4. PROPOSED TRANSMUTATION CONCEPTS

Although many different types of nuclear particles are available to transmute waste isotopes, neutron reactions are most effective to transmute them from the energy balance point of view. Therefore, there have been many studies of transmutation in neutron fields generated by a variety of devices,including thermal reactors, fast reactors,accelerators ,and fusion reactors.

4.1 Thermal Reactors

Thermal neutrons have high reaction cross-sections with the actinide isotopes than fast neutrons. In thermal reactors,transmutation by neutron capture is the dominant process for the long lived actinide isotopes, such as Np-237,Am-241 and Am-243. These isotopes are incinerated in an indirect way by formation of a heavier decay product with very high fission cross–section, such as Pu-238,Pu-239,Am-242m ,Cm-243 and Cm-245.

Introduction of minor actinides with high neutron capture cross-section into reactor core will decease the reactivity and require higher fissile enrichment. During the life of the reactor core , the reactivity may increase with the formation of fissile nuclides. This means that most of the minor actinides play a role as burnable poison. The presence of non-negligeable rare earths co–extracted with Am and Cm in the separation process reduces the reactivity. Separation of rare earths from Am and Cm should be needed from the neutron economy point of view.

Two types of minor actinide recycling modes can be considered: homogeneous and heterogeneous recycling. The latter could transmute roughly the same amount of minor actinides as the homogeneous recycling from reactor physics point of view, and minimize the number of fuel pin and assembly containing minor actinides. However, the thermal characteristics of fuel assemblies loaded with high concentration of minor actinides require the use of specially designed fuel pins and assemblies. In this case, strong neutron self-shielding may lead to significant reduction of transmutation.

The long-lived fission products of interest, such as Tc-99 and I-129, can be transmuted to stable isotopes by neutron capture reaction. The thermal neutron cross-sections of these nuclides are bigger than the fast ones, but are not big enough to transmute them effectively. This leads to need of high-flux thermal reactor for effective transmutation of Tc-99 and 1-129.

(1) PWR based transmutation concept proposed by the CEA [151

Two types of transmutation concepts based on PWR are proposed by the CEA. They are MOX felled PWRS with homogeneous and heterogeneous loading of minor actinides. In the latter, volume ratio of fuels with transmutation materials to all fuels is 30%. Nuclides to be transmuted in the reactors are Np-237, Am-241, Am-242 and Am-243.

The principal design considerations are paid for followings :

- highest transmutation rate and radiotoxicity reduction,

- Use of well known current reactor technology with little development ,and
- Same safety and performance levels as current reactors.

The reactor design and physics parameters are given in Table 4.1 and 4.2 for homogeneous loading, and Table 4.3 and 4.4 for heterogeneous loading, respectively.

(2) **PWR based transmutation concept proposed by JAERI [16]**

JAERI proposes a concept to transmute Np-237,which is based on the existing PWR with much higher enriched uranium (8.2 w/o) fuel. The transmutation target nuclide Np-237 is homogeneously mixed with uranium fuel.

The principal design considerations are paid for followings:

- The transmutation target is limited only to Np-237 which is the most important nuclide with long half-life and high radiotoxicity generated in uranium-oxide fuel, and
- The Np transmutation should be made by the existing PWR without any significant modification.

The reactor design and physics parameters are given in Table 4.4 and 4.5.

(3) **PBR based burner concept proposed by BNL [6]**

A high flux particle bed reactor concept (PBR) for rapid transmutation of actinides and long-lived fission products is proposed by BNL. This concept is based on the PBR nuclear rocket system currently under development by the Air Force Space Nuclear

Thermal Propulsion (SNTP) Program and draws on much of the technology that has been developed by the SNTP program.

The basic building of the PBR are the fuel particles which are similar to the proven HTGR BISO. Two types of particles would be employed: one containing plutonium for the “driver” fuel elements,and one containing minor actinides for the “target”. The fuel elements consist of a bed made up of the appropriate particles, and constrained between two porous, co-axial cylindrical “frits’’(see Fig.4.1).

Several potential core designs were evaluated, falling into two general categories: heavy water moderated,and solid moderator systems. The major constraints for the core design are the desire to minimize the Pu/minor-actinides inventory in the reactor, and the overall reactor size; therefore the total number of elements, the particle fissile and minor actinide loading ,and the radial reflector are minimized.

The selected characteristics of heavy water moderated PBR burner concept are given in Table 4.7.

4.2 Fast Reactors

Fast neutrons will fission all of the actinides, but the reaction cross-sections are much smaller than for thermal neutrons . This effect will be compensated by the neutron flux in the fast reactors, which is 100 to 1000 times higher than in the thermal reactors. The build-up of higher actinides by neutron capture is much smaller with fast neutrons than thermal neutrons.

The fission to capture ratio of minor actinides increases with the mean neutron energy. If a fast reactor concept with very hard neutron spectrum is established,the minor actinides are additional fissionable resources instead of waste materials as in the thermal reactor. However,loading amount of minor actinides may be seriously limited, because of their unfavorable characteristics to safety physics parameters, such as coolant-void coefficient, Doppler coefficient, effective delayed neutron fraction and prompt neutron life time.

There are two types of minor actinide recycling modes also for fast reactors: homogeneous and heterogeneous recycling. The feature is similar to that of the thermal reactors, except lower neutron self-shielding in the fast reactors.

The long-lived fission products such as Tc-99 and 1-129 can also be transmuted in the fast reactors, using neutrons with appropriate energy.

(1) LMFBR based transmutation concept proposed by CEA [15]

Two types of 1450 MWe LMFBR based transmutation concepts are proposed by CEA: one with homogeneous loading of minor actinides, and one with heterogeneous loading of separate Np and Am targets. The nuclides to be transmuted are Np-237 and Am-241 for the first concept,and Np-237 and Am isotopes for the second.

The Principal design considerations are paid for followings:

- Highest transmutation rate and radiotoxicity reduction,
- Use of well known current LMFBR technology with little development ,and

- Same safety and performance levels as conventional LMFBRs.

The principal design and physics parameters are listed in Table 4.8 and 4.9 for homogeneous loading of minor actinides, and Table 4.10 and 4.11 for heterogeneous loading, respectively.

(2) LMFBR based transmutation concept proposed by PNC [17]

PNC has investigated various kinds of LMFBR based transmutation concepts. The present proposal is one of these concepts with homogeneous loading of minor actinides. The nuclides to be transmuted are Np-237,Am-241 and Am-243.

The design principle is to develop a LMFBR core concept loaded with minor actinides which brings no serious issue to core performances in consideration of fuel cycle technology.

The principal design and physics parameters are given in Table 4.12 and 4.13.

(3) ALMR based transmutation concept proposed by GE and ANL [181

The ALMR plant utilizes six reactor modules. The thermal rating of each module is 840 MWt. Conventional ALMR core designs utilize a radially heterogeneous configuration; the inclusion of internal blanket zones allows fuel cycle operation in a 'breakeven' mode where the fissile material (transuranics, primarily Pu-239 and Pu-241) is consumed and destroyed at roughly equal rates. The 840 MWt breakeven core has a total of 192 fueled assemblies (108 drivers and 84 blankets). The driver fuel form is metal fuel alloy (U-TRU-10%Zr). Minor actinides are included in the source LWR spent fuel (10.7% MA/TRU).

Two burner configurations are presented. A primary goal in developing the burner core configurations is to maintain compatibility with the breakeven reactor design; design changes to the conventional reactor are to be minimized. Net consumption of transuranics in the burner designs is achieved by removing fertile material from the breakeven configuration.

The Core layouts of the burner designs are shown in Fig.4.2 and the neutronics parameters are given in Table 4.14.

(4) LMFBR based transmutation concept proposed by CRIEPI [19]

CRIEPI proposes a 1000 MWe LMFBR based transmutation concept of minor actinides. The fuel is metallic alloy type with minor actinides (Np,Am,Cm) of 5 w/o. The design principle is to develop 600-1000 MWe commercial FBR with U-Pu-MA-Zr fuel, which is produced from dry process with pyrochemical partitioning. The proposed 1000 MWe FBR is expected to transmute minor actinides generated from 6 plants of 1000 MWe LWR.

The principal design and physics parameters are listed in Table 4.15 and 4.16.

(5) LMFBR based transmutation concept proposed by Toshiba Corporation [10]

The transmutation concept based on 600 MWe LMFBR with flat core is proposed by Toshiba Corporation. The fuel is metallic alloy type of 3 w/o minor actinides. In the core, the minor actinides mixed fuels are homogeneously arranged, and in the blanket,the fuels are heterogeneously arranged. This arrangement is effective to reduce Na void reactivity effect.

The principal design considerations are paid for followings:

- Homogeneous TRU-recycling called "actinide recycling" without separation of minor actinides from Pu in LWR and FBR spent fuel
- Safety consideration,and
- Excess neutron utilization for balancing breeding capacity, storaged minor actinides transmutation and long-lived fission products incineration.

The principal design and physics parameters are listed in Table 4.17 and 4.18.

(6) Fast burner reactors proposed by JAERI

Three types of fast burner reactors with nitride fuel for TRU transmutation are proposed by JAERI.

The first is a helium-cooled fast reactor with coated particle fuel (P-ABR:see Fig.4.3) and the second is a lead-cooled modular type fast reactor with pin type fuel (L-ABR) [20]. The both reactors have the core with very hard neutron energy spectrum, in which much of the minor actinide transmutation occurs by fission reaction, not by neutron capture.

The principal design considerations for these two reactors are paid for followings:

- Minor actinides burner reactor specially designed for efficient fissioning of minor actinides,
- Primary fuel material of minor actinides,and enriched uranium or plutonium,

- A fast reactor with very hard neutron spectrum and high neutron flux .

Use of enriched uranium instead of plutonium increases effective delayed neutron fraction of the reactor.

The principal design and physics parameters are given in Table 4.19 and 4.20 for the P-ABR,and Table 4.21 and 4.22 for the L-ABR .

The third concept is a lead-cooled fast reactor with nitride fuel of Th-Pu-10w/oMA [16]. In this reactor, minor actinides can be incinerated simultaneously by burning excess plutonium in a closed fast reactor fuel cycle.

The principal design and physics parameters are given in Table 4.23 and 4.24.

4.3 Accelerator Driven Transmutation Systems

These systems use spallation reaction to produce,high energy particles (e.g.1 GeV protons), a large amount of neutrons that in a second moment are introduced in a multiplying medium.

Spallation, a reaction in which a high-energy primary particle interacts with a target nucleus, is thought to take place in two stages. In the first stage (the intranuclear cascade phase), the incident proton creates a high energy particle cascade inside the nucleus. During the intranuclear cascade,high-energy (>20MeV) "secondary" particles and low-energy(<20 MeV) "cascade" particles escape the nucleus; at the end the nucleus is typically left in a highly excited state. In the second stage (the evaporation phase) ,the excited nucleus relaxes, primarily by emitting low-energy (<20 MeV) “ evaporation” neutrons. It is defined low-energy "spallation" neutron the sum of the low–energy cascade and evaporation neutrons.

For thick targets, the high-energy secondary particles (plus their progeny) can undergo further spallation reactions. For some target materials, low-energy spallation neutrons can enhance neutron production through low-energy (n,xn) reactions. The total low-energy neutron production from a target is the sum of low-energy spallation neutron production plus the net production from low-energy (n,xn) reactions.

Using a calculation code as a model which is approximately correct, about 90% of the neutrons coming from a cylindrical target bombarded by 1 GeV protons, have less than 20 MeV with an average energy of only 4.8 MeV; remainder, 10% of the total, have energies below 400 MeV with an average of 105 MeV.

(1) Accelerator-driven system proposed by JAERI [211

Three types of accelerator-driven system are proposed by JAERI , each of which uses a large linear proton accelerator to drive and control its specific subcritical core containing minor actinides and other long–lived nuclides.

The first concept called “Alloy fueled core system” is shown in Fig.4.4. In this concept, the accelerator injects 1.5 GeV proton beam of 39 mA into the tungsten target located at the center of the sodium–cooled fast reactor core, which is loaded with alloy fuel containing minor actinides. The principal design parameters are given in Table 4.25.

The second is called “Molten salt core” concept. The accelerator injects 1.5 GeV proton beam of 25 mA in the core with hard neutron spectrum, which is loaded with chloride molten salt fuel containing minor actinides. This concept would be a continuous processing system,in which the reaction products are removed from the fuel on line. The principal design parameters are listed in Table 4.26.

The third is called “Eutectic target-core” concept. The accelerator injects 1.5 GeV proton beam of 20 mA into the eutectic alloy (Np-Pu-Co-Ce-Tc) target-core with graphite blanket, which is cooled by molten fluoride salt. ‘ This system intends simultaneous transmutation of NP-237 and Tc-99. The design parameters are given in Table 4.27.

(2) **Accelerator-driven systems proposed by BNL**

Three types of transmutation concepts are proposed by BNL: one with a large linear proton accelerator [5], and two with a small power accelerator [221.

The first is the PHOENIX concept using a large linear proton accelerator which can produce a 104 mA beam of 1.6 GeV protons. A modular concept is developed for the PHOENIX subcritical lattice. Each module resembles the core of the Fast Flux Test Facility (FF TF), with the minor actinides,formed into oxide fuel rods replacing the uranium and plutonium in the FFTF fuel. The concept is shown in Fig.4.5.

The second is the “MOX fueled core” concept,in which a multi segmented cyclotron injects 2.5–5 mA beam of 1.5 GeV protons into the lead target located at the center of MOX fueled fast reactor core which operates at slightly subcritical condition. Minor actinides are incinerated by fast neutron fission reaction, and long-lived fission products such as Tc-99 and 1-129 are transmuted in yttrium-hydride moderator surrounding the core. The design parameters are given in Table 4.28.

The third is the “Particle fueled core” concepts. This uses a multi–segmented cyclotron to inject 4-8 mA beam of 1.5 GeV protons into the lead spallation target located at the center of the core with fast neutron spectrum, which is loaded with nitride coated particle fuel. The core operates at slightly subcritical condition. The long-lived fission products can also be transmuted as in the second concept. The principal design parameters are given in Table 4.29.

(3) **Accelerator-driven systems proposed by CEA [151**

Two types of transmutation systems are under investigation at CEA;one with an essential potential for Pu (or TRU) burnout as well as Tc–99 incineration, and one with maximum Pu (or TRU) mass burnout. The first is called “Breeder-Burner Subcritical System (BBR)” consisting of an accelerator with 1.5 GeV proton beam of 270 mA and a thorium–bearing molten salt core with fast neutron spectrum. The second is now under preparation and its description is not given in the reference [15].

The principal design considerations for the first concept are as follows:

use of thorium cycle for low fuel waste and inventory toxicity,

- high fuel burnup to minimize fuel waste toxicity,
- to increase neutron surplus for Tc-99 incineration,
- fuel breeding to maintain a reactivity during a long fuel life and to avoid an unacceptable margin of reactivity.

The principal design parameters are given in Table 4.30.

(4) **Los Alamos ATW concepts**

Contrary to the above mentioned accelerator-driven transmutation concepts in which the transmutation occurs mainly by fast neutron, the ATW concepts uses the thermal neutrons to transmute minor actinides and long-lived fission products.

In the ATW concept,the linear proton accelerator operates at 1.6 GeV at a continuous-wave current of 250 mA. The primary proton beam is then split into four beams, each having a current of 62.5 mA. Each of the four beams directed into four separated target/blanket modules. The high-energy proton beam strikes a centrally located spallation target to produce an intense source of neutrons.

The base-case design is comprised of heavy-water-cooled tungsten rods, and its blanket region and balance-of-plant design is based on existing heavy-water reactor technology employed in the CANDU reactor system [23]. Another option is the use of a flowing lead target. The use of such a target adds complexity to the design but has the potential to increase the neutron utilization efficiency. The layout for the target/blanket of the

ATW is shown in Fig.4.5, and the key design parameters are compared with those of the CANDU in Table 4.31.

An advanced ATW concept is also proposed,which has a target-blanket with slowly circulating higher actinide liquid fuel and heat removal by a larger, thorium-bearing molten salt loop [24]. This concept is shown in Fig.4.6.

(5) Other proposed systems

There are some ATW type concepts proposed by the ENEA [81, the Royal Institute of Technology [11] and the ITEP **[131.** In the ENEA concept, a subcritical. core with lead spallation target is driven by a proton accelerator with the beam of 1.6 GeV and 200 mA. The core is loaded with minor actinides and long-lived fission products. In the concept of the Royal Institute of Technology, a subcritical core with lithium fluoride salt (liquid Pb, solid Th) spallation target is driven by a proton (deutron) linear accelerator or a cyclotron with the beam of 1 GeV and 5-100 mA. The core is cooled by helium and is loaded with minor actinide molten salt fuel or graphite pebble bed particle fuel.

'l'he design parameters of the concepts proposed by the three organizations mentioned above are given in Table 4.32, 4.33 and 4.34, respectively.

Table 4.1 Principal Design Parameters of PWR Based Transmutation Concept Proposed by CEA - Homogeneous Loading of Minor Actinides - [15]

Items	
Thermal power (MWt)	4250
Electric power (MWe)	1450
Equivalent core diameter (cm)	376
Equivalent core height (cm)	420
Averaged core composition (v/o)	
fuel/clad+structure/coolant	23.2/7.45/69.35
Type of fuel	oxide
Core averaged fresh fuel composition (w/o)	
U/Pu/Np, Am and Cm	91/8/ 1
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	1.8/58.0/22.5/12. 0/5.7
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	55.7/27.8/0.07/16. 4/0/0

Table 4.2 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.1

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm')	90	
maximum in core		
- Linear heat rate: average (w/cm)	180	
maximum		
- Neutron flux averaged in core (n/cm' see)	2.5×10^{14}	
- Neutron energy averaged in core (KeV)	-	-
- Fuel dwelling time in core (EFPD)[3)]	1220	
- Burnup reactivity swing (%δ k/k/365 EFPD)	4.1	
- Coolant void reactivity effect (%δ k/k)		
All reactor region voided	-0.24	
Core and axial blanket voided		
Only core voided	-	
- Doppler reactivity coefficient (Tdk/dt)	-2.6×10^{-2}	
- Effective delayed neutron fraction	-	-
- Control rod material		
- Central control rod worth (%δ k/k/kg)		-

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.3 Principal Design Parameters of PWR Based Transmutation Concept Proposed by CEA - Heterogeneous Loading of Np and Am Target - [15]

Items	
Thermal power (MWt)	2785
Electric power (MWe)	960
Equivalent core diameter (cm)	304
Equivalent core height (cm)	366
Averaged core composition (v/o)	
fuel/clad+structure/coolant	30.0/10.8/59.2
Type of fuel	oxide
Np target composition (w/o)	
U/Pu/^{237}Np	0/ 0/100
Am target composition (w/o)	
U/Pu/Am	0/ 0/100
Isotopic composition of Am (w/o)	
^{241}Am/^{242}Am/^{243}Am	72.4/ 0.2/27.4

Table 4.4 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.3

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm^3)	105	
maximum in core	245	
- Linear heat rate: average (w/cm)	178	
maximum	419	
- Neutron flux averaged in core (n/cm^2 see)	3.0×10^{14}	
- Neutron energy averaged in core (KeV)	-	–
- Fuel dwelling time in core (EFPD)[3)]	1120	–
- Burnup reactivity swing (% δ k/k/365 EFPD)	11	
- Coolant void reactivity effect (% δ k/k)		
All reactor region voided		–
Core and axial blanket voided		
Only core voided		
- Doppler reactivity coefficient (Tdk/dt)	-	–
- Effective delayed neutron fraction		–
- Control rod material	Ag, In, Cd	–
- Central control rod worth (% δ k/k/kg)		–

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.5 Principal Design Parameters of PWR Based Transmutation Concept Proposed by JAERI [16]

Items	
Thermal power (MWt)	3410
Electric power (MWe)	1146
Equivalent core diameter (cm)	337
Equivalent core height (cm)	366
Averaged core composition (v/o)	
fuel/clad+structure/coolant	31/11/58
Type of fuel	oxide
Core averaged fresh fuel composition (w/o)	
U/Pu/Np, Am and Cm	97/ 0/ 3
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	100/0/0/0/0/0

Table 4.6 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.5

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm')	91	
maximum in core		
- Linear heat rate: average (w/cm)	183	
maximum		
- Neutron flux averaged in core (n/cm* see)	1.2 x 10^{14}	
- Neutron energy averaged in core (KeV)	-	
- Fuel dwelling time in core (EFPD)[3)]	1500	–
- Burnup reactivity swing (% δ k/k/365 EFPD)		
- Coolant void reactivity effect (% δ k/k)		
All reactor region voided	-50	
Core and axial blanket voided		
Only core voided		
- Doppler reactivity coefficient (Tdk/dt)		–
- Effective delayed neutron fraction	–	–
- Control rod material	Ag-In-Cd	
- Central control rod worth (% δ k/k/kg)		

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.7 Selected Characteristics of Heavy Water Moderated PBR Burner

Moderator	D_2O	
Number of Pu Driver Elements	72	
Number of MA Target Elements	42	
Power Level with Driver Elements, ave. MW/l	1080	
K_{eff} (Clean)	1.040+0.005	
(Average Flux)$_{target}$/(Average Flux)$_{driver}$	0.86	
Target (Flux E>5.5 KeV/Total Flux)	0.39	
Initial Loadings, Kg.		
Plutonium	30.0	
Neptunium	7.3	
Americium	9.9	
Curium	0.3	
Total Minor Actinides	1’/.5	
Final Loadings after 20 days, ave. Φ(driver)=Φ (target), Kg.		
Plutonium	8.77[1]	9.86[2]
Neptunium	2.46	1.64
Americium		2.10
Curium		3.45
Total Minor Actinides	11.19	7.19

(1) Pu/LWR Spectrum in ORIGEN2
(2) FFTF Spectrum in ORIGEN2

Table 4.8 Principal Design Parameters of MOX-LMFBR Based Transmutation Concept Proposed by CEA - Homogeneous Loading of Minor Actinides - [15]

Items	
Thermal power (MWt)	3600
Electric power (MWe)	1450
Equivalent core diameter (cm)	390
Equivalent core height (cm)	140
Averaged core composition (v/o)	
fuel/clad+structure/coolant(Na)	31/25/38
Type of fuel	oxide
Core averaged fresh fuel composition (w/o)	
U/Pu/Np, Am and Cm	76/19/ 5
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	1.9/57.3/23.5/11. 8/5.5
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	50/50/0/0/0/0

Table 4.9 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.8

Items	BOL [1]	BOEC [2]
- Power density: average in core (w/cm')	215	
maximum in core	320	
- Linear heat rate: average (w/cm)	320	
maximum	480	
- Neutron flux averaged in core (n/cm^2 see)	3.0×10^{15}	
- Neutron energy averaged in core (KeV)	530	
- Fuel dwelling time in core (EFPD) [3]	1500	
- Burnup reactivity swing (%δ k/k/365 EFPD)	1.5	
- Coolant void reactivity effect (%δ k/k)		
All reactor region voided		-
Core and axial blanket voided		
Only core voided	2, 5	
- Doppler reactivity coefficient (Tdk/dt)	-6.03×10^{-3}	
- Effective delayed neutron fraction	0.00340	-
- Control rod material	B_4C	-
- Central control rod worth (%δ k/k/kg)		
- Prompt neutron life time (see)		

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.10 Principal Design Parameters of **MOX-LMFBR** Based Transmutation Concept Proposed by CEA - Heterogeneous Loading of **Np** and Am Targets - [15]

Items	
Thermal power (MWt)	3600
Electric power (MWe)	1450
Equivalent core diameter (cm)	390
Equivalent core height (cm)	140
Averaged core composition (v/o)	
fuel/clad+structure/coolant(Na)	31/25/38
Type of fuel	
Core averaged fresh fuel composition (w'/o)	
U/Pu/Np, Am and Cm	80/20/ O
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	1.9/57.3/23.5/11.8/ 5.5
Isotopic composition of Np and Am targets (w/o)	
^{237}Np and $^{241}Am/^{242}Am/^{243}Am$	100 63.4/0.2/36.4

Table 4.11 Generic and Safety-Related Physics **Parametes** of the Proposed Concept Given in Table 4.10

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm^3)	215	
maximum in core	320	
- Linear heat rate: average (w/cm)	320	
maximum	480	
- Neutron flux averaged in core (n/cm^2 see)	3.1 x 10^{15}	
- Neutron energy averaged in core (KeV)	505	
- Fuel dwelling time in core (EFPD)[3)]	1500	–
- Burnup reactivity swing (%δ k/k/365 EFPD)	2.6	
- Coolant void reactivity effect (%δ k/k)		
All reactor region voided	1.5	
Core and axial blanket voided		–
Only core voided	1.4	
- Doppler reactivity coefficient (Tdk/dt)	1.06 x 10^{-2}	
- Effective delayed neutron fraction	0.00365	
- Control rod material	B_4C	
- Central control rod worth (%8 k/k/kg)		
- Prompt neutron life time (see)		

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.12 Principal Design Parameters of MOX-LMFBR Based Transmutation Concept Proposed by PNC [17]

Items	
Thermal power (MWt)	2517
Electric power (MWe)	1000
Equivalent core diameter (cm)	368
Equivalent core height (cm)	100
Averaged core composition (v/o)	
fuel/clad+structure/coolant(Na)	41.6/20.9/37.5
Type of fuel	oxide
Core averaged fresh fuel composition (w/o)	
U/Pu/Np, Am and Cm	76.6/18.4/ 5.0
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	- /58/24/14/ 4
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm/^{245}Cm$	49.1/30.0/0.08/15. 5/0.05/ /5. 0/0. 26

Table 4.13 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.12

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm')		224
maximum in core		400
- Linear heat rate: average (w/cm)		231
maximum		413
- Neutron flux averaged in core (n/cm' see)		2.3×10^{15}
- Neutron energy averaged in core (KeV)		
- Fuel dwelling time in core (EFPD)[3)]		456
- Burnup reactivity swing (%δ k/k/365 EFPD)		1.52
- Coolant void reactivity effect (%δ k/k)		
All reactor region voided		
Core and axial blanket voided	2.78	
Only core voided		
- Doppler reactivity coefficient (Tdk/dt)	-7.1×10^{-3}	
- Effective delayed neutron fraction	0.0035	
- Control rod material	B_4C(^{10}B:33. 3%)	-
- Central control rod worth (%δ k/k)	1.46	
- Prompt neutron life time (see)	3.4×10^{-7}	

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.14 Neutronics Results of ALMR Actinide Recycling

	Breakeven	Small Burner	Large Burner
Core Height (in.)	42	26	18
Core Diameter(in)	141	141	175
# of Fuel Assy	108	192	354
# of Blanket Assy	84		
Conversion Ratio	1.06	0.72	0.59
Cycle Length (months)	23	12	12
Burnup Reactivity Swing (S)	0.57	8.99	8.45
Peak Linear Power	9.5	10.4	8.2
Sodium Void Worth	6.2	~2.50	< 0
TRU Enr. (wt% in U-TRU-Zr)	21	19/23	24/29
TRU Inventory (kg/core)	2681	2554	3890
TRU Consumption Rate			
kg/year /core	-28.2	83.2	121.0
% inventory/year	-1.1	3.3	3.1

Table 4.15 Principal Design Parameters of Metal-Fuel-LMFBR Based Transmutation Concept Proposed by CRIEPI [19]

Items	
Thermal power (MWt)	2632
Electric power (MWe)	1000
Equivalent core diameter (cm)	290
Equivalent core height (cm)	100
Averaged core composition (v/o)	
fuel/clad+structure/coolant(Na)	35.8/24.8/39.4
Type of fuel	Pu-U-MA-Zr
Core averaged fresh fuel composition (w/o)	
U/Pu/Np,Am and Cm/rare earths	72/18/5/5
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	0/58/24/14/4
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	54/23/0/17/0/6

Table 4.16 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.15

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm^3)		379
maximum in core		587
- Linear heat rate: average (w/cm)		320
maximum		500
- Neutron flux averaged in core (n/cm^2 see)		5.15×10^{15}
- Neutron energy averaged in core (KeV)		423
- Fuel dwelling time in core (EFPD)[3)]		1095
- Burnup reactivity swing (%δ k/k/365 EFPD)		3.75
- Coolant void reactivity effect (%6 k/k)		
All reactor region voided	3.74	
Core and axial blanket voided		–
Only core voided		–
- Doppler reactivity coefficient (Tdk/dt)	-3.2×10^{-3}	
- Effective delayed neutron fraction	0.0031	
- Control rod material	B_4C	
- Central control rod worth (%δ k/k/^{10}B kg)	0.054	
- Prompt neutron life time (see)		
- Axial thermal expansion (δ k/k)/(δ L/L)	-0.586	

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.17 Principal Design Parameters of Metal-Fuel-LMFBR Based Transmutation Concept Proposed by Toshiba Corporation [10]

Items	
Thermal power (MWt)	1575
Electric power (MWe)	600
Equivalent core diameter (cm)	358
Equivalent core height (cm)	45
Averaged core composition (v/o) fuel/clad+structure/coolant(Na)	38.5/35.9/25.6
Type of fuel	metallic
Core averaged fresh fuel composition (w/o) U/Pu/Np, Am and Cm	71/26/3
Isotopic composition of Pu in fresh fuel (w/o) $^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	1.0/57.1/22.4/15. 1/4.4
Isotopic composition of minor actinides (w/o) $^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	50.9/23.6/0.9/23. 6/0.4/0.6

Table 4.18 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.17

Items	BOL[1]	EOC[2]
- Power density: average in core (w/cm'		360
maximum in core		
- Linear heat rate: average (w/cm		
maximum		495
- Neutron flux averaged in core (n/cm² sec		
- Neutron energy averaged in core (KeV)		
- Fuel dwelling time in core (EFPD)[3]		1095
- Burnup reactivity swing (% δ k/k/365 EFPD)		4.6
- Coolant void reactivity effect (% δ k/k)		
All reactor region voided		
Core and axial blanket voided		-0.35 - 0.00
Only core voided		0.25 - 0.60
- Dopplerreactivity coefficient (Tdk/dt)		-1.7×10^{-3}
- Effective delayed neutron fraction		0.0035
- Control rod material		B_4C
- Central control rod worth (% δ k/k/kg)		..
- Prompt neutron life time (see)		2.4×10^{-7}

1) Begining of Life, 2) Equilibrium Cycle.
3) Equivalent full power days

Table 4.19 Principal Reactor Design Parameters of Helium-Cooled **Actinide** Burner Concept **(P-ABR)** Proposed by **JAERI** [20]

Items		
Thermal power	(MWt)	1200
Electric power	(MWe)	185
Equivalent core diameter	(cm)	124
Equivalent core height	(cm)	124
Averaged core composition	(v/o)	
fuel/clad+structure/coolant(He)		22.1/25.9/52.0
Type of fuel		nitride
Core averaged fresh fuel composition	(w/o)	
U/Pu/Np, Am and Cm		35/ 0/65
Isotopic composition of U in fresh fuel	(w/o)	
$^{235}U/^{236}U/^{238}U$		90.0/ 0/10.0
Isotopic composition of minor actinides	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		56.2/26.4/0/12.0/0. 03/5.1

Table 4.20 Generic and Safety-Related Physics **Paramaetes** of the Proposed Concept Given in Table **4.19**

Items		BOL[1)]	BOEC[2)]
- Power density: average in core	(w/cm’)	801	801
maximum in core		1090	1090
- Linear heat rate: average	(w/cm)		
maximum			
- Neutron flux averaged in core	(n/cm’ see)	5.9 x 10^{15}	5.9 x 10^{15}
- Neutron energy averaged in core	(KeV)	722	700
- Fuel dwelling time in core	(EFPD)[3)]	300	300
- Burnup reactivity swing	(%δ k/k/365 EFPD)	6.11	7.96
- Coolant void reactivity effect	(%δ k/k)		
All reactor region voided			
Core and axial blanket voided			
Only core voided			
- Doppler reactivity coefficient	(Tdk/dt)	-1.7 x 10^{-4}	
- Effective delayed neutron fraction		0.0026	
- Control rod material		B4C	
- Central control rod worth	(%δ k/k)	-1.01	
- Prompt neutron life time	(see)	1.5 x 10^{-7}	

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.21 Principal Design Parameters of Lead–Cooled Actinide Burner Concept Proposed by JAERI [20]

Items		
Thermal power	(MWt)	180 x 6
Electric power	(MWe)	370
Equivalent core diameter	(cm)	98
Equivalent core height	(cm)	47
Averaged core composition	(v/o)	
fuel/clad+structure/coolant(Pb)		28.9/10.3/60.8
Type of fuel		nitride
Core averaged fresh fuel composition	(w/o)	
U/Pu/Np, Am and Cm		36/ 0/64
Isotopic composition of U in fresh fuel	(w/o)	
$^{235}U/^{236}U/^{238}U$		90/ 0/10
Isotopic composition of minor actinides	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		56.2/26.4/0/12.0/0. 3/5.1

Table 4.22 Generic and Safety-Related Physics Parametes of the Proposed Concept Given in Table 4.21

Items		BOL[1)]	BOEC[2)]
- Power density: average in core	(w/cm’)	580	580
maximum in core		754	754
- Linear heat rate: average	(w/cm)		
maximum			
- Neutron flux averaged in core	(n/cm* see)	2.8 x 10^{15}	3.0 x 10^{15}
- Neutron energy averaged in core	(KeV)	720	700
- Fuel dwelling time in core	(EFPD)[3)]	550	550
- Burnup reactivity swing	(%δ k/k/365 EFPD)	3.09	4.46
- Coolant void reactivity effect	(%δ k/k)		
All reactor region voided		-1.3	
Core and axial blanket voided			–
Only core voided		-1.3	–
- Doppler reactivity coefficient	(Tdk/dt)	-1.3 x 10^{-4}	
- Effective delayed neutron fraction		0.0026	
- Control rod material		B_4C	
- Central control rod worth	(%δ k/k/kg)	-0.511	
-- Prompt neutron life time	(see)	1.3 x 10^{-7}	–

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.23 Principal Design Parameters of Th-Loaded Lead–Cooled Fast Reactor Based Transmutation Concept Proposed by JAERI [16]

Items	
Thermal power (MWt)	1500
Electric power (MWe)	600
Equivalent core diameter (cm)	355
Equivalent core height (cm)	100
Averaged core composition v/o	
fuel/clad+structure/coolant(Pb)	30/10/60
Type of fuel	nitride
Core averaged fresh fuel composition w/o	
Th/Pu/Np, Am and Cm	63/17/10
Isotopic composition of Pu in fresh fuel (w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	0/58/24/14/4
Isotopic composition of minor actinides (w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm/^{245}Cm$	59/28/0.1/10/0.2/2. 6/0.1

Table 4.24 Generic and Safety-Related Physics Paramete s of the Proposed Concept Given in Table 4.23

Items	BOL[1)]	BOEC[2)]
- Power density: average in core (w/cm^3)		
maximum in core	230	300
- Linear heat rate: average (w/cm)		
maximum	470	600
- Neutron flux averaged in core (n/cm^2 see)		
- Neutron energy averaged in core (KeV)		
- Fuel dwelling time in core (EFPD)[3)]	3000	–
- Burnup reactivity swing (%δ k/k/365 EFPD)	-0.61 - 0.57	
- Coolant void reactivity effect (%6 k/k)		
All reactor region voided		–
Core and axial blanket voided	-3.8	–
Only core voided		–
- Doppler reactivity coefficient (Tdk/dt)		
- Effective delayed neutron fraction		
- Control rod material		–
- Central control rod worth (%δ k/k/kg)		–
- Prompt neutron life time (see)		–

1) Begining of Life, 2) Begining of Equilibrium Cycle,
3) Equivalent full power days

Table 4.25 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by JAERI -A11oY Fuel Core System- [21]

Items		
Accelerator		
-Type		Proton LINAC
-Particle		Proton
-Energy	(MeV)	1500
-Current	(mA)	39
Target		
-Equivalent diameter	(cm)	40
-Equivalent height	(cm)	140
-Target material		w
-Cooling material		Na
Subcritical core		
-Equivalent diameter	(cm)	140
-Equivalent height	(cm)	140
-Material composition	(v/o)	
Fuel/Target/Clad+Structure/Coolant		3.6/1.7/80.7/14. 0/0
-Chemical form of fuel		metallic
-Materials of coolant and moderator		Na / -
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np,Am,Cm/LLFP		0/25.8/74.2/0
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$		1.6/49.5/35.8/8. 5/4.7
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{2}$ 'Am/$^{243}Am/^{243}Cm/^{244}Cm/^{245}Cm$		56.2/26.4/12.0/0. 0/5.1/0.3
-Averaged composition of Long-lived FP	(w/o)	
$^{99}Tc/^{129}I$		
System Characteristics		
-Effective multiplication factor: k_{eff}		0.89
-Thermal power in core	(MWt)	820 (246 MWe)
-Power density: average	(W/cm')	400
maximum	(W/cm^3)	930
-Linear heat rate: average	(W/cm)	260
maximum	(W/cm)	610
-Neutron flux averaged in core	(n/cm' s)	4 x 10^{L5}
-Neutron energy averaged in core	(KeV)	690
-Fuel dwelling time	(EFPD)[1]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.26 System Design Parameters of Accelerator–Driven Transmutation Concept Proposed by JAERI -Molten Salt Core System - [21]

Items		
Accelerator		
-Type		Proton LINAC
-Particle		Proton
-Energy	(MeV)	1500
-Current	(mA)	25
Target		
-Equivalent diameter	(cm)	-
-Equivalent height	(cm)	
-Target material		-
-Cooling material		
Subcritical core		
-Equivalent diameter	(cm)	210
-Equivalent height	(cm)	170
-Material composition	(v/o)	
Fuel/Clad+Structure/Coolant/Moderator		14.7/85.3/0/0
-Chemical form of fuei		molten salt
-Materials of coolant and moderator		
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np, Am, Cm/LLFP		0/15/85/0
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$		1.6/49.5/8.5/4.7
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{241}Am/^{243}Am/^{243}Cm/^{244}Cm/^{245}Cm$		56.2/26.4/12.0/0. 0/5.1/0.3
-Averaged composition of Long-lived FP	(w/o)	
$^{99}Tc/^{129}I$		
System Characteristics		
-Effective multiplication factor: k_{eff}		0.92
-Thermal Power in core	(MWt)	800 (240 MWe)
-Power density: average	(W/cm^3)	310
maximum	(W/cm^3)	1660
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
-Neutron flux averaged in core	(n/cm* s)	
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.27 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by JAERI - Eutectic Metal Target–Core System - [21]

Items		
Accelerator		
-Type		Proton LINAC
-Particle		Proton
-Energy	(MeV)	1500
-Current	(mA)	20
Target		
-Equivalent diameter	(cm)	40
-Equivalent height	(cm)	100
-Target material		(Np-Pu-Co-Ce-Tc) liquid fuel
-Cooling material		–
Subcritical core		
-Equivalent diameter	(cm)	160
-Equivalent height	(cm)	160
-Material composition	(v/o)	
Fuel/Clad+Structure/Coolant/Moderator		10/0/5/85
-Chemical form of fuel		(Np-Pu-Co-Ce-Tc) liquid fuel
-Materials of coolant and moderator		$LiF-BeF_2$ / Graphite
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np, Am, Cm/LLFP		0/26.2/68.3/5.5
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$		1.6/49.7/35.7/8. 4/4.6
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		100/0/0/0/0/0
-Averaged composition of Long-lived FP	(w/o)	
$^{99}Tc/^{129}I$		100/0
System Characteristics		
-Effective multiplication factor: k_{eff}		0.93
-Thermal Power in core	(MWt)	455 (150 MWe)
-Power density: average	(W/cm’)	
maximum	(W/cm’)	
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
-Neutron flux averaged in core	(n/cm^2 s)	
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1]	
–Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.28 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by BNL -MOX Fuel Core System - [22]

Items		
Accelerator		
-Type		Multi-Segmented Cyclotron
-Particle		Proton
-Energy	(MeV)	1500
-Current	(mA)	2.0-5.0
Target		
-Equivalent diameter	(cm)	10
-Equivalent height	(cm)	75
-Target material		Pb
-Cooling material		He
Subcritical core		
-Equivalent diameter	(cm)	180
-Equivalent height	(cm)	93
-Material composition	(v/o)	
Fuel/Clad+Structure/Coolant/Moderator		35/24/41/0
-Chemical form of fuel		oxide
-Materials of coolant and moderator		Na / -
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np,Am,Cm/LLFP		73/22/5/0
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$		0/58/24/14/4
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		53.6/23.1/0/17.4/0/5. 9
-Averaged composition of Long-lived FP	(w/o)	
$^{99}Tc/^{129}I$		94/6
System Characteristics		
-Effective multiplication factor: k_{eff}		0.98 - 0.99
-Thermal Power in core	(MWt)	700 (280 MWe)
-Power density: average	(W/cm’)	930
maximum	(W/cm’)	
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
-Neutron flux averaged in core	(n/cm* s)	
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1)]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.29 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by BNL -Particle Fuel Core System - [22]

Items		
Accelerator		
-Type		Multi-Segmented Cyclotron
-Particle		Proton
-Energy	(MeV)	1500
-Current	(mA)	4 - 8
Target		
-Equivalent diameter	(cm)	10
-Equivalent height	(cm)	60
-Target material		–
-Cooling material		–
Subcritical core		
-Equivalent diameter	(cm)	150
-Equivalent height	(cm)	60
-Material composition	(v/o)	
Fuel/Clad+Structure/Coolant/Moderator		
-Chemical form of fuel		nitride coated particle
-Materials of coolant and moderator		He / $YH_{1.7}$
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np,Am,Cm/LLFP		0/34/66/0
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$		15.8/49.6/35.7/8. 4/4.6
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		56.7/26.2/0/11.8/0. 3/5.0
-Averaged composition of Long-lived FP	(w/0)	
$^{99}Tc/^{129}I$		93/7
System Characteristics		
-Effective multiplication factor:k_{eff}		0.98 - 0.99
-Thermal Power in core	(MWt)	1000 (370 MWe)
-Power density: average	(W/cm')	3400
maximum	(W/cm^3)	
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
-Neutron flux averaged in core	(n/cm^{2}s)	8.4 x 1 0^{15}
-Neutron energy averaged in core	(KeV)	740
-Fuel dwelling time	(EFPD)[1)]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	2.0

1) Equivalent Full Power Day

Table 4.30 System Design Parameters of The Fast Molten Salt Hybrid (CEA)

Items		
Accelerator		
- Type		Proton LINAC
- Particle		Proton
- Energy	(GeV)	1.5
- Current	(mA)	270
Target		
- Diameter	(cm)	495 (all core)
- Height	(cm)	600
- Target material		molten salt fuel
- Cooling material		non
Subcritical Core		
- Diameter	(cm)	495
- Height	(cm)	600
- Material composition of core		100% of molten salt
- Chemical form of fuel		$(Th+3\%^{239}Pu)Cl_2$ -60% mol + $PbCl_3$
- Averaged fresh fuel composition Th:Pu:^{99}Tc weight ratios		35:1.1:1.85
- Isotopic composition of Pu		100% ^{239}Pu, no TRU
- Isotopic composition of LLFP		100% ^{99}Tc
System Characteristics		
- K_{eff}		0.85
- Thermal power in core	(MWt)	5000
- Power density: averaged/max.	(w/cm')	40/70
Neutron flux averaged in core	(n/cm')	2X10'^{5}
- Fuel (target) dwelling time	(EFPY)*	50
- Burnup reactivity swing	(%δ k/k/EFPY)	0.003
- Burnup	(% heavy atom)	45
- Reloading interval	(EFPY)	10

*:Equivalent Full Power Years

Table 4-31 Key Design Parameter Comparison Between ATW and CANDU

PARAMETER	CANDU-3	ATW
1. Blanket Arrangement		
Type	horizontal pressure tube	same
Coolant	pressurized heavy water	same
Moderator	heavy water	same
Number of Fuel Assemblies	232	250
Fuel Assembly Material	Zirconium-Niobium	same
Total mass of Fuel	53174 kg	1550 kg
		(total primary loop)
k_{eff}	1.0	0.95
2. Fuel		
Fuel	compacted/sintered	aqueous actinide
	natural UO_2 pellets	solution (75 gin/l);
		(Pu, Np, Am, Cm)
Form	fuel bundle assembly;	flowing fuel solution
	37 elements/assembly	
Bundle Length	0.495 m	
Bundle Outer Diameter	0.1024 m	0.10 m
Bundles/Fuel Assembly	12	
3. Heat Transport System		
Number of Steam Generators	2	same
Steam Generator Type	vertical U-tube	same
Number of Heat-Transport Pumps	2	same
Fump Type	vertical, centrifugal, single	same
	suction. double discharge	
Number of Intermediate Heat Exchangers (IHX)		2
IHX Type		vertical once-through
Number of IHX Pumps		2

Table 4.31 (Continuation)

PARAMETER	CANDU-3	ATW
IHX Pump Type		vertical, centrifugal,
		single suction, double
		discharge
Blanket Outlet Pressure	9.9 MPa	13.1 MPa
Blanket Outlet Temp.	310 c	325 C
Blanket Inlet Temp.	258 C	273 C
Total Flowrate	5300 kg/s	5240 kg/s
Steam Outlet Temp.	260 c	same
Feedwater Inlet Temp.	187 C	"same
steam Quality	99.75%	same
Steam Pressure	4.6 M-Pa	same
IHX Outlet Temp.		31OC
IHX Outlet Pressure		13.2 MPa
IHX Inlet Temp.		258 C
IHX Flowrate		5744 kg/s
4. Power		
Total Fission Heat	1440.3 MW_t	1542 MW_t
Net Electrical Output	450 MWe	487 MWe

Table 4.32 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by ENEA -ATW Type - [8]

Items		
Accelerator		
-Type		Proton LINAC
-Particle		Proton
-Energy	(MeV)	1600
-Current	(mA)	200
Target		
-Equivalent diameter	(cm)	27
-Equivalent height	(cm)	200
-Target material		Liquid Lead
-Cooling material		
subcritical core		
-Equivalent diameter	(cm)	
-Equivalent height	(cm)	
-Material composition Fuel/Clad+Structure/Coolant/Moderator	(v/o)	
-Chemical form of fuel		Molten salt or slurry
-Materials of coolant and moderator		
-Averaged fresh fuel composition U/Pu/Np,Am,Cm/LLFP	(w/o)	0/94/6/0
-Isotopic composition of Pu $^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$	(w'/o)	1.4/55.0/25.5/13. 3/4.8
-Isotopic composition of MA $^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$	(w'/o)	74.1/6.0/0.1/13.7/0. 1/6.0
-Averaged composition of Long-lived FP $^{99}Tc/^{129}I$	(w/0)	100/0
System Characteristics		
-Effective multiplication factor: k_{eff}		
-Thermal Power in core	(MWt	
-Power density: average	(W/cm^3	
maximum	(W/cm^3)	
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
–Neutron flux averaged in core	(n/cm^2 s)	
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1)]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.33 **System** Design Parameters of Accelerator-Driven Transmutation Concept Proposed by Royal Institute of Technology **-ATW Type - [11]**

Items		
Accelerator		
-Type		Proton LINIAC or Cyclotron
-Particle		Proton or Deutron
-Energy	(MeV)	-1000
-Current	(mA)	5 - 100
Target		
-Equivalent diameter	(cm)	40
-Equivalent height	(cm)	400
-Target material		Solid Th or Liquid Pb or ^{7}Li
-Cooling material		
Subcritical core		
-Equivalent diameter	(cm)	‘-400
-Equivalent height	(cm)	-400
-Material composition Fuel/Clad+Structure/Coolant/Moderator	(v/o)	
-Chemical form of fuel		Molten salt or Slurry
-Materials of coolant and moderator		
-Averaged fresh fuel composition U/Pu/Np,Am,Cm/LLFP	(w/o)	
-Isotopic composition of Pu ^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu	(w/o)	
-Isotopic composition of MA ^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm	(w/o)	
-Averaged composition of Long-lived FP ^{99}Tc/^{129}I	(w/o)	
System Characteristics		
-Effective multiplication factor: k_{eff}		
-Thermal Power in core	(MWt)	
-Power density: average	(W/cm’)	
maximum	(W/cm’)	
-Linear heat rate: average	(W/cm)	
maximum	(W/cm)	
-Neutron flux averaged in core	(n/cm* s)	
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

Table 4.34 System Design Parameters of Accelerator-Driven Transmutation Concept Proposed by Institute of Theoretical and Experimental Physics (ITEP) [13]

Items		
Accelerator		
-Type		Proton LIN AC
-Particle		Proton
-Energy	MeV)	1000
-Current	(mA)	100
Target		
-Equivalent diameter	(cm)	50
-Equivalent height	(cm)	400
-Target material		W, Pb-Bi eutectic alloy
-Cooling material		H20
Subcritical core		
-Equivalent diameter	(cm)	600
-Equivalent height	(cm)	600
-Material composition	(v/o)	
Fuel/Clad+Structure/Coolant/Moderator		4.7/4.5/3.5/84.6
-Chemical form of fuel		molten salt
-Materials of coolant and moderator		
-Averaged fresh fuel composition	(w/o)	
U/Pu/Np, Am, Cm/LLFP		
-Isotopic composition of Pu	(w/o)	
$^{238}Pu/^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu/241Am$		2/60/22/10/4/2
-Isotopic composition of MA	(w/o)	
$^{237}Np/^{241}Am/^{242}Am/^{243}Am/^{243}Cm/^{244}Cm$		
-Averaged composition of Long-lived FP	(w/o)	
$^{99}Tc/^{129}I$		
System Characteristics		
-Effective multiplication factor: k_{eff}		0.97
-Thermal Power in core	(MWt)	1100 (380 MWe)
-Power density: average	(W/cm^3)	5.3
maximum	(W/cm^3)	10.6
-Linear heat rate: average	(W/cm)	81.4
maximum	(W/cm)	162.8
-Neutron flux averaged in core	(n/cm^2 s)	10^{14}
-Neutron energy averaged in core	(KeV)	
-Fuel dwelling time	(EFPD)[1]	
-Target dwelling time	(EFPD)	
-Burnup reactivity swing	(%δ k/k/365 EFPD)	

1) Equivalent Full Power Day

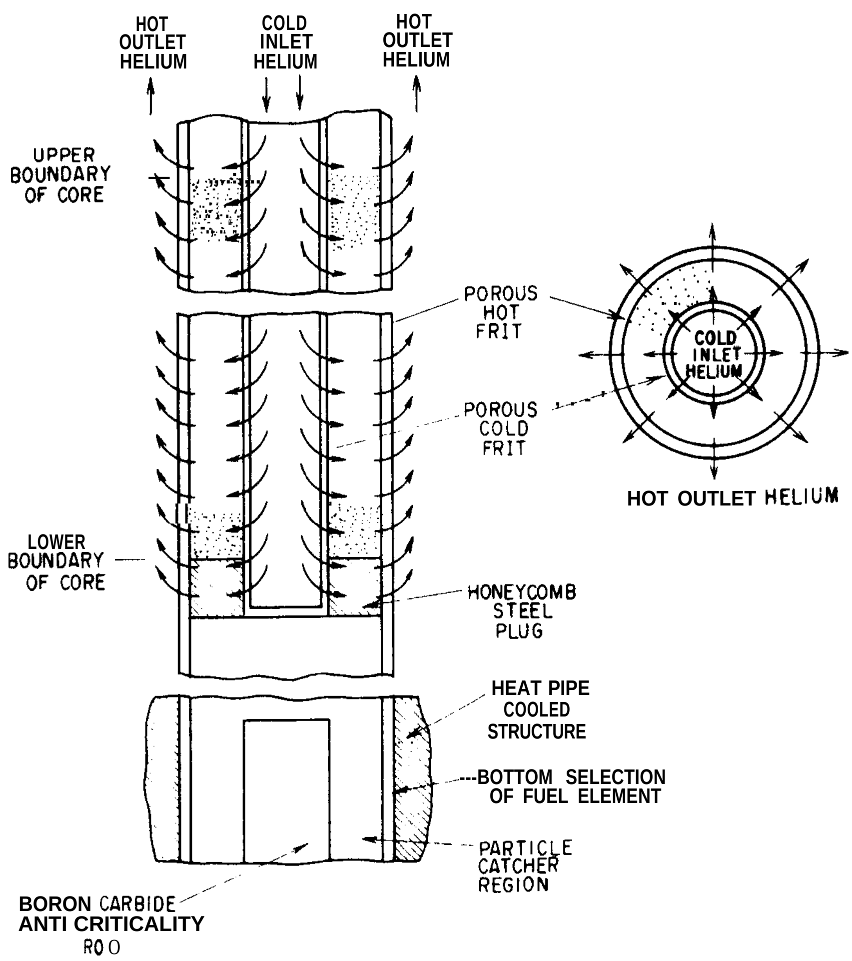
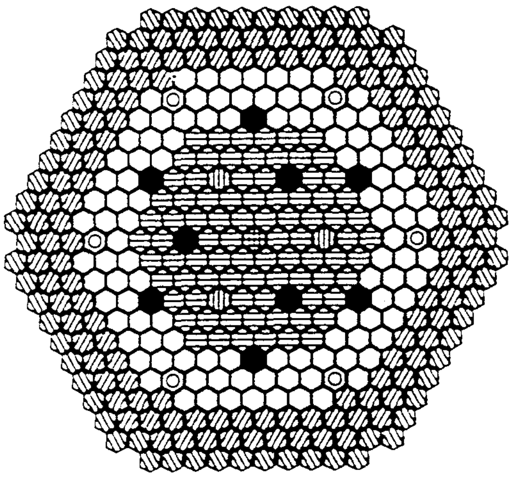


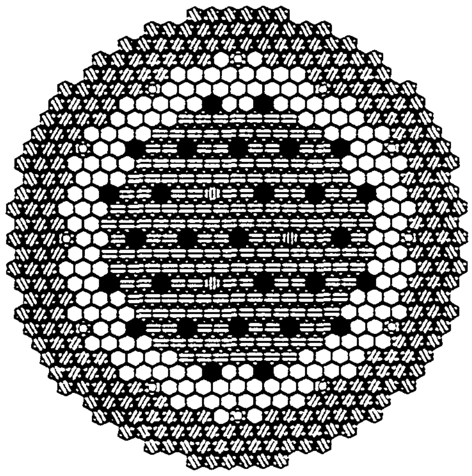
Fig. 4. 1 A Fuel Element for Pressure Vessel Configuration of PBR

Small Burner



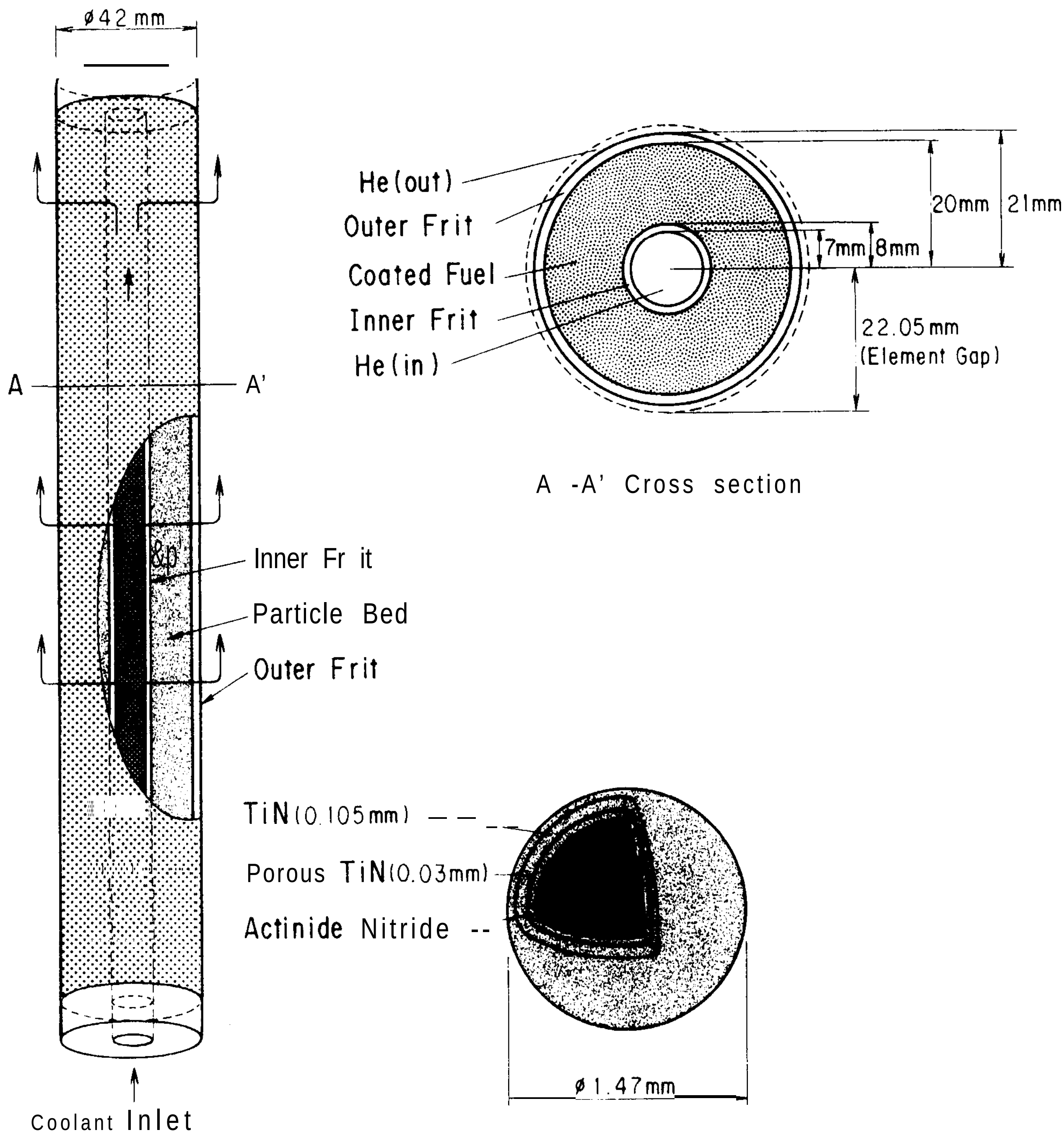
Low Enrichment Fuel	84
High Enrichment Fuel	108
Control	9
Ultimate Shutdown	3
Source	1
Gas Expansion Module	6
Reflector	114
Shield	66
Total	391

Large Burner



Low Enrichment fuel	192
High Enrichment Fuel	162
Control	2a
Ultimate Shutdown	3
Gas Expansion Module	12
Reflector	162
Shield	90
Total	649

Fig. 4.2 Core Configuration of ALMR for Actindes Burning



Coated Fuel Particle

Fuel Element

Fig. 4.3 Fuel Concept of Helium- Cooled Actinides Burner (P -ABR)

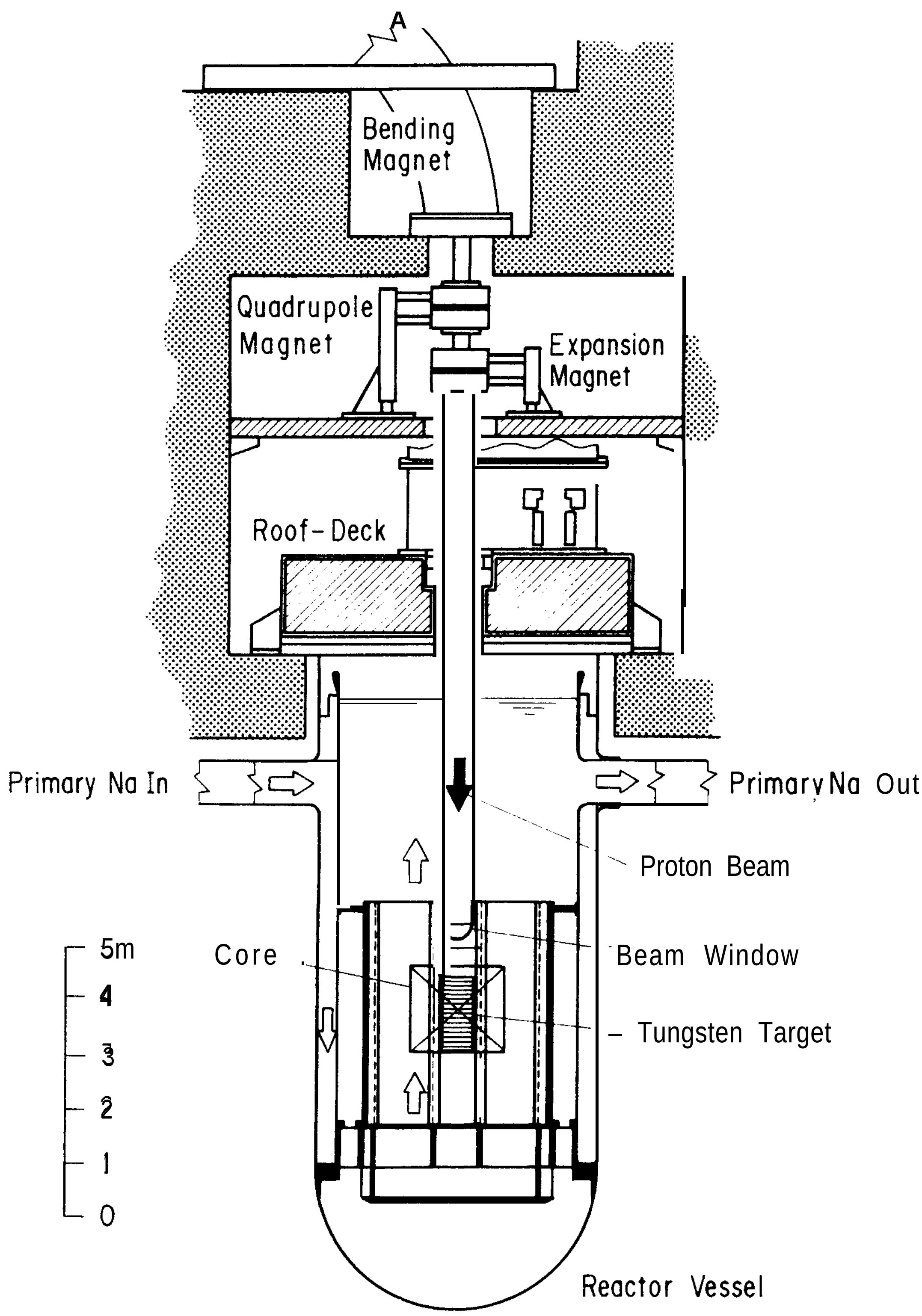


Fig.4.4 Schematic Figure of Accelerator- Driven Transmutation Concept -Alloy Fuel Core System-

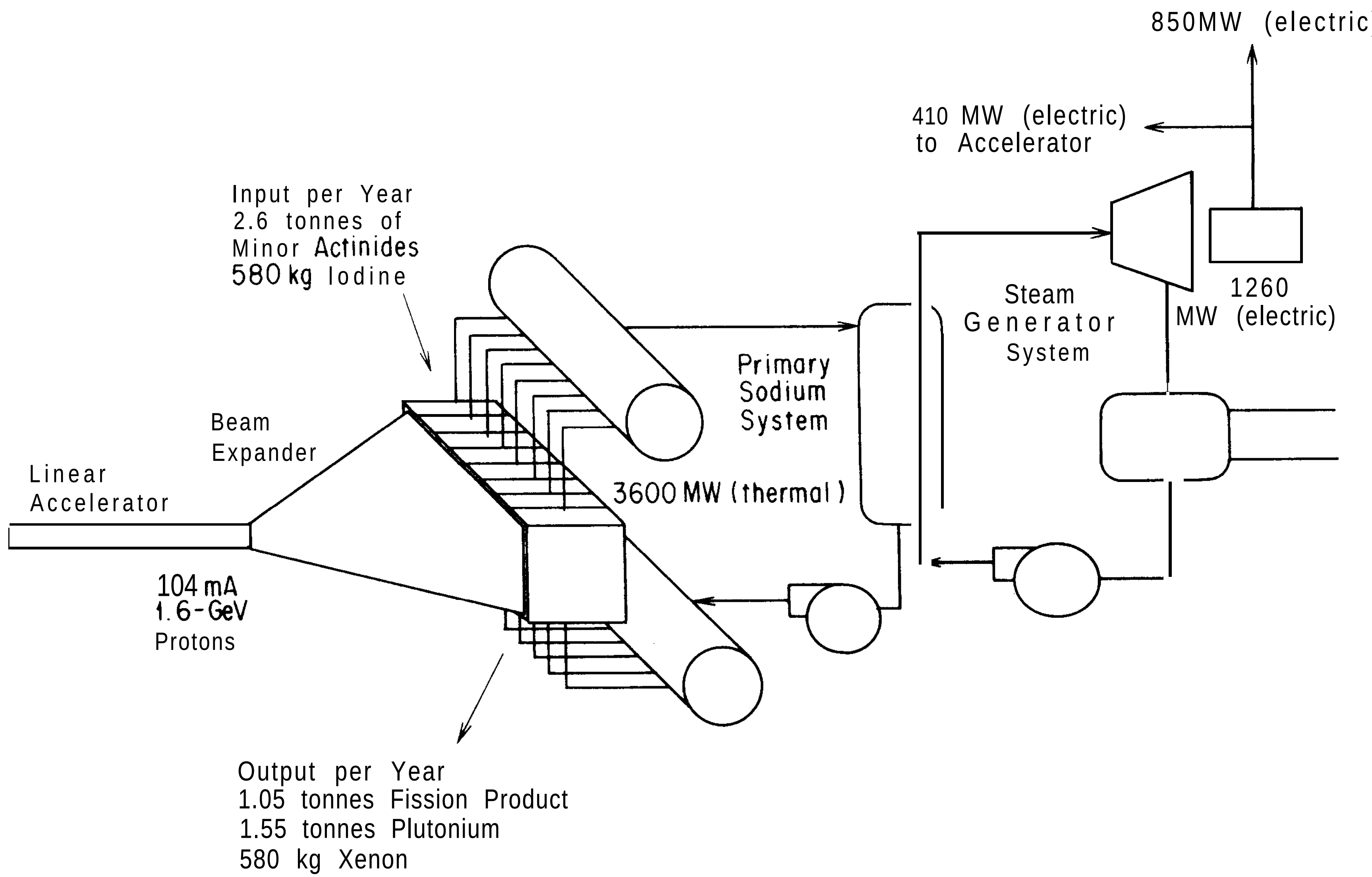
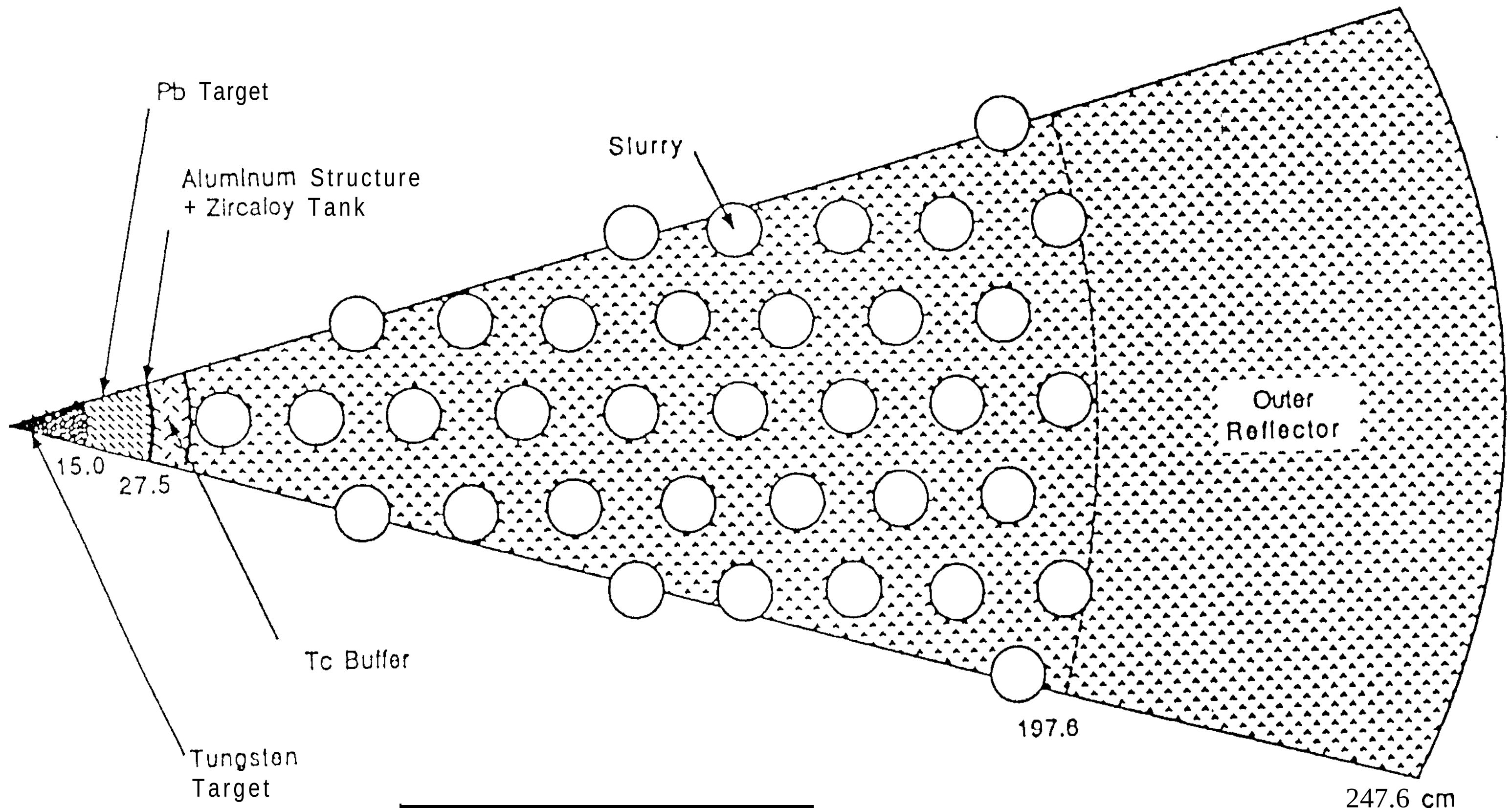


Fig. 4.5 The PHOENIX Concept (intermediate Na system not shown)



Slurry radius - 5 cm
No. tubes = 250
Pitch - 23.8 cm

Fig. 4.6 layout, of Core/Target of the Los Alamos ATW

Schematic layout of the ATW target-blanket. The blanket is divided radially into four parts: (1) a central molten salt column which is the target for the proton beam: (2) a uranium multiplier where most of the source neutrons are generated: (3) a fission product and actinide transmutation region which also prevents thermal neutrons from the multiplying blanket from being parasitically absorbed in the target region: and (4) the outer thorium-uranium multiplying breeding region of the blanket which improves the neutron economy of the system and generates most of the electric power

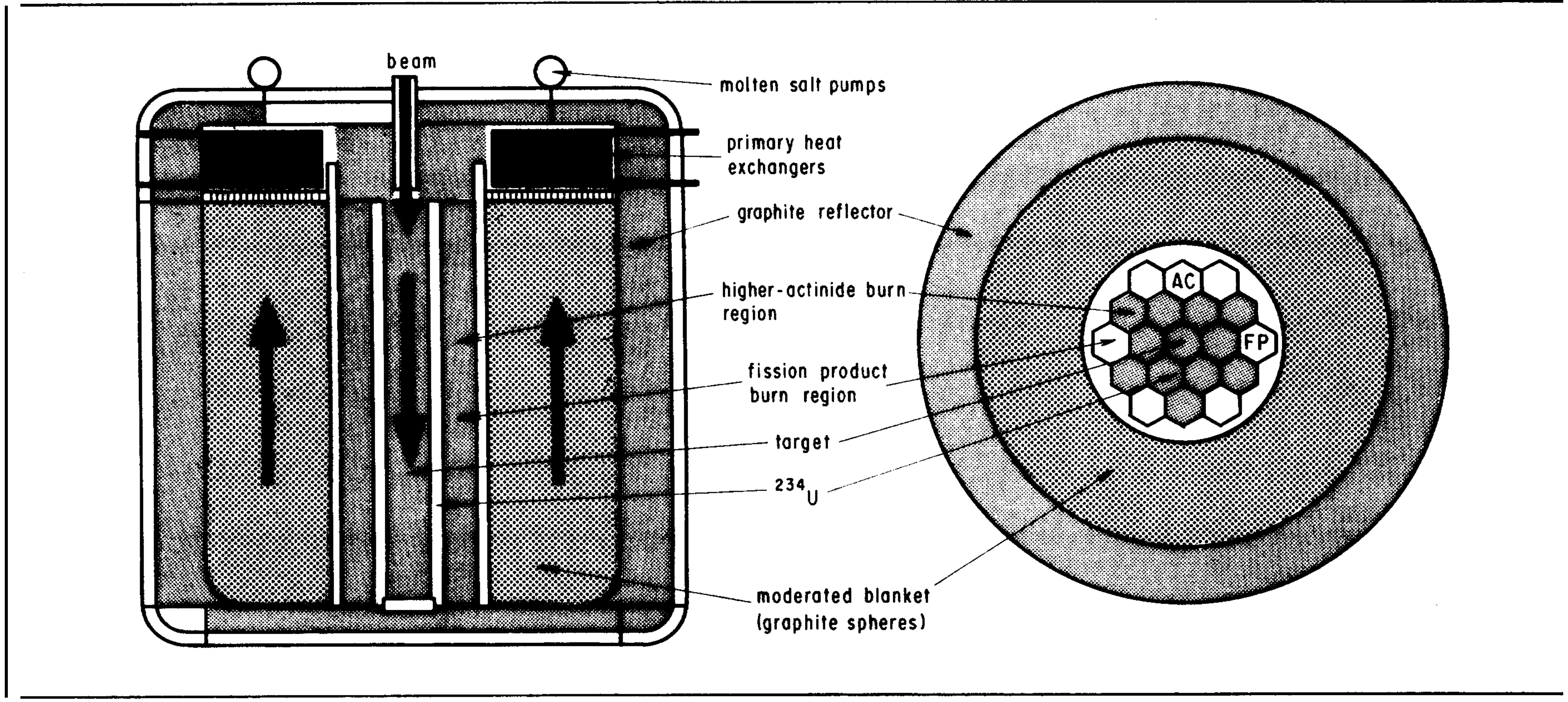


Fig. 4.7 Advanced Los Alamos ATW Concept