

Porto Alegre, Brazil, June 25, 2007.

Dear Colleagues:

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During the Research Coordination Meeting of June 4-8, 2007, it was concluded that the swelling of SiC at low temperatures during irradiation causes doubts about the integrity of TRISO fuel particles in the LWR environment. It was decided that we should use CERMET fuel in the water cooled reactors.

[www.beckmancoulter.com/literature/Bioresearch/ar-409.pdf and PNNL-16245] . As the group decided to recalculate all benchmarks for cells and whole core, now with the cermet fuel, we made the calculations. Enclosed I am sending you the results of our calculations using CERMET fuel in the FBNR reactor utilizing SCALE 5.0 code. Please make calculations with your code system in order to be able to benchmark the results.

Thanking you in advance for your cooperation,

With best regards,

Sefidvash

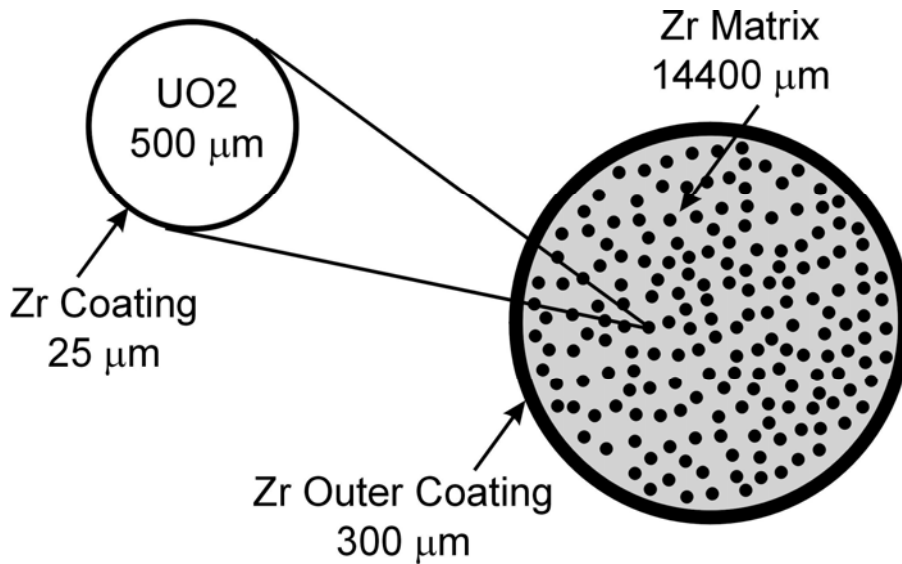
Copy: Dr. Vladimir Kuznetsov [V.V.Kuznetsov@iaea.org].

Criticality Calculations of FBNR using CERMET fuel

1. CERMET Fuel Description:

The 15 mm diameter FBNR Fuel Element is (dimensions given in micron):

- UO₂ microsphere diameter = 500
- Microsphere Zr clad thickness = 25
- Microspheres are embedded in Zr matrix with a porosity of 0.40 (60% microspheres + 40% Zr matrix by volume)
- The 15000 microns diameter fuel element has a Zr cladding of 300 microns in thickness



2. Fraction of each material in the fuel element

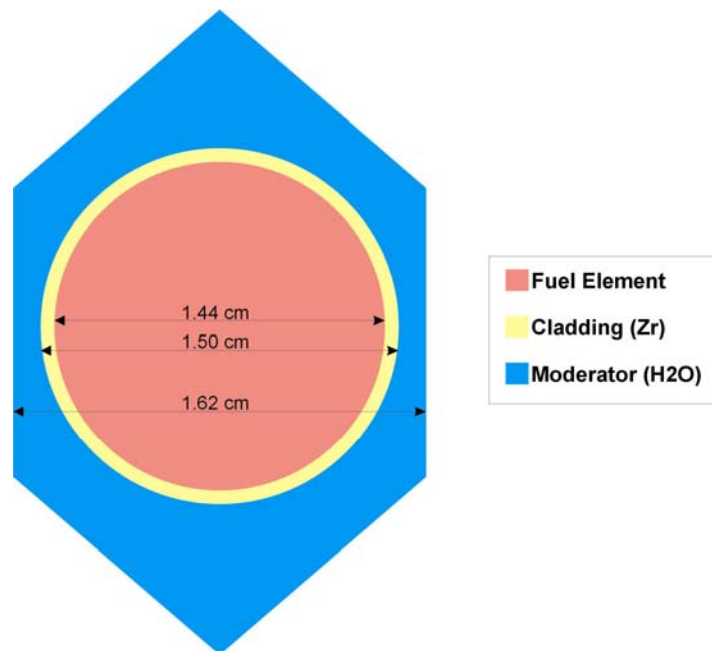
Microsphere

Material	Density (g/cc)	diameter (cm)	Volume (cc)	Mass (gr)	Mass Fraction
UO ₂	10.5	0.0500	6.55E-05	6.87E-04	0.570
Zirconium	6.5	0.0550	2.16E-05	1.41E-04	0.117
Microsphere	9.506	0.0550	8.71E-05	8.28E-04	
Zirconium Matrix	6.5		5.81E-05	3.77E-04	0.313
Total MicroSphere	8.304		1.45E-04	1.21E-03	1.000

Fuel Element

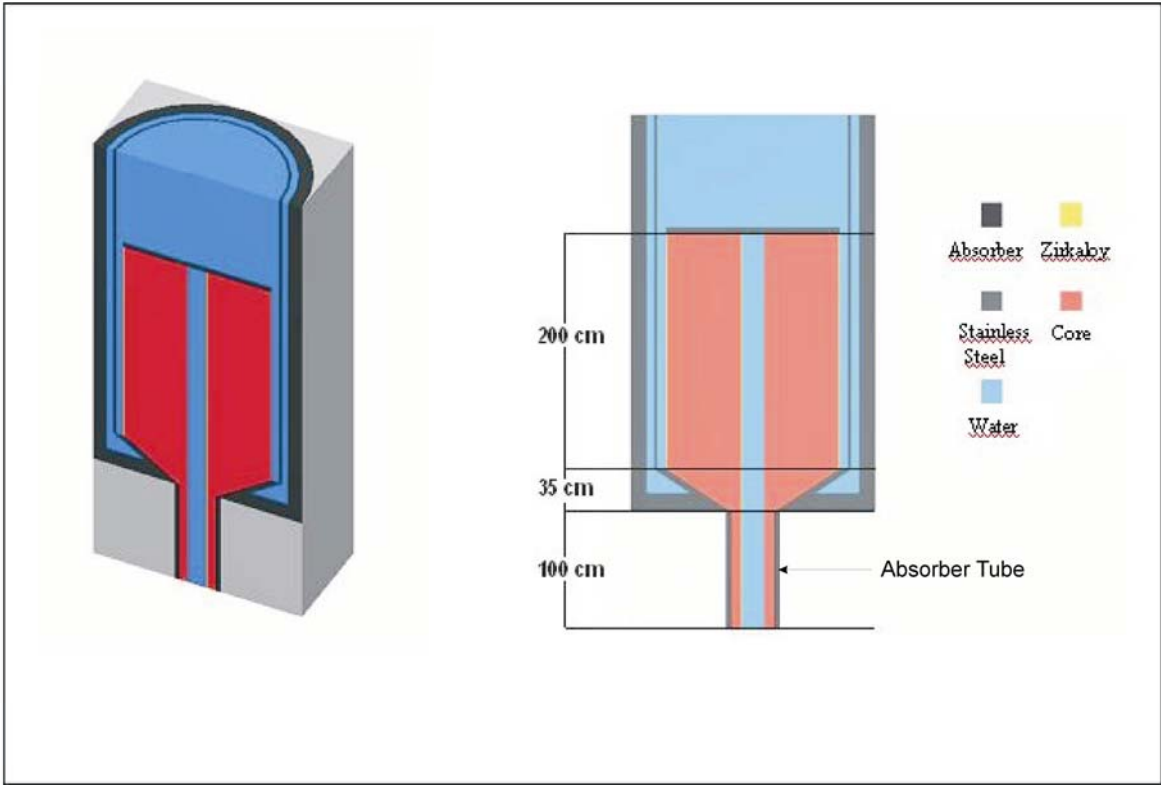
Material	Density (g/cc)	diameter	Volume (cc)	Mass (gr)	Mass Fraction
UO2	10.5		0.705	7.404	0.488
Zirconium	6.5		0.858	5.579	0.367
Total	8.304	1.440	1.563	12.983	
Zirconium Cladding	6.5	1.500	0.204	1.324	0.087
H2O	0.747	1.62 (face to face of dodecahedron)	1.178	0.880	0.058
Total Fuel Element	5.157		2.945	15.186	1.000

3. The unit cell designed by KENO 3D of SCALE 5 :



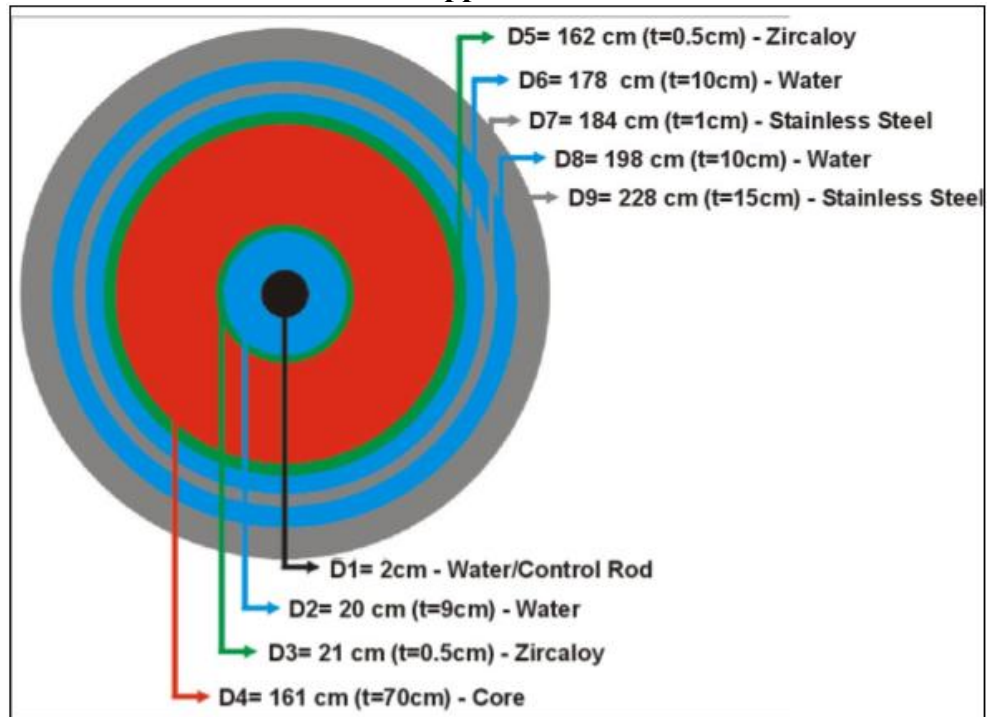
1.62 cm is the distance between face to face of the dodecahedron.

4. The whole reactor with homogenized core designed by KENO 3D of SCALE 5

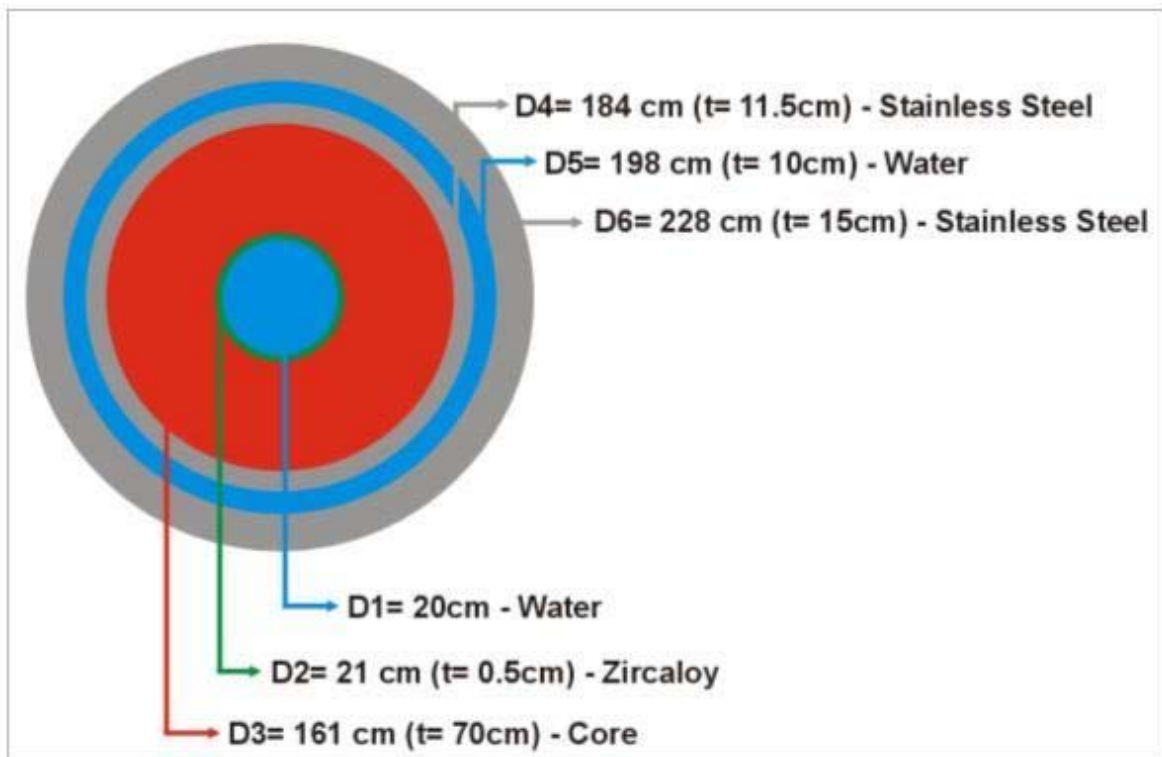


$K_e = 1.1822$

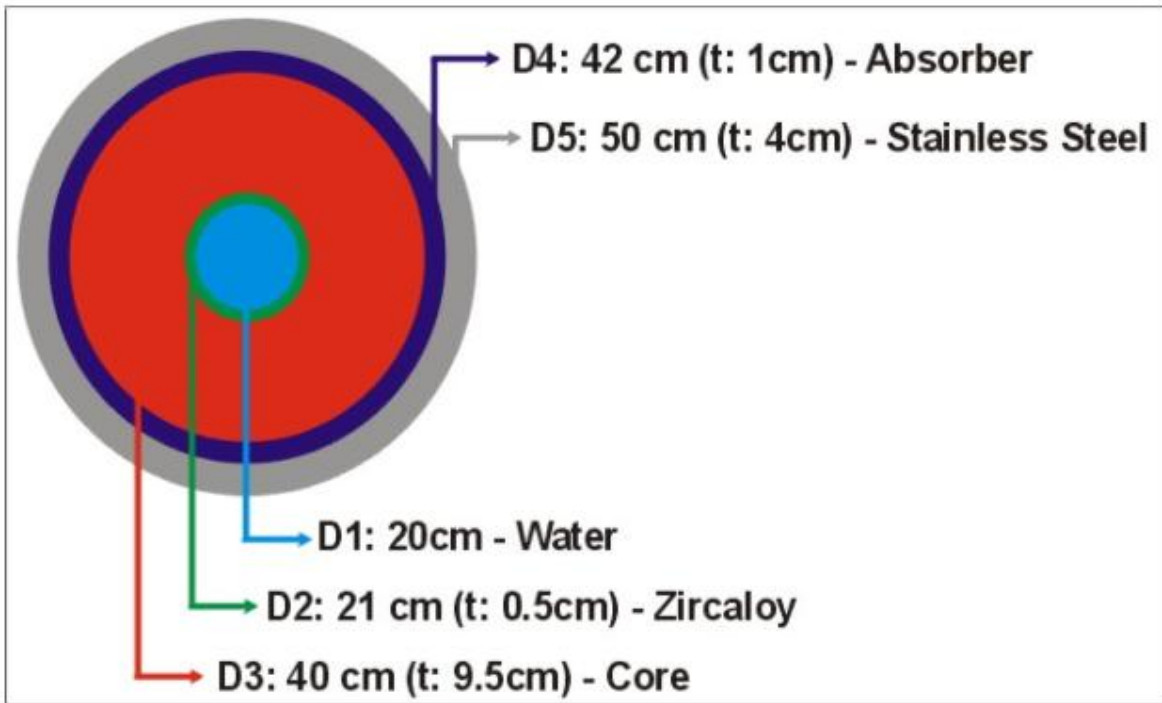
Upper Part



Middle Part

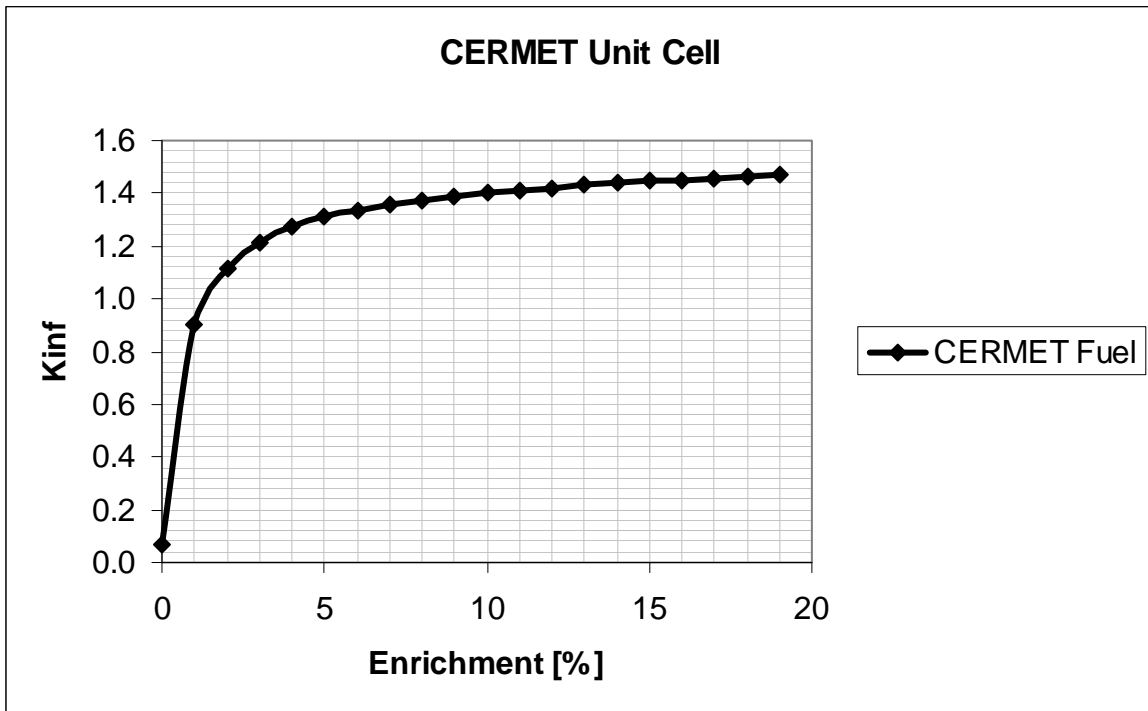


Lower Part



5. The results for K_{inf} of the unit cell as a function of enrichment

Enrichment	K_{inf}
0	0.0717
1	0.9015
2	1.1154
3	1.2146
4	1.2720
5	1.3097
6	1.3376
7	1.3591
8	1.3760
9	1.3880
10	1.4005
11	1.4129
12	1.4196
13	1.4296
14	1.4373
15	1.4449
16	1.4502
17	1.4591
18	1.4654
19	1.4696
99	1.7906



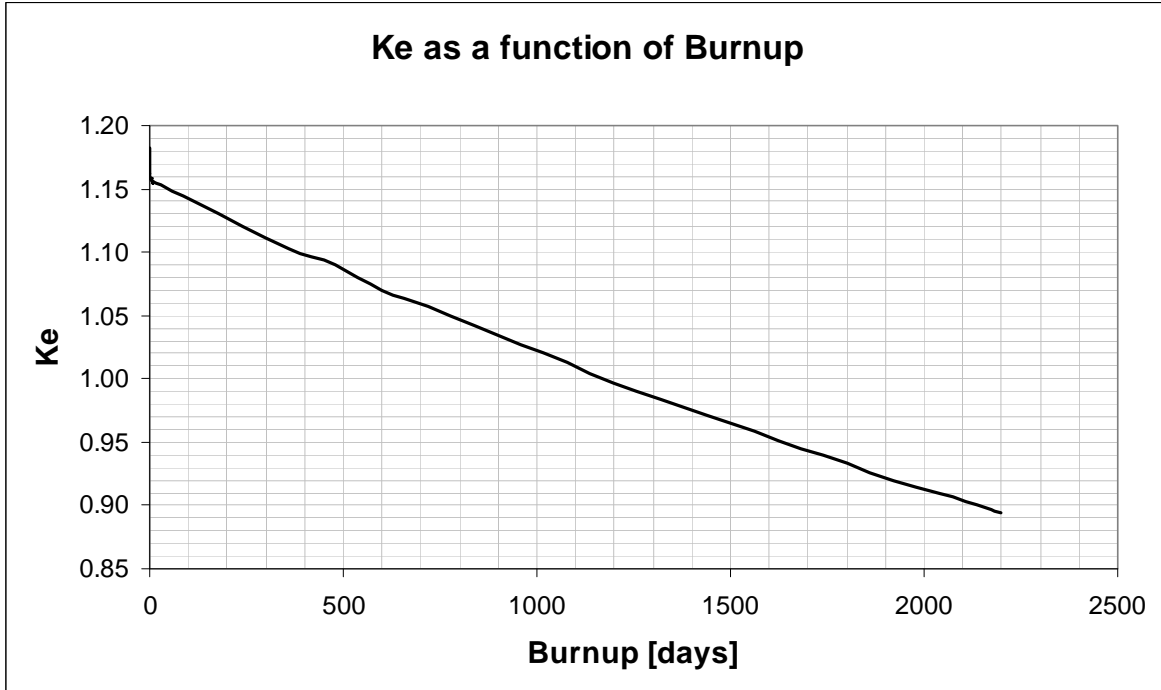
6. The results of K_e for the whole reactor of 200 cm core height of 5% enrichment:

$K_e = 1.1822.$

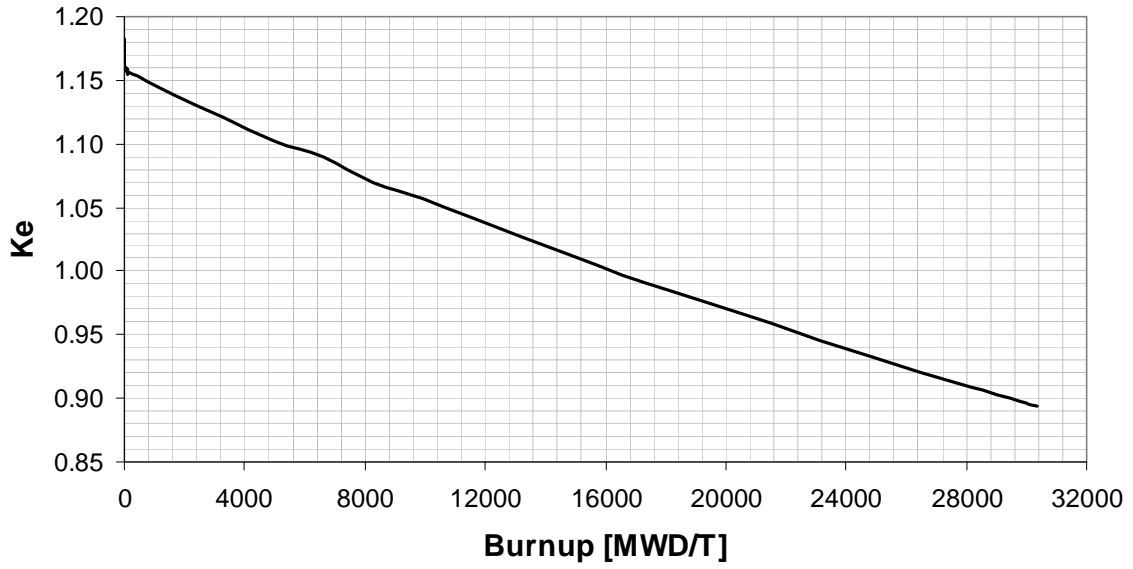
7. The burnup calculations for this reactor configuration of 200 cm core height

Days	MWD/ton	K_e
0	0.000	1.1822
1	13.787	1.1621
2	27.574	1.1597
3	41.361	1.1579
4	55.148	1.1571
5	68.935	1.1581
6	82.722	1.1583
7	96.509	1.1563
8	110.296	1.1564
9	124.083	1.1548
10	137.870	1.1560
120	1654.440	1.1389
240	3308.880	1.1205

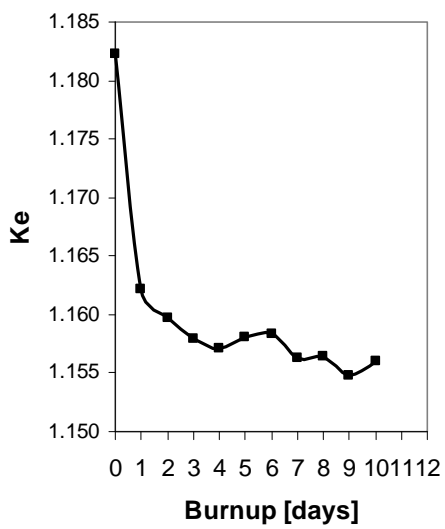
360	4963.320	1.1023
480	6617.760	1.0896
600	8272.200	1.0695
720	9926.640	1.0566
840	11581.080	1.0425
960	13235.520	1.0267
1080	14889.960	1.0124
1200	16544.400	0.9970
1320	18198.840	0.9841
1440	19853.280	0.9716
1560	21507.720	0.9585
1680	23162.160	0.9451
1800	24816.600	0.9331
1920	26471.040	0.9199
2040	28125.480	0.9095
2160	29779.920	0.8983
2200	30331.400	0.8936



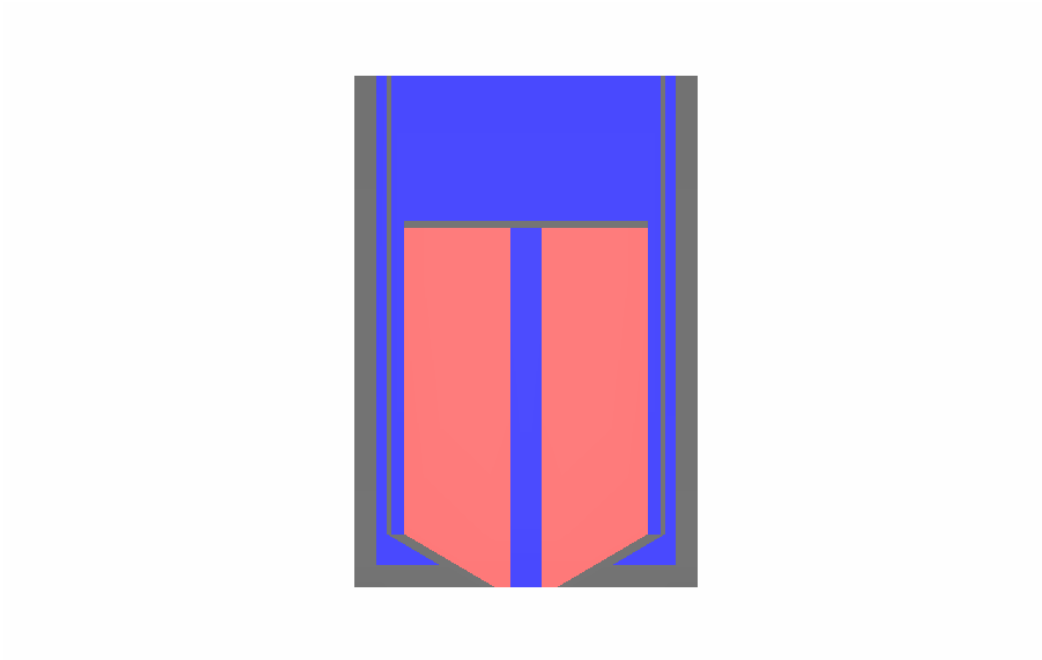
Ke as a function of Burnup



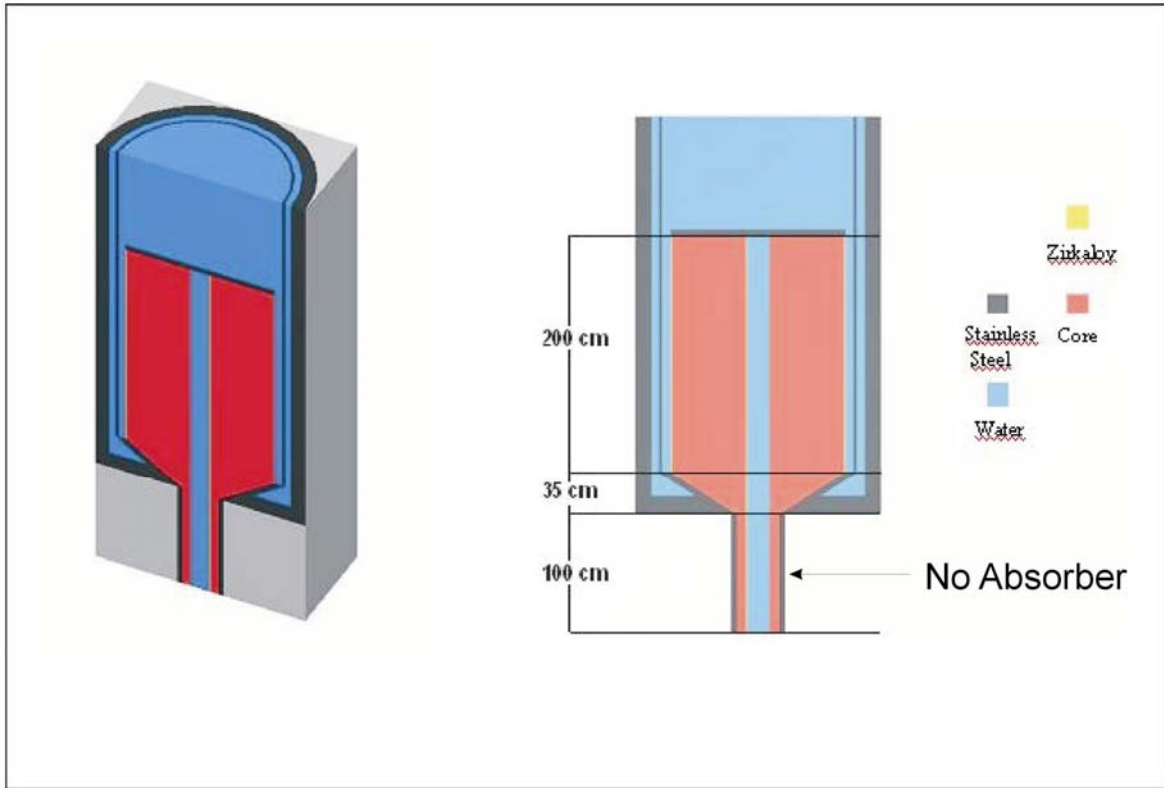
Ke for first 10 days



7. Reactor Without Fuel Chamber



$$K_e = 1.1807$$



Ke= 1.1820

8. Summary

H= 200cm, 5%	Ke
Complete Reactor	1.1822
Without Fuel Chamber	1.1807
With Fuel Chamber Without Absorber Wall	1.1820
Core Life Time =	1200 days
	16500 MWD/T

9. Notes:

- Number of generations used in CSAS26 is 500.
- Homogenized 238groupndf5 used.
- Reactor Power = 134 MWt, UO₂ mass = 11.032 tons, U-metal mass = 9.708 tons
- Power Density = 13.787 MW/Ton

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Annex I: Input file for SCALE CSAS26 for unit cell

```
'Input generated by GeeWiz 5.01a Compiled on March-03-2005
=csas26
Unit_Cell_FBNR_5%
238groupndf5
read comp
  uo2          1 den=8.301 0.57 600 92235 5 92238 95 end
  zirconium    1 den=8.301 0.43 600 end
  h2o          3 den=0.747 1 580 end
  zirconium    2 1 600 end
end comp
read celldata
  latticecell sphsquarep fuelr=0.65 1 hpitch=0.81 3 end
end celldata
read parameter
  gen=500
  flx=yes
  plt=no
end parameter
read geometry
global unit 1
com='upper uranium dodecahedron'
  sphere 1 0.72
  sphere 2 0.75
  dodecahedron 3 0.81
  media 1 1 1
  media 2 1 -1 2
  media 3 1 3 -2
  boundary 3
end geometry
read bnds
  body=3
  all=mirror
end bnds
end data
end
```

Annex II: : Input file for SCALE CSAS26 for the whole reactor

```
'Input generated by GeeWiz 5.01a Compiled on March-03-2005
=csas26
```

```

homogenized
238groupndf5
read comp
uo2          1 den=5.157 0.487 600 92235 5 92238 95 end
zirconium    1 den=5.157 0.455 600 end
h2o          1 den=5.157 0.058 600 end
zirc4        2 1 600 end
h2o          3 den=0.747 1 580 end
ss304        4 1 300 end
cadmium      5 1 300 end
h2o          6 den=0.747 1 580 end
h2o          7 den=0.747 1 580 end
end comp
read celldata
  multiregion cylindrical right_bdy=vacuum left_bdy=reflected
origin=0 end  3 10 2 10.5 1 80.5 2 81 6 89 4 92 7 99 end zone
end celldata
read parameter
  gen=500
  plt=no
end parameter
read geometry
unit 1
com='upper_part'
cylinder 1  10  200  0  origin  x=114 y=114 z=0
cylinder 2 10.5  200  0  origin  x=114 y=114 z=0
cylinder 3 80.5  200  0  origin  x=114 y=114 z=0
cylinder 4  81  200  0  origin  x=114 y=114 z=0
cylinder 5  89  300  0  origin  x=114 y=114 z=0
cylinder 6  92  300  0  origin  x=114 y=114 z=0
cylinder 7  99  300  0  origin  x=114 y=114 z=0
cylinder 8 114  300  0  origin  x=114 y=114 z=0
cuboid 9  228  0  228  0  300  0
hole 6  origin  x=114 y=114 z=200
hole 7  origin  x=114 y=159 z=200
hole 8  origin  x=114 y=69  z=200
hole 9  origin  x=159 y=114 z=200
hole 10 origin  x=69  y=114 z=200
hole 11 origin  x=114 y=114 z=200
media 3 1 1
media 2 1 -1 2
media 1 1 3 -2
media 2 1 4 -3
media 3 1 5 -4
media 4 1 6 -5
media 3 1 7 -6
media 4 1 8 -7

```

```

media 0 1 9 -8
boundary 9
unit 2
com='lower_part'
cylinder 1 10 100 0 origin x=114 y=114 z=0
cylinder 2 10.5 100 0 origin x=114 y=114 z=0
cylinder 3 20 100 0 origin x=114 y=114 z=0
cylinder 4 21 100 0 origin x=114 y=114 z=0
cylinder 5 25 100 0 origin x=114 y=114 z=0
cuboid 6 228 0 228 0 100 0
media 3 1 1
media 2 1 2 -1
media 1 1 3 -2
media 5 1 4 -3
media 4 1 5 -4
media 0 1 6 -5
boundary 6
unit 3
com='middle_part'
cylinder 1 10 20 0 origin x=114 y=114 z=0
cylinder 2 10.5 20 0 origin x=114 y=114 z=0
cone 3 80.5 20 46 0 origin x=114 y=114 z=0
cone 4 92 20 57.5 0 origin x=114 y=114 z=0
cylinder 5 99 20 0 origin x=114 y=114 z=0
cylinder 6 114 20 0 origin x=114 y=114 z=0
cuboid 7 228 0 228 0 20 0
media 3 1 1
media 2 1 2 -1
media 1 1 3 -2
media 4 1 4 -3
media 3 1 5 -4
media 4 1 6 -5
media 0 1 7 -6
boundary 7
unit 4
com='middle_part'
cylinder 1 10 15 0 origin x=114 y=114 z=0
cylinder 2 10.5 15 0 origin x=114 y=114 z=0
cone 3 46 15 20 0 origin x=114 y=114 z=0
cylinder 4 114 15 0 origin x=114 y=114 z=0
cuboid 5 228 0 228 0 15 0
media 3 1 1
media 2 1 2 -1
media 1 1 3 -2
media 4 1 4 -3
media 0 1 5 -4
boundary 5

```

```

global unit 5
com='array'
  cuboid 1 228 0 228 0 435 0
  cuboid 2 228 0 228 0 435 0
  array 1 1 place 1 1 1 0 0 0
  media 0 1 -1 2
  boundary 2
unit 6
com='control rod inside'
  cylinder 1 1 0 -100
  media 3 1 1
  boundary 1
unit 7
com='1. control rod core '
  cylinder 1 1 0 -100
  media 1 1 1
  boundary 1
unit 8
com='2. control rod core'
  cylinder 1 1 0 -100
  media 1 1 1
  boundary 1
unit 9
com='3. control rod core'
  cylinder 1 1 0 -100
  media 1 1 1
  boundary 1
unit 10
com='4. control rod core'
  cylinder 1 1 0 -100
  media 1 1 1
  boundary 1
unit 11
com='top-steel'
  cylinder 1 81 5 0
  media 4 1 1
  boundary 1
end geometry
read array
ara=1 nux=1 nuy=1 nuz=4 typ=square
com=''
fill 2 4 3 1
end fill
end array
read plot
scr=yes
ttl='titlr'

```

```

pic=mixtures
xul=0
yul=228
zul=300
xlr=228
ylr=0
zlr=300
nax=3000
clr=1 255 85 85
      2 255 255 0
      3 0 0 255
      4 97 97 97
      5 205 205 0
      6 0 0 0
      7 0 0 255
end color
uax=1 vdn=-1
end
end plot
read bnds
end bnds
end data
end

```

Annex III: Input file for SCALE – STARBUCS for the whole reactor (120 days).

```

=starbucs
PWR 17x17 Fuel Assembly - uniform axial burnup rods
238groupndf5
read comp
uo2          1 den=5.157 0.487 600 92235 4.99 92238 95.01 end
zirconium    101 den=5.157 0.455 600 end
h2o          101 den=5.157 0.058 600 end
zirc4        2 1 600 end
h2o          3 den=0.747 1 580 end
ss304        4 1 300 end
cadmium      5 1 300 end
h2o          6 den=0.747 1 580 end
h2o          7 den=0.747 1 580 end
end comp
read celldata
      latticecell squarepitch pitch=89 3 fueld=80.5 1 cladd=81
2 end

```

```

end celldata
read control
    arp=17x17
    axp= 2 end
    nuc= all
end control
read hist
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
power=13.787 burn=15 nlib=5 end
'***** 120 days *****'
end hist
read kenovi
'
' infinite pin cell lattice
'
'*****
'* materials
'* 101 = uo2, uniform axial region
'* 2 = Zircaloy
'* 3 = Water
'*****
read param gen=500 end parm
read geometry
unit 1
com='upper_part'
cylinder 1 10 200 0 origin x=114 y=114 z=0
cylinder 2 10.5 200 0 origin x=114 y=114 z=0
cylinder 3 80.5 200 0 origin x=114 y=114 z=0
cylinder 4 81 200 0 origin x=114 y=114 z=0
cylinder 5 89 300 0 origin x=114 y=114 z=0
cylinder 6 92 300 0 origin x=114 y=114 z=0
cylinder 7 99 300 0 origin x=114 y=114 z=0
cylinder 8 114 300 0 origin x=114 y=114 z=0
cuboid 9 228 0 228 0 300 0
hole 6 origin x=114 y=114 z=200
hole 7 origin x=114 y=159 z=200
hole 8 origin x=114 y=69 z=200
hole 9 origin x=159 y=114 z=200
hole 10 origin x=69 y=114 z=200
hole 11 origin x=114 y=114 z=200
media 3 1 1

```

```

media 2 1 -1 2
media 101 1 3 -2
media 2 1 4 -3
media 3 1 5 -4
media 4 1 6 -5
media 3 1 7 -6
media 4 1 8 -7
media 0 1 9 -8
boundary 9
unit 2
com='lower_part'
cylinder 1 10 100 0 origin x=114 y=114 z=0
cylinder 2 10.5 100 0 origin x=114 y=114 z=0
cylinder 3 20 100 0 origin x=114 y=114 z=0
cylinder 4 21 100 0 origin x=114 y=114 z=0
cylinder 5 25 100 0 origin x=114 y=114 z=0
cuboid 6 228 0 228 0 100 0
media 3 1 1
media 2 1 2 -1
media 101 1 3 -2
media 5 1 4 -3
media 4 1 5 -4
media 0 1 6 -5
boundary 6
unit 3
com='middle_part'
cylinder 1 10 20 0 origin x=114 y=114 z=0
cylinder 2 10.5 20 0 origin x=114 y=114 z=0
cone 3 80.5 20 46 0 origin x=114 y=114 z=0
cone 4 92 20 57.5 0 origin x=114 y=114 z=0
cylinder 5 99 20 0 origin x=114 y=114 z=0
cylinder 6 114 20 0 origin x=114 y=114 z=0
cuboid 7 228 0 228 0 20 0
media 3 1 1
media 2 1 2 -1
media 101 1 3 -2
media 4 1 4 -3
media 3 1 5 -4
media 4 1 6 -5
media 0 1 7 -6
boundary 7
unit 4
com='middle_part'
cylinder 1 10 15 0 origin x=114 y=114 z=0
cylinder 2 10.5 15 0 origin x=114 y=114 z=0
cone 3 46 15 20 0 origin x=114 y=114 z=0
cylinder 4 114 15 0 origin x=114 y=114 z=0

```

```

cuboid 5 228 0 228 0 15 0
media 3 1 1
media 2 1 2 -1
media 101 1 3 -2
media 4 1 4 -3
media 0 1 5 -4
boundary 5
global unit 5
com='array'
cuboid 1 228 0 228 0 435 0
cuboid 2 228 0 228 0 435 0
array 1 1 place 1 1 1 0 0 0
media 0 1 -1 2
boundary 2
unit 6
com='control rod inside'
cylinder 1 1 0 -100
media 3 1 1
boundary 1
unit 7
com='1. control rod core '
cylinder 1 1 0 -100
media 101 1 1
boundary 1
unit 8
com='2. control rod core'
cylinder 1 1 0 -100
media 101 1 1
boundary 1
unit 9
com='3. control rod core'
cylinder 1 1 0 -100
media 101 1 1
boundary 1
unit 10
com='4. control rod core'
cylinder 1 1 0 -100
media 101 1 1
boundary 1
unit 11
com='top-steel'
cylinder 1 81 5 0
media 4 1 1
boundary 1
end geometry
read array
ara=1 nux=1 nuy=1 nuz=4 typ=square

```

```
com=''  
fill 2 4 3 1  
end fill  
end array  
end data  
end keno  
end
```