Gaseous Core Reactor Technology

Concepts and Future Designs

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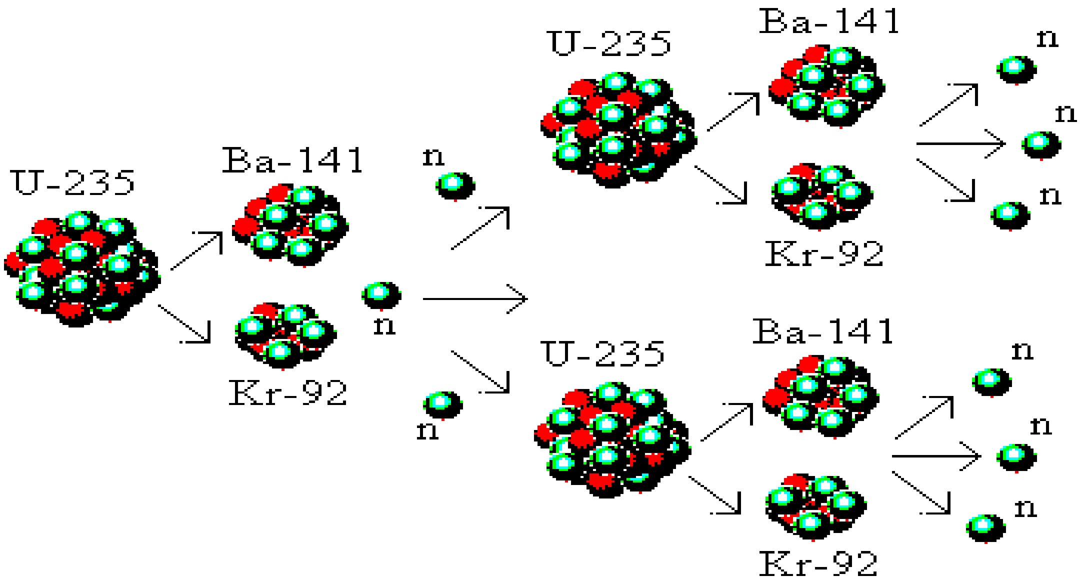
The Importance of Fission Reactors

- Greatest conversion of mass to energy with our present technology
- With Fission Reactors we can generate large heat gradients and use it as a means of propulsion or as a means of generating electricity



Limitations of Standard Fission Reactors

- Solid core fission reactors are usually limited to the amount and the intensity of heat that they can generate due to structural limitations
- High percentage of nuclear waste products
- Low Burnup Capability
- Difficulty in Long Term Maintenance and complex control parts
- To much dependance on the human factor

Elimination of Waste Nuclear Fuel

- One of the biger challenges of nuclear sector is the elimination of waste nuclear fuel
- Currently two major methods exist:

1) Using PUREX and Nitric acid to remove useful fuel from waste products.

2) Actinide Transmutation through Neutron Acceleration with Linac or Cyclotron

All of these methods are comercially expensive and require constant up time.

Advantages of Gas Core Reactors

- Ability to produce high temperatures as compared to solid core or liquid core reactors
- High burn up capability
- Easier control capability and less movable parts
- Ability to Limit Actinide Inventory either by burning actinides as they are produced or by limiting the production of those actinides.

Limitation of Actinide Production

- This is the most important aspect as the limitation of actinide production in nuclear reactors goes a long way in limiting waste nuclear fuel.
- Currently %17 of the cost of nuclear energy production goes to removing waste fuel and additive actinides from the inventory of the reactor
- Actinide production and depletion is based on neutron energy spectrum and this is based on the physical properties of the nuclear core.

Gaseous Core Reactors

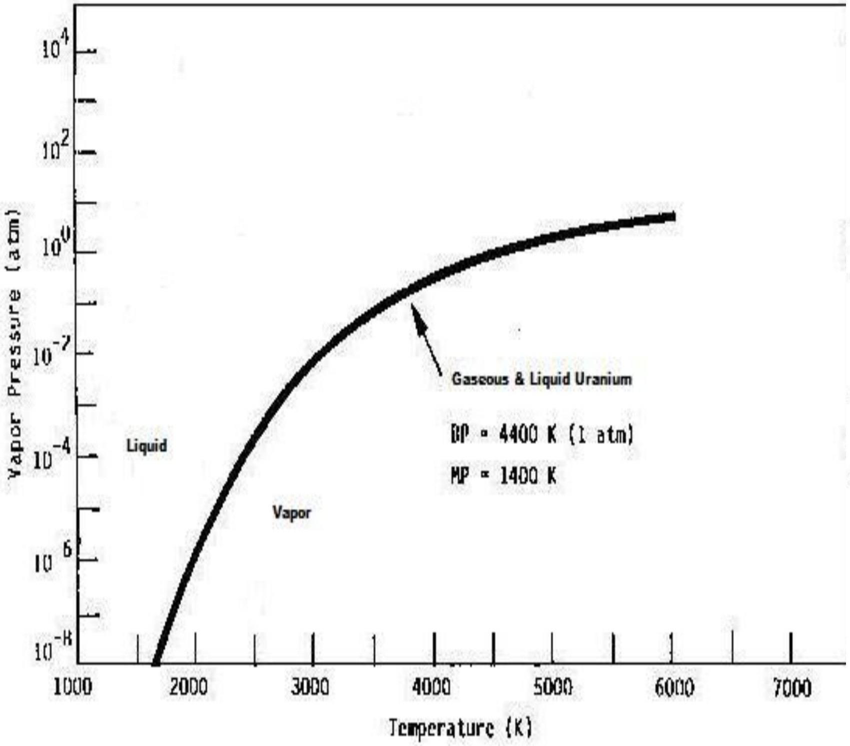
- Gaseous core reactors are used as an answer to the problems outlined above.
- Uranium Tetrafluoride UF4 or Uranium Hexafluoride (UF6) are generally used as nuclear fuels in GCR.
- Berillyum Oxide (BeO) is used as a Moderator / Reflector in a GCR.

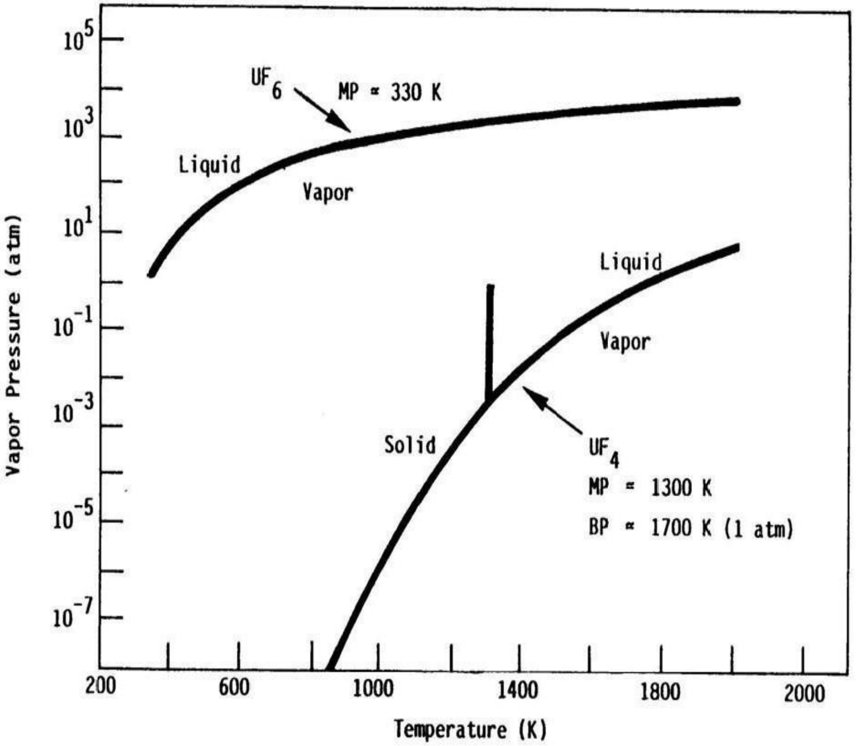
Selection of Nuclear Fuels

- Uranium Tetrafluoride is the better choice since it performs better than UF6 under high pressures.
- UF4 is more stable under terrestrial conditions.
- Material decomposition is less with UF4.
- However, UF6 is better used with nuclear propulsion applications in space.

Properties of UF4 and UF6

Saturation Curves of Gaseous Uranium



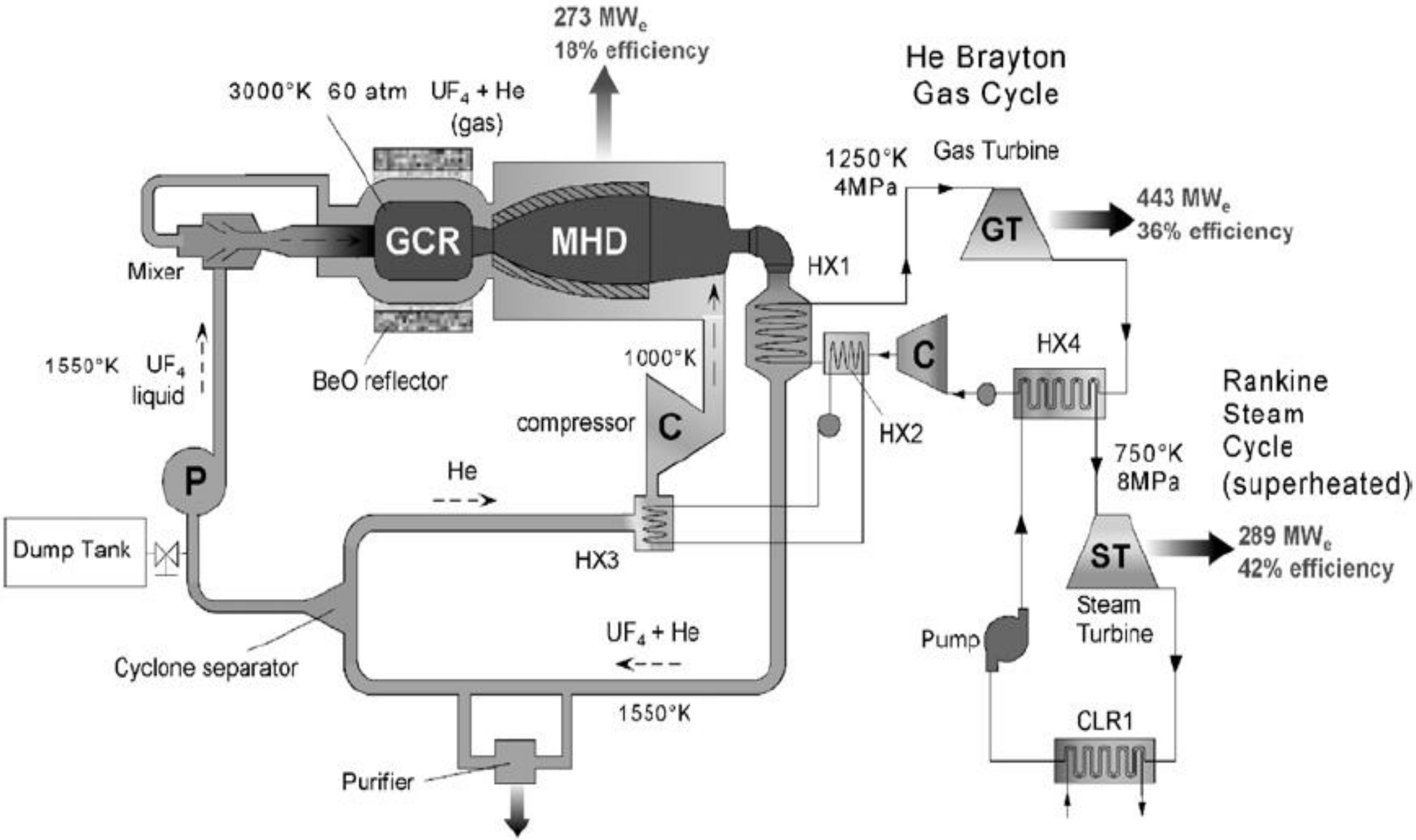


Selection of BeO as Moderator

- Traditional moderator reflector materials include water (H2O), Deuterium (D2O), and Graphite.
- BeO is chosen due to its ability to lead to a faster spectrum.
- Faster spectrum leads to higher fission cross section ratios which lead to higher removal rates.
- Thus actinide removal is increased by using BeO making it perfect choice for limiting nuclear waste fuel. Thus, GCR becomes technologically feasible and less costly to operate in the long run.

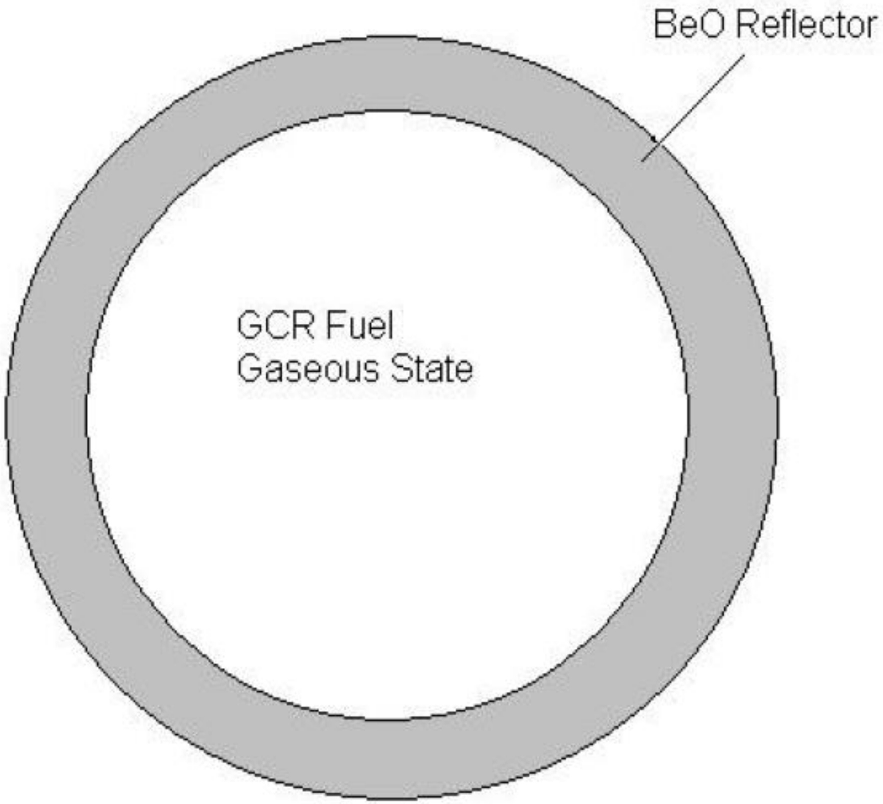
Sample GCR

Combined Cycle GCR with %69 Efficiency



Fuel Element in a GCR

- Unlike a solid core reactor, there are no fuel elements in a GCR.



Neutronics of a GCR

- The reactivity and the neutronics of a GCR is controlled by:

  - The pressure of the core

  - The geometry of the core

  - Size and the geometry of the reflector / moderator

  - The amount of fissonable fuel available for the reaction

Fuel Advantages of GCR

- The continuous recycling of fuel in G/VCR systems allows for continuous burning and transmutation of actinides without removing and reprocessing of the fuel.
- The only waste product at the backend of the gas core reactors' fuel cycle is fission fragments that are continuously separated from the fuel.
- GCR systems do not require spent fuel storage or reprocessing
- Even for comparable spectral characteristic, gas core reactors produce fissile plutonium two orders of magnitude less than Light Water Reactors (LWRs).
- The low fuel inventory (about two orders of magnitude lower than LWRs for the same power generation level) combined with continuous burning of actinides, significantly reduces the need for emergency planning and the vulnerability to external threats

Advantages of GCR

- Low Fuel Inventory
- Low Fuel Heat Content
- Online Separation of Fission Fragments
- Reactor Outlet Temperature is not Constrained by Solid Fuel-Cladding Temperature Limitations
- Fully integrated fuel cycle with exceptional sustainability and safety characteristics
- No Fuel Burn-up Limit for Gas Core Reactors due to Continuous Recycling of the fuel
- Less Vulnerability to External Threats

Keff Values for GCR

» Table 4-1. Keff values for 10 cm reflected core

Fuel *	Enrichment	MFP (cm)	U *	U235 *	U238 *	F *	P (bar)	K eff	%Rel Error
1.42E-04	10.00%	1210.5	2.84E-05	2.84E-06	2.56E-05	1.14E-04	9.42	0.2133	1.41E-03
1.42E-03	10.00%	131.2	2.84E-04	2.84E-05	2.56E-04	1.14E-03	94.16	0.4558	2.06E-03
1.42E-02	10.00%	12.899	2.84E-03	2.84E-04	2.56E-03	1.14E-02	941.6	0.7974	1.74E-03
3.40E-02	10.00%	5.351	6.80E-03	6.80E-04	6.12E-03	2.72E-02	2253.9	0.9048	1.21E-03
4.40E-02	10.00%	4.129	8.80E-03	8.80E-04	7.92E-03	3.52E-02	2916.81	0.9227	1.55E-03
8.40E-02	10.00%	2.159	1.68E-02	1.68E-03	1.51E-02	6.72E-02	5568.45	0.9553	1.25E-03
1.40E-01	10.00%	1.295	2.80E-02	2.80E-03	2.52E-02	1.12E-01	9280.74	0.9647	1.03E-03
2.80E-01	10.00%	0.647	5.60E-02	5.60E-03	5.04E-02	2.24E-01	1.86E+04	0.9668	9.90E-04
5.60E-01	10.00%	0.324	1.12E-01	1.12E-02	1.01E-01	4.48E-01	3.71E+04	0.9668	9.90E-04
1.20E+00	10.00%	0.151	2.40E-01	2.40E-02	2.16E-01	9.60E-01	7.95E+04	0.9668	9.90E-04
1.20E+01	10.00%	0.015	2.40E+00	2.40E-01	2.16E+00	9.60E+00	7.95E+05	0.9668	9.90E-04
1.20E+04	10.00%	1.51E-05	2.40E+03	2.40E+02	2.16E+03	9.60E+03	7.95E+08	0.9668	9.90E-04
1.42E-02	15.00%	12.923	2.84E-03	4.26E-04	2.41E-03	1.14E-02	941.6	0.9436	1.20E-03
1.93E-02	15.00%	9.48	3.86E-03	5.79E-04	3.28E-03	1.54E-02	1279.42	0.9996	1.26E-03
2.00E-02	15.00%	9.145	4.00E-03	6.00E-04	3.40E-03	1.60E-02	1325.82	1.0084	1.23E-03
2.50E-02	15.00%	7.304	5.00E-03	7.50E-04	4.25E-03	2.00E-02	1657.28	1.0422	1.36E-03
3.40E-02	15.00%	5.36	6.80E-03	1.02E-03	5.78E-03	2.72E-02	2253.9	1.084	1.48E-03

- * Units of (atoms/barn*cm)
- Volume (m^3) 21.21
- BeO Thickness(cm) 10

Keff Values for GCR

» Table 4-3. Keff values for 30 cm reflected core

Fuel *	Enrichment %Rel Error	Core Radius (m) MFP (cm)	U *	U235 *	U238 *	F *	P (bar)	K eff
1.42E-04	10.00% 2.15E-03	3 1041	2.84E-05	2.84E-06	2.56E-05	1.14E-04	9.42	0.80734
1.42E-03	10.00% 2.17E-03	3 126.17	2.84E-04	2.84E-05	2.56E-04	1.14E-03	94.16	1.13973
5.00E-04	10.00% 2.41E-03	3 333.45	1.00E-04	1.00E-05	9.00E-05	4.00E-04	33.15	1.07378
2.50E-04	10.00% 2.27E-03	3 623.16	5.00E-05	5.00E-06	4.50E-05	2.00E-04	16.57	0.96226
4.00E-04	10.00% 2.36E-03	3 432.77	8.00E-05	8.00E-06	7.20E-05	3.20E-04	26.52	1.03446
3.25E-04	10.00% 2.52E-03	3 492.21	6.50E-05	6.50E-06	5.85E-05	2.60E-04	21.54	1.01311
3.13E-04	10.00% 2.32E-03	3 509.8	6.25E-05	6.25E-06	5.63E-05	2.50E-04	20.72	1.0078
3.00E-04	10.00% 2.19E-03	3 529.18	6.00E-05	6.00E-06	5.40E-05	2.40E-04	19.89	1.00045
1.80E-03	7.50% 3.16E-03	3 101.54	3.60E-04	2.70E-05	3.33E-04	1.44E-03	119.32	1.14515
2.00E-03	7.50% 2.60E-03	4 91	4.00E-04	3.00E-05	3.70E-04	1.60E-03	132.58	1.11223
2.17E-03	7.50% 4.72E-03	4 100.64	4.34E-04	3.26E-05	4.01E-04	1.74E-03	143.85	1.07764
2.17E-03	6.00% 4.72E-03	4 69.22	4.34E-04	2.60E-05	4.08E-04	1.74E-03	143.85	1.07764
1.80E-03	5.00% 3.63E-03	4 101.72	3.60E-04	1.80E-05	3.42E-04	1.44E-03	119.32	1.04945
2.40E-03	5.00% 2.99E-03	4 76.64	4.80E-04	2.40E-05	4.56E-04	1.92E-03	159.1	1.04255
2.66E-03	5.00% 3.51E-03	4 69.22	5.32E-04	2.66E-05	5.05E-04	2.13E-03	176.33	1.03093

- * Units of (atoms/barn*cm)

Keff Values for GCR

» Table 4-4. Keff values for 40 cm reflected core

Fuel *	Enrichment	MFP (cm)	U *	U235 *	U238 *	F *	P (bar)	K eff	%Rel Error
1.42E-04	10.00%	1018.2	2.84E-05	2.84E-06	2.56E-05	1.14E-04	9.42	0.93312	2.02E-03
2.80E-04	10.00%	556.01	5.60E-05	5.60E-06	5.04E-05	2.24E-04	18.56	1.09133	2.04E-03
2.00E-04	10.00%	749.61	4.00E-05	4.00E-06	3.60E-05	1.60E-04	13.26	1.02232	2.45E-03
1.80E-04	10.00%	824.42	3.60E-05	3.60E-06	3.24E-05	1.44E-04	11.93	0.99529	1.88E-03
1.90E-04	10.00%	786.08	3.80E-05	3.80E-06	3.42E-05	1.52E-04	12.6	1.00431	2.36E-03

- * Units of (atoms/barn*cm)
- Volume (m^3) 21.21
- BeO Thickness(cm) 40

» Table 4-5. Keff values for 50 cm reflected core.

Fuel *	Enrichment	MFP (cm)	U *	U235 *	U238 *	F *	P (bar)	K eff	%Rel Error
1.42E-04	10.00%	1010.8	2.84E-05	2.84E-06	2.56E-05	1.14E-04	9.42	0.986	2.12E-03
1.45E-04	10.00%	992.09	2.90E-05	2.90E-06	2.61E-05	1.16E-04	9.61	0.9899	2.57E-03
1.50E-04	10.00%	962.65	3.00E-05	3.00E-06	2.70E-05	1.20E-04	9.94	0.9986	2.06E-03
1.52E-04	10.00%	908.47	3.04E-05	3.04E-06	2.74E-05	1.22E-04	10.08	1.0003	2.39E-03
1.55E-04	10.00%	934.71	3.10E-05	3.10E-06	2.79E-05	1.24E-04	10.28	1.0116	2.50E-03
1.60E-04	10.00%	951.1	3.20E-05	3.20E-06	2.88E-05	1.28E-04	10.61	1.018	1.96E-03
3.60E-04	5.00%	460.45	7.20E-05	3.60E-06	6.84E-05	2.88E-04	23.86	1.0207	2.06E-03

- * Units of (atoms/barn*cm)
- Volume (m^3) 21.21
- BeO Thickness(cm) 50

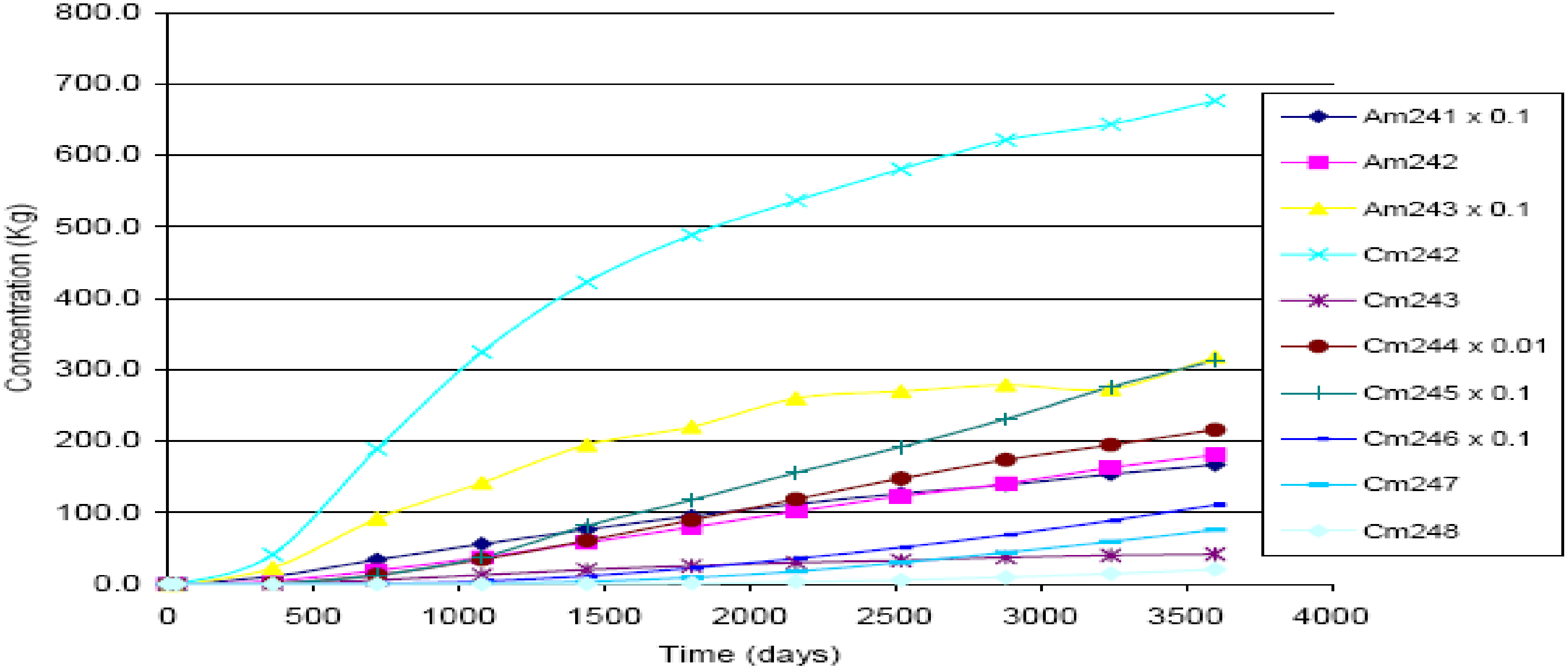
Enrichment Optimization

- GCR allows for online fuel feeding and this enables the reactor operator to accurately control criticality and actinide production.
- The feed fuel can change by the flow rate as well as by the fuel enrichment.
- Higher flow rate will induce a positive reactivity insertion since fissile material will be replaced after fission.
- Using highly enriched fuel, lowers the amount of fuel needed for injection, but rises the overall core enrichment to non permissible levels for licensing.

Effect of Pressure on GCR

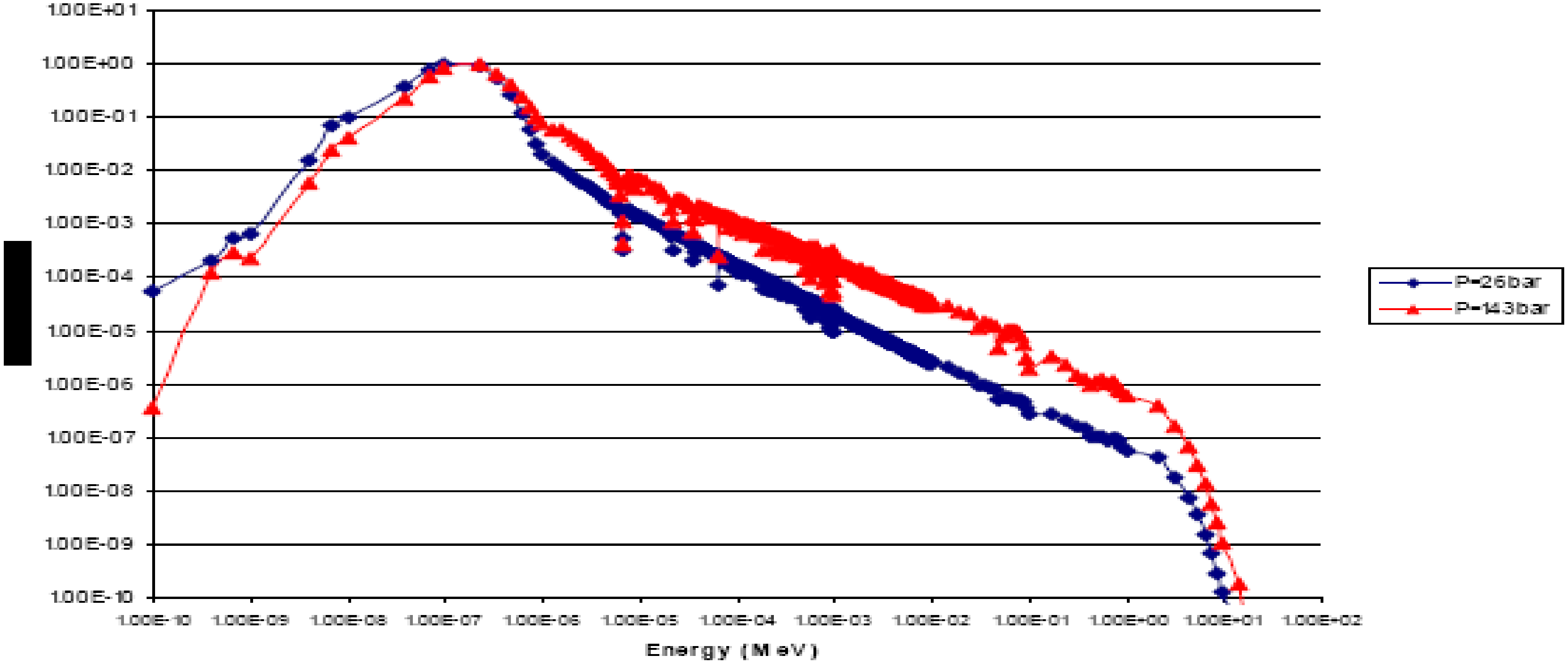
- In low pressure GCR reactors, transmutation of isotopes into heavier actinides.
- More actinides are fissioned in high pressure cores, thus in low pressure cores less actinides are produced. This is an advantage in propulsion.
- In the high and intermediate-pressure cores Pu239, Pu240, and Pu241 approach the equilibrium concentration
- In low-pressure cores Pu241 and Am243 are approaching their equilibrium point

Actinide Production in GCR



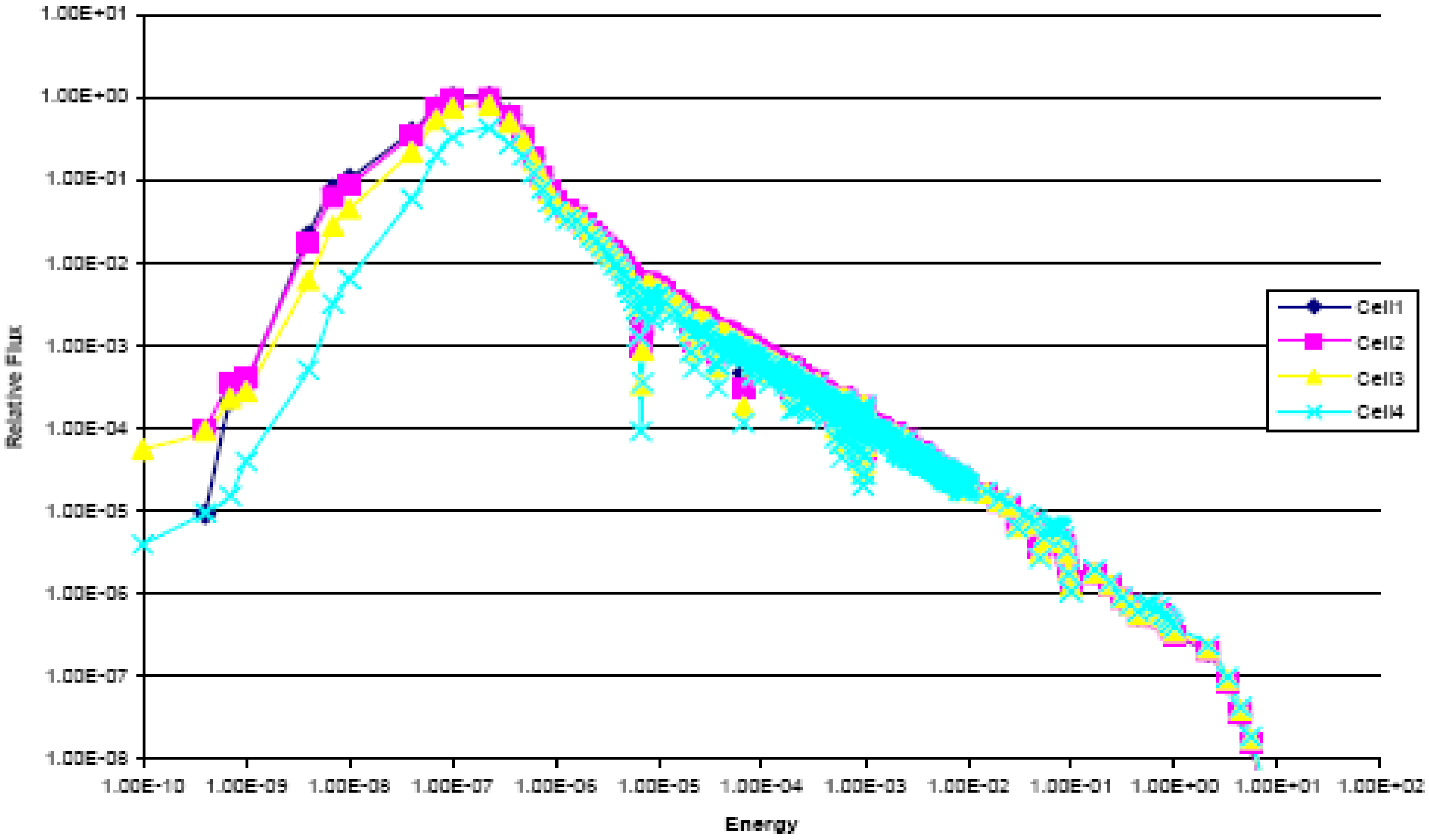
Mass abundance of minor actinides present in the high-pressure (Core 1) core as a function of time.

Relative Flux Plots in GCR



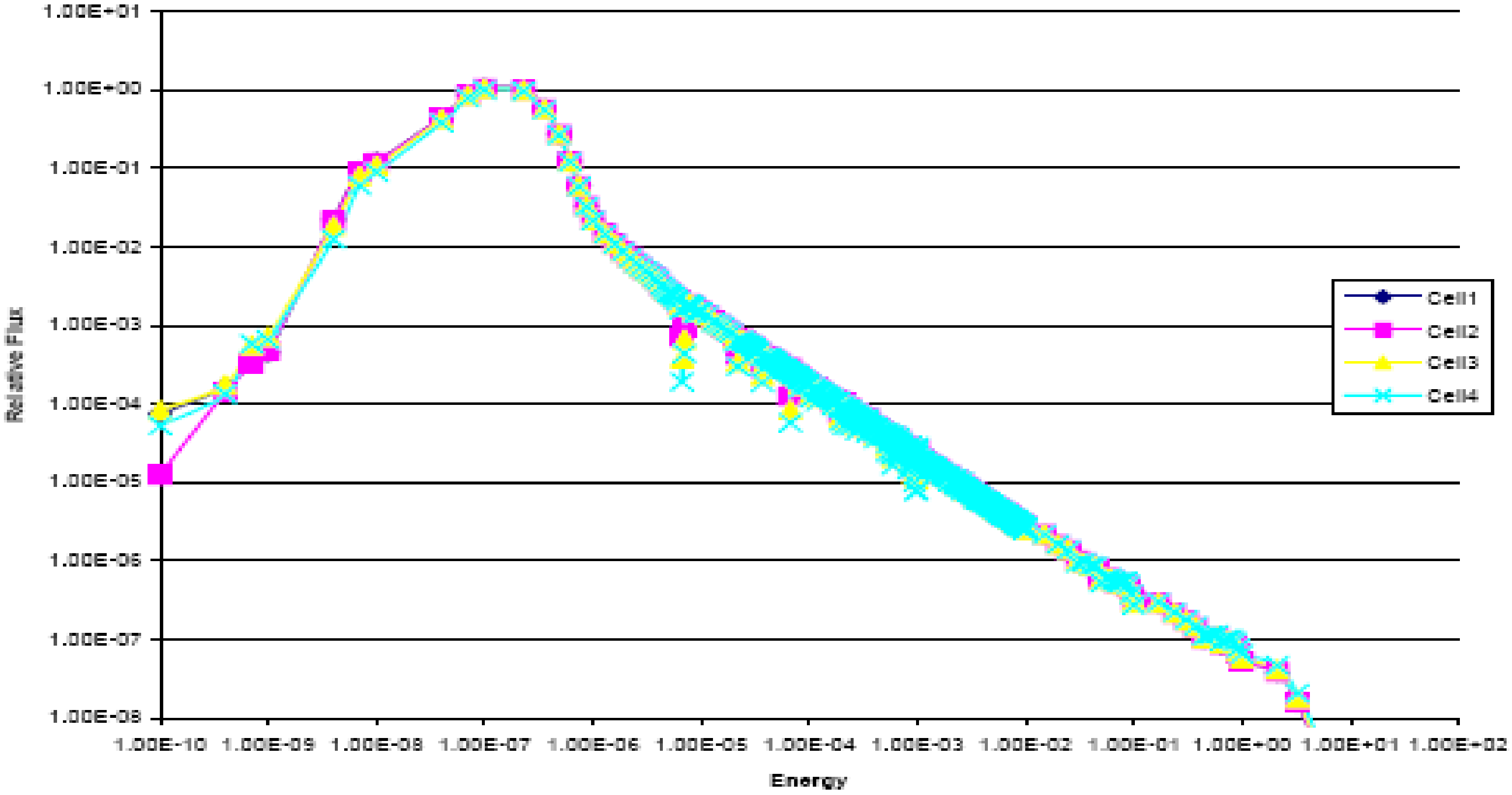
Relative flux plots for the low and high-pressure cores. Fluxes were normalized by maintaining the maximum value of 1.0.

Spatial Flux High Pressure GCR



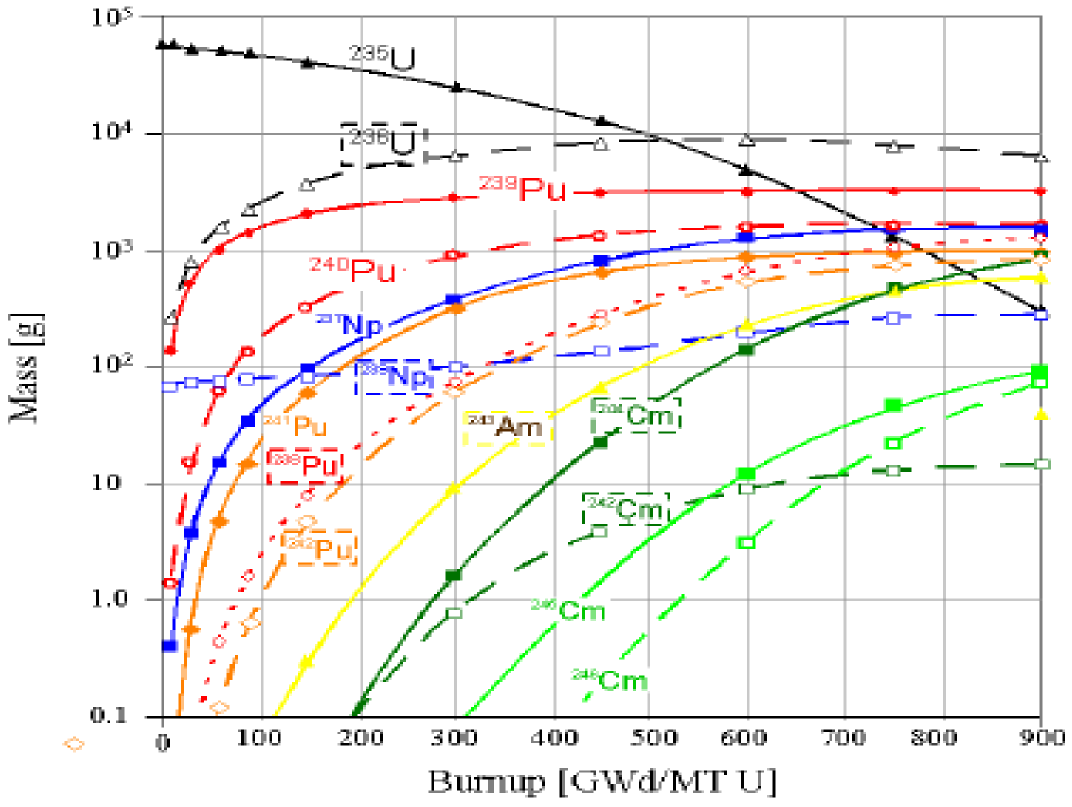
Spatial flux plots for the high-pressure core, split into different volumes.

Spatial Flux Low Pressure GCR



Spatial flux plots for the low-pressure core, split into different

Actinide Burnup in GCR



Masses of actinide radioisotopes in fuel versus burnup for 10% enriched fuel in a gaseous core reactor with UF_4 (10% mole fraction)-He(90% mole fraction) fuel.

Actinide Waste Production in GCR

- A thermal spectrum in GCR produces half the waste as compared to faster spectrum since fast spectrum causes more production of actinides.
- As compared to LWR, GCR produces 2 orders of less magnitude of waste.
- GCR design limits actinide production by a factor of 7.03
- Weapons grade plutonium is produced in less quantities in GCR