171725E-05
     42000.22c  4.777649E-05
     14000.22c  6.528243E-05
     23000.22c  1.799603E-05
     41093.22c  4.933702E-06
     82000.22c  3.489557E-03
c
c Lead
m10  82000.22c  1.00
c
c
c
```

```
c
c ---  MODE CARDS ---
mode n
kcode 1000 1.0 10 110
print
```

A.2 Latest standard model

```
c ELSY - European Lead cooled SYstem
c
c   Created on 22/10/2007
c
c
c ------------- CELL CARDS ------------------------------------------
c
c --- Internal Assembly
c Foot Assembly
   1   5   3.566993E-02   -8               u=5         imp:n=1  TMP=6.1460E-08
c Plenum
   2   4   2.402454E-02    8  -9           u=5         imp:n=1  TMP=6.1460E-08
c Fuel
   4   1   4.257619E-02    9 -12           u=5         imp:n=1  TMP=1.0541E-07
c Top Assembly
   6   5   3.566993E-02   12 -13           u=5         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
   7   7   2.402455E-02   13 -14           u=5         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
   8   6   4.396166E-02   14               u=5         imp:n=1  TMP=6.1460E-08
c
c --- Intermediate Assembly
c Foot Assembly
  11   like 1 but                          u=6         imp:n=1  TMP=6.1460E-08
c Plenum
  12   like 2 but                          u=6         imp:n=1  TMP=6.1460E-08
c Fuel
  14   like 4 but   mat=2 rho=4.257397E-02  u=6         imp:n=1  TMP=1.0541E-07
c Top Assembly
  16   like 6 but                          u=6         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
  17   like 7 but                          u=6         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
  18   like 8 but                          u=6         imp:n=1  TMP=6.1460E-08
c
c --- External Assembly
c Foot Assembly
  21   like 1 but                          u=7         imp:n=1  TMP=6.1460E-08
c Plenum
  22   like 2 but                          u=7         imp:n=1  TMP=6.1460E-08
c Fuel
  24   like 4 but   mat=3 rho=4.259982E-02  u=7         imp:n=1  TMP=1.0541E-07
c Top Assembly
  26   like 6 but                          u=7         imp:n=1  TMP=6.1460E-08
c Lead Chamber (for Control Cloak movement)
  27   like 7 but                          u=7         imp:n=1  TMP=6.1460E-08
c B4C_15% Control Cloak
  28   like 8 but                          u=7         imp:n=1  TMP=6.1460E-08
c
c --- Control Assembly
c Foot Assembly
  31   like 1 but                          u=4         imp:n=1  TMP=6.1460E-08
c Lower Lead Chamber (for Control Assembly movement)
  32   7   2.402455E-02    8 -12           u=4         imp:n=1  TMP=6.1460E-08
```

```
c B4C_70% Control Assembly
  33   8   1.017630E-01   12 -15            u=4         imp:n=1  TMP=6.1460E-08
c Upper Lead Chamber (for Control Assembly movement)
  34   7   2.402455E-02   15                u=4         imp:n=1  TMP=6.1460E-08
c
c --- Assembly Lattice Cell
  19   9   2.34276243E-02  1  -2   3  -4    u=9  lat=1
            fill=-12:13 -12:13 0:0
     9 25r
     9 25r
     9 25r
     9 25r
     9 7r 7 9r 9 7r
     9 6r 7 2r 4 6 3r 4 7 2r 9 6r
     9 5r 7 2r 6 7r 7 2r 9 5r
     9 4r 7 7 4 6 6 5 5r 6 6 4 7 7 9 4r
     9 3r 7 2r 6 6 5 7r 6 6 7 2r 9 3r
     9 3r 7 7 6 6 5 9r 6 6 7 7 9 3r
     9 3r 7 4 6 5 11r 6 4 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 6 6 5 11r 6 6 7 9 3r
     9 3r 7 4 6 5 11r 6 4 7 9 3r
     9 3r 7 7 6 6 5 9r 6 6 7 7 9 3r
     9 3r 7 2r 6 6 5 7r 6 6 7 2r 9 3r
     9 4r 7 7 4 6 6 5 5r 6 6 4 7 7 9 4r
     9 5r 7 2r 6 7r 7 2r 9 5r
     9 6r 7 2r 4 6 3r 4 7 2r 9 6r
     9 7r 7 9r 9 7r
     9 25r
     9 25r
     9 25r
     9 25r
c
c The explicit geometry follows for clarity
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-13
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-12
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-11
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=-10
c    9 9 9 9 9 9 9 9 7 7 7 7 7 7 7 7 7 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= -9
c    9 9 9 9 9 9 9 7 7 7 4 6 6 6 6 4 7 7 7 9 9 9 9 9 9 9 9 $x=-13:12,y= -8
c    9 9 9 9 9 9 7 7 7 6 6 6 6 6 6 6 6 7 7 7 9 9 9 9 9 9 9 $x=-13:12,y= -7
c    9 9 9 9 9 7 7 4 6 6 5 5 5 5 5 5 6 6 4 7 7 9 9 9 9 9 9 $x=-13:12,y= -6
c    9 9 9 9 7 7 7 6 6 5 5 5 5 5 5 5 5 6 6 7 7 7 9 9 9 9 9 $x=-13:12,y= -5
c    9 9 9 9 7 7 6 6 5 5 5 5 5 5 5 5 5 5 6 6 7 7 9 9 9 9 9 $x=-13:12,y= -4
c    9 9 9 9 7 4 6 5 5 5 5 5 5 5 5 5 5 5 5 6 4 7 9 9 9 9 9 $x=-13:12,y= -3
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y= -2
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y= -1
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y=  0
c    9 9 9 9 7 6 6 5 5 5 5 5 5 5 5 5 5 5 5 6 6 7 9 9 9 9 9 $x=-13:12,y=  1
c    9 9 9 9 7 4 6 5 5 5 5 5 5 5 5 5 5 5 5 6 4 7 9 9 9 9 9 $x=-13:12,y=  2
c    9 9 9 9 7 7 6 6 5 5 5 5 5 5 5 5 5 5 5 6 6 7 7 9 9 9 9 $x=-13:12,y=  3
c    9 9 9 9 7 7 7 6 6 5 5 5 5 5 5 5 5 5 6 6 7 7 7 9 9 9 9 $x=-13:12,y=  4
c    9 9 9 9 9 7 7 4 6 6 5 5 5 5 5 5 5 6 6 4 7 7 9 9 9 9 9 $x=-13:12,y=  5
```

```
c    9 9 9 9 9 9 7 7 7 6 6 6 6 6 6 6 6 7 7 7 9 9 9 9 9 9 $x=-13:12,y=  6
c    9 9 9 9 9 9 9 7 7 7 4 6 6 6 6 4 7 7 7 9 9 9 9 9 9 9 $x=-13:12,y=  7
c    9 9 9 9 9 9 9 9 7 7 7 7 7 7 7 7 7 7 9 9 9 9 9 9 9 9 $x=-13:12,y=  8
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y=  9
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 10
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 11
c    9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 $x=-13:12,y= 12
c
                                                          imp:n=1  TMP=6.1460E-08
c
c --- Fuel Region
c
  29   0                7 -16 -17         fill=9        imp:n=1  TMP=6.1460E-08
c --- Universe
  20   0               -7:16:17                         imp:n=0

c
c
c ------------- SURFACE CARDS -----------------------------------------
c
c Lattice 2 (Assembly) Elementary cell surfaces
   1 px -11.896274325
   2 px  11.896274325
   3 py -11.896274325
   4 py  11.896274325
   7 pz   0.0       $ Core lower limit
   8 pz  59.10138   $ End Foot Assembly, Start Plenum
   9 pz 150.02658   $ End Plenum, Start Fuel
  12 pz 240.95178   $ End Fuel, Start Top Assembly & Control Assembly
  13 pz 249.53916   $ End Top Assembly, Start Lead Chamber
  14 pz 350.56716   $ End Lead Chamber, Start Control Cloak
  15 pz 355.61856   $ End Control Assembly, Start Lead Channel
  16 pz 451.59516   $ Core Upper Limit
  17 c/z -11.896274325 -11.896274325 290.5858
c
c

c
c
c ------------- TALLY CARDS -------------------------------------------
c
c --- MATERIALS CARDS ---
c
c MOX - Internal Region Composition
m1   47109.24c  2.238649E-30
     95241.24c  1.011379E-15
     95242.24c  1.007189E-15
     95242.25c  1.007189E-15
     95243.24c  1.003041E-15
     56138.24c  1.767884E-30
     6000.23c   3.692273E-05
     48111.24c  2.198298E-30
     48112.24c  2.178673E-30
     48113.24c  2.159357E-30
     48114.24c  2.140418E-30
```

```
     58140.24c  1.742612E-30
     58141.24c  1.730207E-30
     58142.24c  1.718003E-30
     58144.24c  1.694068E-30
     96242.24c  1.007193E-15
     96243.24c  1.003041E-15
     96244.24c  9.989227E-16
     96245.24c  9.948383E-16
     96246.24c  9.907873E-16
     96247.24c  9.867651E-16
     96248.24c  9.827794E-16
     24050.23c  3.444242E-05
     24052.23c  6.436405E-04
     24053.23c  7.199930E-05
     24054.23c  1.761129E-05
     55133.24c  1.834394E-30
     55134.24c  1.820667E-30
     55135.24c  1.807185E-30
     55137.24c  1.780771E-30
     63153.24c  1.594288E-30
     63154.24c  1.583909E-30
     63155.24c  1.573685E-30
     26054.23c  4.225231E-04
     26056.23c  6.417003E-03
     26057.23c  1.506250E-04
     26058.23c  2.230596E-05
     64156.24c  1.563603E-30
     64157.24c  1.553619E-30
     49115.24c  2.121772E-30
     57139.24c  1.755144E-30
     57140.24c  1.742562E-30
     25055.23c  4.036191E-05
     42000.23c  4.622429E-05
c     42100.24c  2.568864E-30
     42095.24c  2.515841E-30
     42097.24c  2.490160E-30
     42098.24c  2.464925E-30
     42099.24c  2.440258E-30
     41093.23c  4.773412E-06
     41095.24c  2.568837E-30
     60143.24c  1.705969E-30
     60144.24c  1.694115E-30
     60145.24c  1.682389E-30
     60146.24c  1.670859E-30
     60147.24c  1.659452E-30
     60148.24c  1.648222E-30
     60150.24c  1.626200E-30
     28058.23c  2.078420E-05
     28060.23c  7.769870E-06
     28061.23c  3.639364E-07
     28062.23c  1.038373E-06
     28064.23c  2.774875E-07
     93237.24c  1.028484E-15
     93239.24c  1.019858E-15
c     8000.24c   1.420159E-02
```

```
      8016.24c   1.419619E-02
      8017.24c   5.407691E-06
      82000.22c  1.307247E-02
      46105.24c  2.324008E-30
      46106.24c  2.302107E-30
      46107.24c  2.280530E-30
      46108.24c  2.259416E-30
      46110.24c  2.218280E-30
      61147.24c  1.659463E-30
      61148.24m  1.648222E-30
      61149.24c  1.637143E-30
      59141.24c  1.730207E-30
      59143.24c  1.705945E-30
      94238.24c  2.389353E-05
      94239.24c  5.800261E-04
      94240.24c  2.741829E-04
      94241.24c  6.173459E-05
      94242.24c  7.748334E-05
      94243.24c  1.003037E-15
      94244.24c  9.989186E-16
c      37085.24c  2.871216E-30
c      37087.24c  2.805227E-30
      45103.24c  2.369153E-30
      45105.24c  2.323986E-30
      44101.24c  2.416111E-30
      44102.24c  2.392448E-30
      44103.24c  2.369153E-30
      44104.24c  2.346375E-30
      44106.24c  2.302020E-30
      51121.24c  2.016476E-30
      51125.24c  1.951884E-30
      14000.23c  6.316148E-05
      62147.24c  1.659463E-30
      62149.24c  1.637154E-30
      62150.24c  1.626233E-30
      62151.24c  1.615426E-30
      62152.24c  1.604792E-30
      62154.24c  1.583920E-30
      38090.24c  2.711670E-30
      65159.24c  1.534057E-30
      43099.24c  2.464960E-30
      52128.24c  1.906118E-30
      52130.24c  1.876742E-30
      92234.24c  1.911774E-07
      92235.24c  2.563536E-05
      92236.24c  6.318450E-07
      92238.24c  6.239107E-03
      23000.23c  1.741136E-05
      39089.24c  2.742229E-30
      39091.24c  2.681853E-30
      40091.24c  2.681904E-30
      40092.24c  2.652740E-30
      40093.24c  2.624144E-30
      40094.24c  2.596205E-30
      40095.24c  2.568804E-30
```

```
     40096.24c  2.542012E-30
c
c MOX - Intermediate Region Composition
m2   47109.24c  2.486503E-30
     95241.24c  1.123355E-25
     95242.24c  1.118700E-25
     95242.25c  1.118700E-25
     95243.24c  1.114093E-25
     56138.24c  1.963617E-30
     6000.23c   3.690961E-05
     48111.24c  2.441685E-30
     48112.24c  2.419887E-30
     48113.24c  2.398432E-30
     48114.24c  2.377396E-30
     58140.24c  1.935547E-30
     58141.24c  1.921769E-30
     58142.24c  1.908213E-30
     58144.24c  1.881628E-30
     96242.24c  1.118556E-25
     96243.24c  1.114093E-25
     96244.24c  1.109520E-25
     96245.24c  1.104982E-25
     96246.24c  1.100483E-25
     96247.24c  1.096015E-25
     96248.24c  1.091589E-25
     24050.23c  3.443016E-05
     24052.23c  6.434113E-04
     24053.23c  7.197368E-05
     24054.23c  1.760502E-05
     55133.24c  2.037490E-30
     55134.24c  2.022244E-30
     55135.24c  2.007268E-30
     55137.24c  1.977931E-30
     63153.24c  1.770800E-30
     63154.24c  1.759273E-30
     63155.24c  1.747918E-30
     26054.23c  4.223729E-04
     26056.23c  6.414722E-03
     26057.23c  1.505714E-04
     26058.23c  2.229802E-05
     64156.24c  1.736718E-30
     64157.24c  1.725629E-30
     49115.24c  2.133838E-30
     57139.24c  1.949467E-30
     57140.24c  1.935491E-30
     25055.23c  4.034755E-05
     42000.23c  4.620783E-05
c     42100.24c  2.710433E-30
     42095.24c  2.853278E-30
     42097.24c  2.794384E-30
     42098.24c  2.765860E-30
     42099.24c  2.737832E-30
     41093.23c  4.771714E-06
     41095.24c  2.853248E-30
     60143.24c  1.894847E-30
```

```
     60144.24c  1.881680E-30
     60145.24c  1.868656E-30
     60146.24c  1.855850E-30
     60147.24c  1.843180E-30
     60148.24c  1.830706E-30
     60150.24c  1.806246E-30
     28058.23c  2.077681E-05
     28060.23c  7.767106E-06
     28061.23c  3.638069E-07
     28062.23c  1.038003E-06
     28064.23c  2.773886E-07
     93237.24c  1.142353E-25
     93239.24c  1.132772E-25
c     8000.24c   1.420508E-02
     8016.24c   1.419967E-02
     8017.24c   5.409019E-06
     82000.22c  1.306782E-02
     46105.24c  2.581313E-30
     46106.24c  2.557004E-30
     46107.24c  2.533021E-30
     46108.24c  2.509569E-30
     46110.24c  2.463879E-30
     61147.24c  1.843193E-30
     61148.24m  1.830706E-30
     61149.24c  1.818401E-30
     59141.24c  1.921769E-30
     59143.24c  1.894820E-30
     94238.24c  2.653892E-05
     94239.24c  6.442440E-04
     94240.24c  3.045393E-04
     94241.24c  6.856958E-05
     94242.24c  8.606194E-05
     94243.24c  1.114089E-25
     94244.24c  1.109515E-25
c     37085.24c  3.189105E-30
c     37087.24c  3.115811E-30
     45103.24c  2.631456E-30
     45105.24c  2.581288E-30
     44101.24c  2.683612E-30
     44102.24c  2.657330E-30
     44103.24c  2.631456E-30
     44104.24c  2.606155E-30
     44106.24c  2.556891E-30
     51121.24c  2.239732E-30
     51125.24c  2.167988E-30
     14000.23c  6.313901E-05
     62147.24c  1.843193E-30
     62149.24c  1.818413E-30
     62150.24c  1.806284E-30
     62151.24c  1.794279E-30
     62152.24c  1.782468E-30
     62154.24c  1.759285E-30
     38090.24c  3.011896E-30
     65159.24c  1.703902E-30
     43099.24c  2.737870E-30
```

```
     52128.24c  2.117155E-30
     52130.24c  2.084527E-30
     92234.24c  1.877954E-07
     92235.24c  2.518185E-05
     92236.24c  6.206673E-07
     92238.24c  6.128734E-03
     23000.23c  1.740517E-05
     39089.24c  3.045837E-30
     39091.24c  2.978777E-30
     40091.24c  2.978833E-30
     40092.24c  2.946441E-30
     40093.24c  2.914679E-30
     40094.24c  2.883647E-30
     40095.24c  2.853212E-30
     40096.24c  2.823454E-30
c
c MOX - External Region Composition
m3   47109.24c  2.983803E-30
     95241.24c  1.348026E-25
     95242.24c  1.342439E-25
     95242.25c  1.342439E-25
     95243.24c  1.336911E-25
     56138.24c  2.356339E-30
     6000.23c   3.690960E-05
     48111.24c  2.930021E-30
     48112.24c  2.903863E-30
     48113.24c  2.878119E-30
     48114.24c  2.852874E-30
     58140.24c  2.322655E-30
     58141.24c  2.306122E-30
     58142.24c  2.289855E-30
     58144.24c  2.257953E-30
     96242.24c  1.342267E-25
     96243.24c  1.336911E-25
     96244.24c  1.331423E-25
     96245.24c  1.325978E-25
     96246.24c  1.320579E-25
     96247.24c  1.315218E-25
     96248.24c  1.309906E-25
     24050.23c  3.443016E-05
     24052.23c  6.434113E-04
     24053.23c  7.197371E-05
     24054.23c  1.760502E-05
     55133.24c  2.444989E-30
     55134.24c  2.426692E-30
     55135.24c  2.408721E-30
     55137.24c  2.373516E-30
     63153.24c  2.124960E-30
     63154.24c  2.111127E-30
     63155.24c  2.097501E-30
     26054.23c  4.223726E-04
     26056.23c  6.414723E-03
     26057.23c  1.505714E-04
     26058.23c  2.229802E-05
     64156.24c  2.084062E-30
```

```
     64157.24c  2.070754E-30
     49115.24c  2.560605E-30
     57139.24c  2.339359E-30
     57140.24c  2.322588E-30
     25055.23c  4.034754E-05
     42000.23c  4.620784E-05
c     42100.24c  3.252519E-30
     42095.24c  3.423932E-30
     42097.24c  3.353261E-30
     42098.24c  3.319031E-30
     42099.24c  3.285397E-30
     41093.23c  4.771713E-06
     41095.24c  3.423898E-30
     60143.24c  2.273816E-30
     60144.24c  2.258015E-30
     60145.24c  2.242387E-30
     60146.24c  2.227019E-30
     60147.24c  2.211816E-30
     60148.24c  2.196847E-30
     60150.24c  2.167495E-30
     28058.23c  2.077681E-05
     28060.23c  7.767106E-06
     28061.23c  3.638069E-07
     28062.23c  1.038003E-06
     28064.23c  2.773887E-07
     93237.24c  1.370823E-25
     93239.24c  1.359326E-25
c     8000.24c   1.422217E-02
     8016.24c   1.421675E-02
     8017.24c   5.415526E-06
     82000.22c  1.306782E-02
     46105.24c  3.097574E-30
     46106.24c  3.068404E-30
     46107.24c  3.039624E-30
     46108.24c  3.011482E-30
     46110.24c  2.956653E-30
     61147.24c  2.211830E-30
     61148.24m  2.196847E-30
     61149.24c  2.182081E-30
     59141.24c  2.306122E-30
     59143.24c  2.273784E-30
     94238.24c  3.184670E-05
     94239.24c  7.730928E-04
     94240.24c  3.654472E-04
     94241.24c  8.228349E-05
     94242.24c  1.032743E-04
     94243.24c  1.336906E-25
     94244.24c  1.331417E-25
c     37085.24c  3.826925E-30
c     37087.24c  3.738971E-30
     45103.24c  3.157746E-30
     45105.24c  3.097544E-30
     44101.24c  3.220334E-30
     44102.24c  3.188795E-30
     44103.24c  3.157746E-30
```

```
     44104.24c  3.127385E-30
     44106.24c  3.068267E-30
     51121.24c  2.687678E-30
     51125.24c  2.601585E-30
     14000.23c  6.313904E-05
     62147.24c  2.211830E-30
     62149.24c  2.182094E-30
     62150.24c  2.167540E-30
     62151.24c  2.153134E-30
     62152.24c  2.138961E-30
     62154.24c  2.111141E-30
     38090.24c  3.614273E-30
     65159.24c  2.044681E-30
     43099.24c  3.285443E-30
     52128.24c  2.540585E-30
     52130.24c  2.501432E-30
     92234.24c  1.811673E-07
     92235.24c  2.429308E-05
     92236.24c  5.987616E-07
     92238.24c  5.912423E-03
     23000.23c  1.740517E-05
     39089.24c  3.655004E-30
     39091.24c  3.574531E-30
     40091.24c  3.574599E-30
     40092.24c  3.535727E-30
     40093.24c  3.497614E-30
     40094.24c  3.460375E-30
     40095.24c  3.423853E-30
     40096.24c  3.388143E-30
c
c Fuel Plenum
m4   6000.22c   3.816259E-06
     26054.22c  4.367113E-05
     26056.22c  6.632484E-04
     26057.22c  1.556829E-05
     26058.22c  2.305499E-06
     24050.22c  3.559898E-06
     24052.22c  6.652538E-05
     24053.22c  7.441701E-06
     24054.22c  1.820267E-06
     28058.22c  2.148213E-06
     28060.22c  8.030779E-07
     28061.22c  3.761572E-08
     28062.22c  1.073241E-07
     28064.22c  2.868055E-08
     25055.22c  4.171725E-06
     42000.22c  4.777649E-06
     14000.22c  6.528243E-06
     23000.22c  1.799603E-06
     41093.22c  4.933701E-07
     82000.22c  2.319569E-02
c
c Assembly Foot and Top Plates
m5   6000.22c   7.861494E-05
     26054.22c  8.996254E-04
```

```
     26056.22c  1.366292E-02
     26057.22c  3.207068E-04
     26058.22c  4.749327E-05
     24050.22c  7.333390E-05
     24052.22c  1.370423E-03
     24053.22c  1.532991E-04
     24054.22c  3.749750E-05
     28058.22c  4.425319E-05
     28060.22c  1.654340E-05
     28061.22c  7.748840E-07
     28062.22c  2.210877E-06
     28064.22c  5.908192E-07
     25055.22c  8.593754E-05
     42000.22c  9.841957E-05
     14000.22c  1.344818E-04
     23000.22c  3.707183E-05
     41093.22c  1.016343E-05
     82000.22c  1.859557E-02
c
c Control Cloak (B4_15%)
m6   6000.22c   3.894658E-03
     5010.22c   1.388338E-02
     5011.22c   1.542598E-03
     26054.22c  4.367114E-04
     26056.22c  6.632485E-03
     26057.22c  1.556829E-04
     26058.22c  2.305499E-05
     24050.22c  3.559898E-05
     24052.22c  6.652538E-04
     24053.22c  7.441702E-05
     24054.22c  1.820267E-05
     28058.22c  2.148213E-05
     28060.22c  8.030779E-06
     28061.22c  3.761573E-07
     28062.22c  1.073241E-06
     28064.22c  2.868055E-07
     25055.22c  4.171725E-05
     42000.22c  4.777649E-05
     14000.22c  6.528243E-05
     23000.22c  1.799603E-05
     41093.22c  4.933702E-06
     82000.22c  1.639066E-02
c
c Control Assembly Plenum
m7   6000.22c   3.816259E-06
     26054.22c  4.367113E-05
     26056.22c  6.632484E-04
     26057.22c  1.556829E-05
     26058.22c  2.305499E-06
     24050.22c  3.559898E-06
     24052.22c  6.652538E-05
     24053.22c  7.441701E-06
     24054.22c  1.820267E-06
     28058.22c  2.148213E-06
     28060.22c  8.030779E-07
```

```
     28061.22c  3.761572E-08
     28062.22c  1.073241E-07
     28064.22c  2.868055E-08
     25055.22c  4.171725E-06
     42000.22c  4.777649E-06
     14000.22c  6.528243E-06
     23000.22c  1.799603E-06
     41093.22c  4.933701E-07
     82000.22c  2.319569E-02
c
c Control Assembly (B4_70%)
m8   6000.22c   1.803514E-02
     5010.22c   6.478912E-02
     5011.22c   7.198791E-03
     26054.22c  4.367114E-04
     26056.22c  6.632485E-03
     26057.22c  1.556829E-04
     26058.22c  2.305499E-05
     24050.22c  3.559898E-05
     24052.22c  6.652538E-04
     24053.22c  7.441702E-05
     24054.22c  1.820267E-05
     28058.22c  2.148213E-05
     28060.22c  8.030779E-06
     28061.22c  3.761573E-07
     28062.22c  1.073241E-06
     28064.22c  2.868055E-07
     25055.22c  4.171725E-05
     42000.22c  4.777649E-05
     14000.22c  6.528243E-05
     23000.22c  1.799603E-05
     41093.22c  4.933702E-06
     82000.22c  3.489557E-03
c
c Lead
m9   82000.22c  1.00
c
c
c
c
c --- MODE CARDS ---
mode n
kcode 2000 1.0 50 250
print
```

References

[1] A Technology Roadmap for Generation IV Nuclear Energy Systems. Technical report, U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum, December 2002.

[2] *ELSY Work Program*. European Lead-cooled SYstem (ELSY) Project. Technical report, EURATOM, Management of Radioactive Waste, 2006.

[3] F. B. Brown *et al.* MCNP Version 5. *Trans. Am. Nucl. Soc.*, 87:273, 2002.

[4] G. Rimpault *et al.* Schema de Calcul de Reference du Formulaire Eranos et Orientations pour le Schema de Calcul de Projet. Technical Report XT-SBD-0001, CEA, August 1997.

[5] C. Artioli and M. Sarotto. Open Square Fuel Assembly design (and drawings). Technical Report D6 Deliverable, EURATOM, 2007.

[6] V. Sobolev. Preliminary design variant for fuel rod, assembly and core of ELSY-600. Technical Report D5 Deliverable, EURATOM, 2007.

[7] V. Sobolev *et al.* Preliminary Fuel Pin and Hexagonal Assembly design (and drawings). Technical Report D5.1 Deliverable, EURATOM, 2007.

[8] X-5 Monte Carlo Team. *MCNP – A General Monte Carlo N-Particle Transport Code, Version 5 – Volume II: User's Guide*. Los Alamos National Laboratories, 2003.

[9] C. D. Harmon *et al. Criticality Calculations with MCNP5: A Primer*. Los Alamos National Laboratories, 2 edition, 2004.

[10] G. Grasso. NJoyInputMaker: a tool for automatically processing cross section libraries with NJoy. Technical Report LIN-R06.2007, LIN, 2007.

[11] R. E. MacFarlane and D. W. Muir. The NJOY Nuclear Data Processing System Version 91. Technical Report LA-12740-M, Los Alamos National Laboratories, October 1994.