PROSPECTS OF SUBCRITICAL MOLTEN SALT REACTOR FOR MINOR ACTINIDES INCINERATION IN CLOSED FUEL CYCLE

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Problem of Minor Actinides Incineration (1)

Fast reactor hard neutron spectrum permits, in principle, transmute and incinerate MA from the spent fuel of thermal and fast reactors. But this implementation results in decreasing delayed neutron effective fraction (which itself in fast neutron reactors using plutonium fuel is lesser essentially then in thermal neutron reactors using uranium fuel) and in degrading Doppler-effect part of reactivity feedback (reactivity feedback may remain negative but lesser in absolute value or even, depending on loading and MA content, become positive). Thus reactor safety deteriorates significantly with relation to reactivity accidents.

Problem of Minor Actinides Incineration (2)

- The development of spent fuel and radioactive waste reprocessing is another necessary component on MA transmutation work. Present processing aqueous technologies based on one or another of PUREX-process modifications result in rather large liquid radioactive wastes what require special utilization or large storage volumes.
- Innovative spent fuel and radioactive wastes reprocessing technologies based on dry gas-fluoride methods may be alternative way. For this purpose reactor has been proposed with molten salt as coolant and fuel with MA dissolved in molten fluorides.

Problems of Creation Molten Salt Reactor (1)

- The design of reactor with molten salt and dissolved MA involves some difficulties and one of problem is lowered effective part of delayed neutrons. The reason is MA using (this part is small for most of MA) and delayed neutron precursors removing from the core in circulation (some precursors are decayed in outer circuit).
- These molten-salt reactor design technical problems can be solved using subcritical mode of MA incineration in MSR with external neutron source.

Problems of Creation Molten Salt Reactor (2)

- For the first time the conception of subcritical MSR was proposed in NRC KI in 1995
- Over a long period conception of subcritical MSR was elaborated on the base of cascade principle of neutrons from target source multiplication due to special designed multiplication parameters of subcritical blanket and zone of cascade multiplication posed between target and subcritical blanket.
- It was expected that such design implementation permit decrease the requirements to accelerator proton beam by a factor equal 10 to provide needed for MA transmutation and incineration neutron flux at level $1 \cdot 10^{15}$ n·cm-2·sec^{-1}.

Problems of Creation Molten Salt Reactor (3)

- However careful investigation of cascade subcritical reactor physical features, shows that needed proton beam current can be decreased only by a factor 2, and in some situations it is necessary to provide solid-fuel or liquid-metal insertions around the target. Solid-fuel insertion materials (fuel and structural) in the process are situated in practically extreme conditions, so their long-time functioning cannot be guaranteed. (The 2500 MW installation was considered).

Ways of Decision

- **The possible ways from this situation were to replace molten-salt compositions LiF- BeF2-NaF or LiF-BeF2 to another with more MA solubility,**
- **Decrease unit thermal power**
- **Reject the cascade amplification principle**

Parametrical investigations

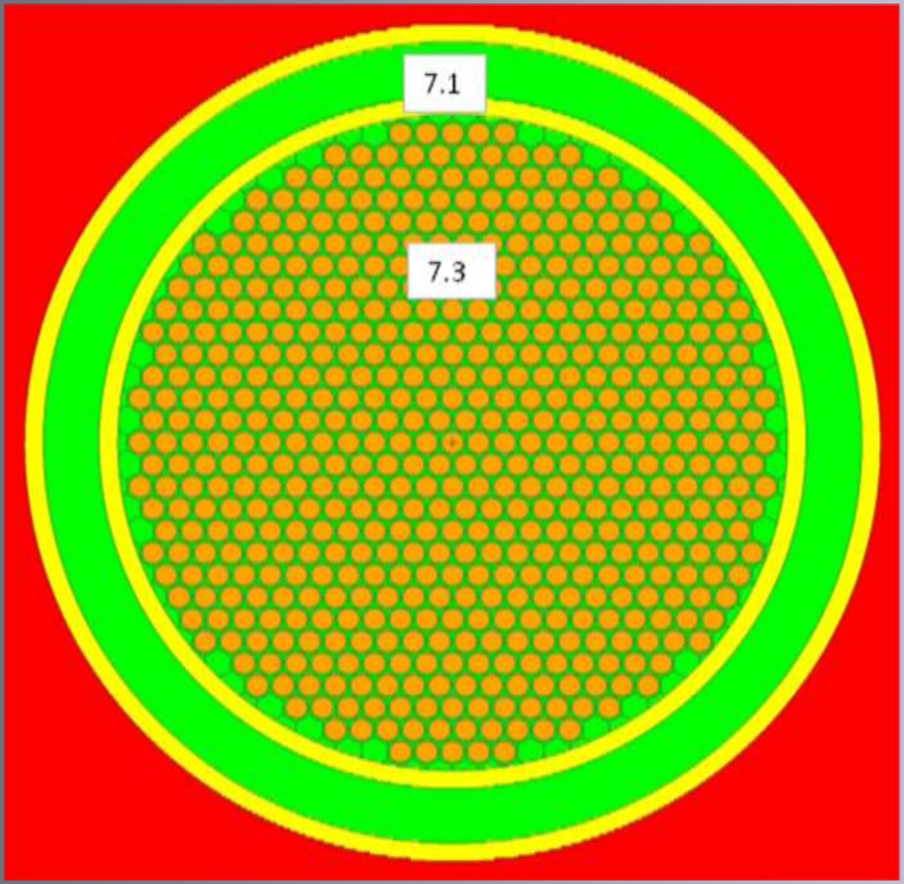
The possibility was considered to use electro-nuclear neutron source for transmutation and incineration of MA from spent fuel of light-water VVER-type reactor, and for conversion Th-232 to U-233 and Pa-231 in thorium molten salt blanket

FLiNaK molten salt composition was considered.

Fuel salt circuit in MSR consists of blanket (subcritical core with neutron flux) and outer loop (without neutron flux). There was adopted that during 30% of cycle time fuel salt is situated in blanket and during 70% of cycle time – in outer loop without neutron flux. Equilibrium fuel cycle parameters were investigated at 3 levels of average neutron flux in circuit:

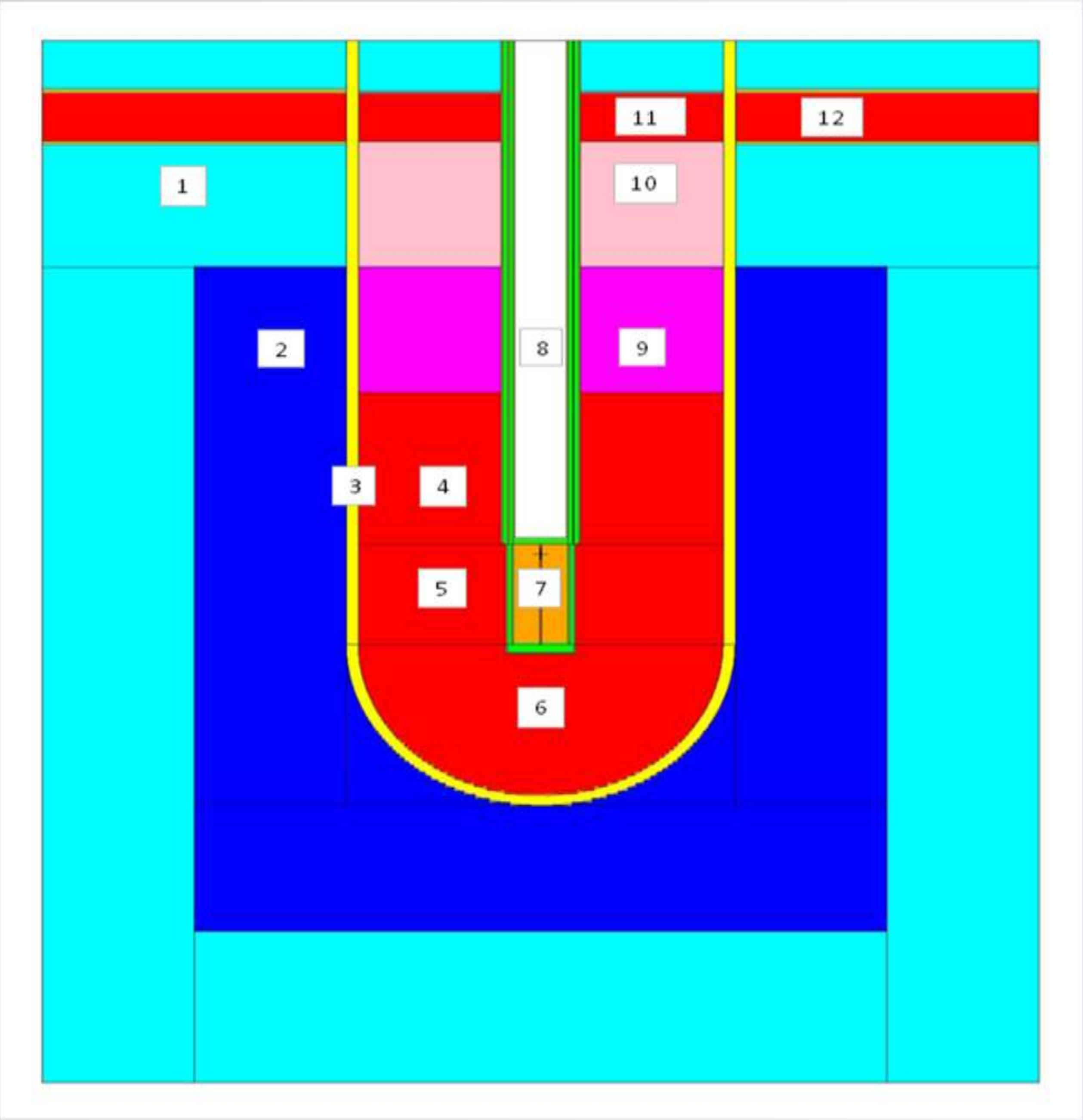
- **$1 \cdot 10^{14}$ n·sm^{-2}·sec^{-1} ($3.33 \cdot 10^{14}$ in blanket)**
- **$5 \cdot 10^{14}$ n·sm^{-2}·sec^{-1} ($1.67 \cdot 10^{15}$ in blanket)**
- **$1 \cdot 10^{15}$ n·sm^{-2}·sec^{-1} ($3.33 \cdot 10^{15}$ in blanket).**

Spallation Target Unit Cross-section Layout



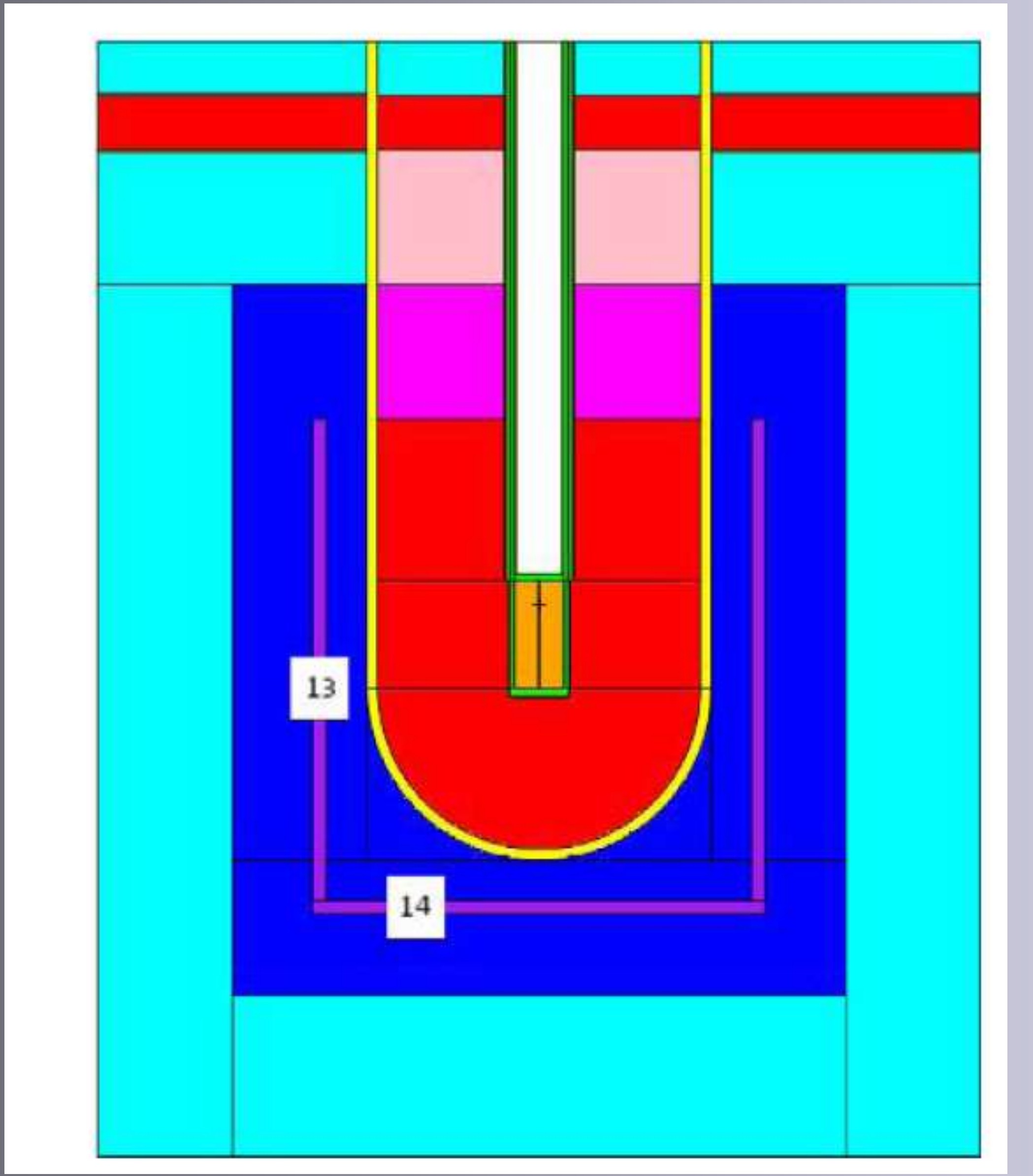
7.1-Channel for Coolant (Na),
7.3 – Tungsten rods and Sodium

Target Unit Cross-section Layout

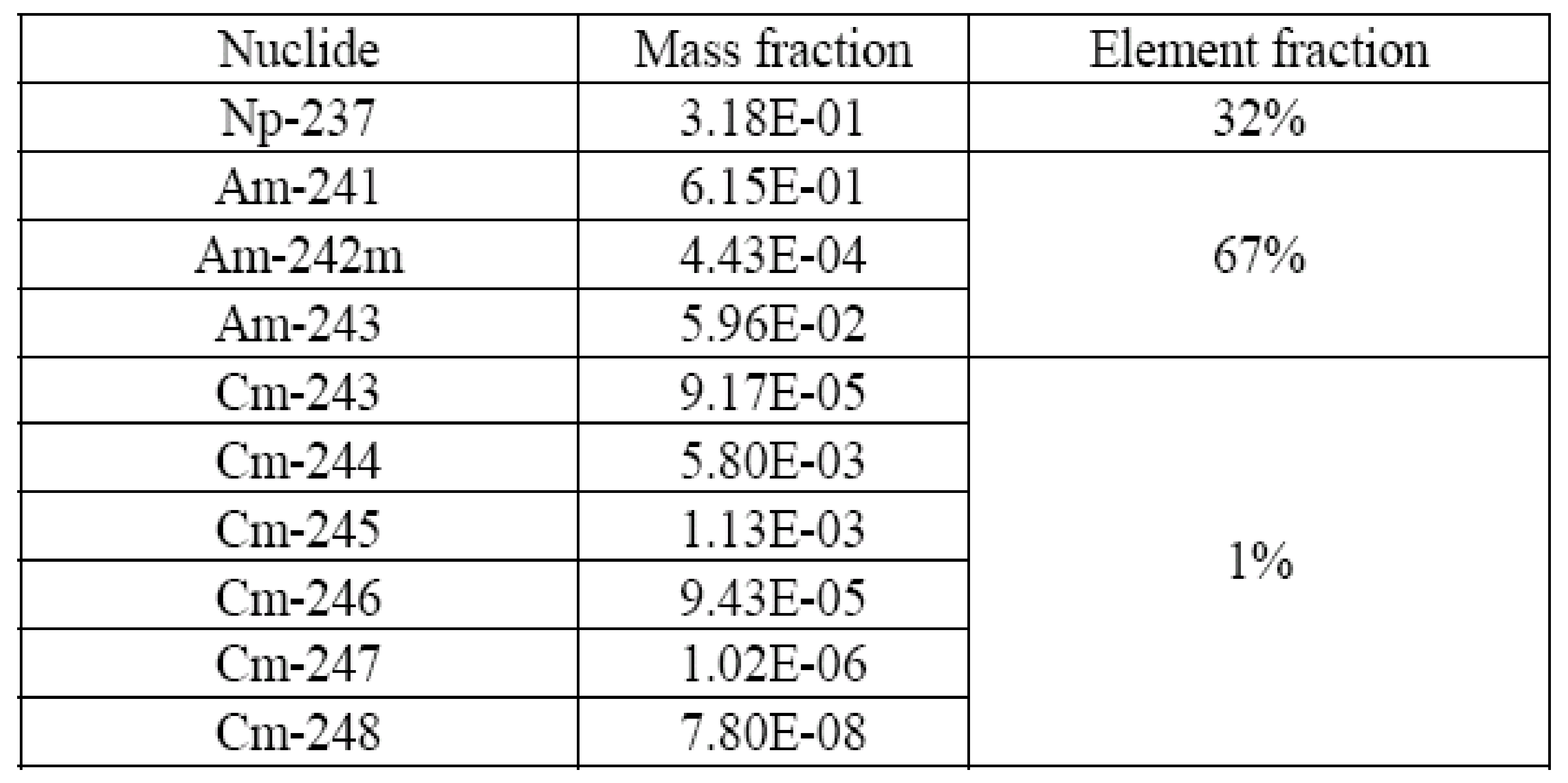


1-Shilding,
2-Graphite,
3-Vessel (Hastelloy),
4,5,6 –Core
7- Target (W)
8-Channel for Proton Beam
9-Mixing Zone (Salt and Graphite)
10 – (Mixing Zone (Salt and Steel)
11, 12 – Salt Collector

Target Unit Cross-section Layout with Additional Blanket with Th

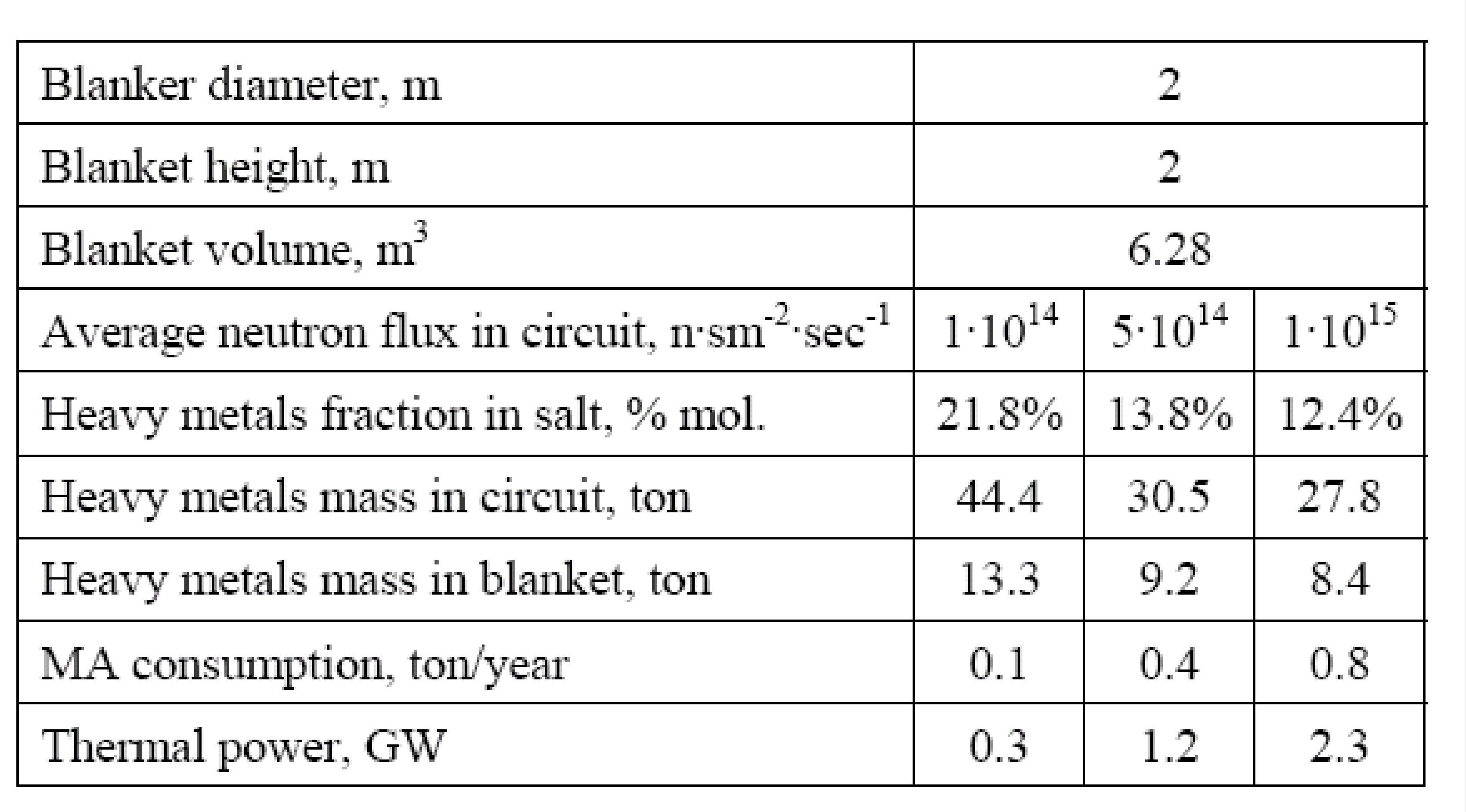


Minor actinides feed to SMSR



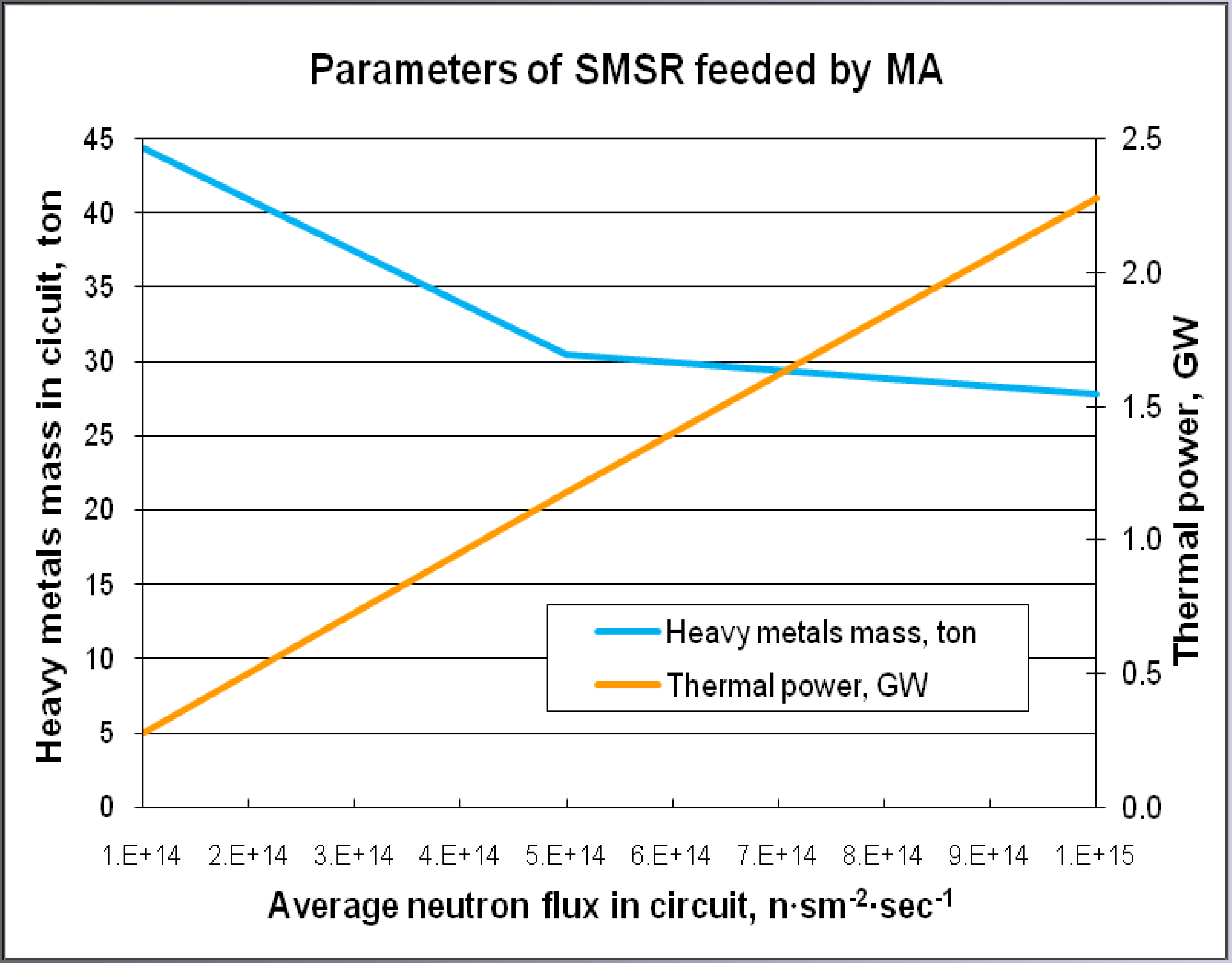
Nuclide	Mass fraction	Element fraction
Np-237	3.18E-01	32%
Am-241	6.15E-01	67%
Am-242m	4.43E-04	
Am-243	5.96E-02	
Cm-243	9.17E-05	1%
Cm-244	5.80E-03	
Cm-245	1.13E-03	
Cm-246	9.43E-05	
Cm-247	1.02E-06	
Cm-248	7.80E-08	

Parameters of SMSR Model-1 with external neutron source

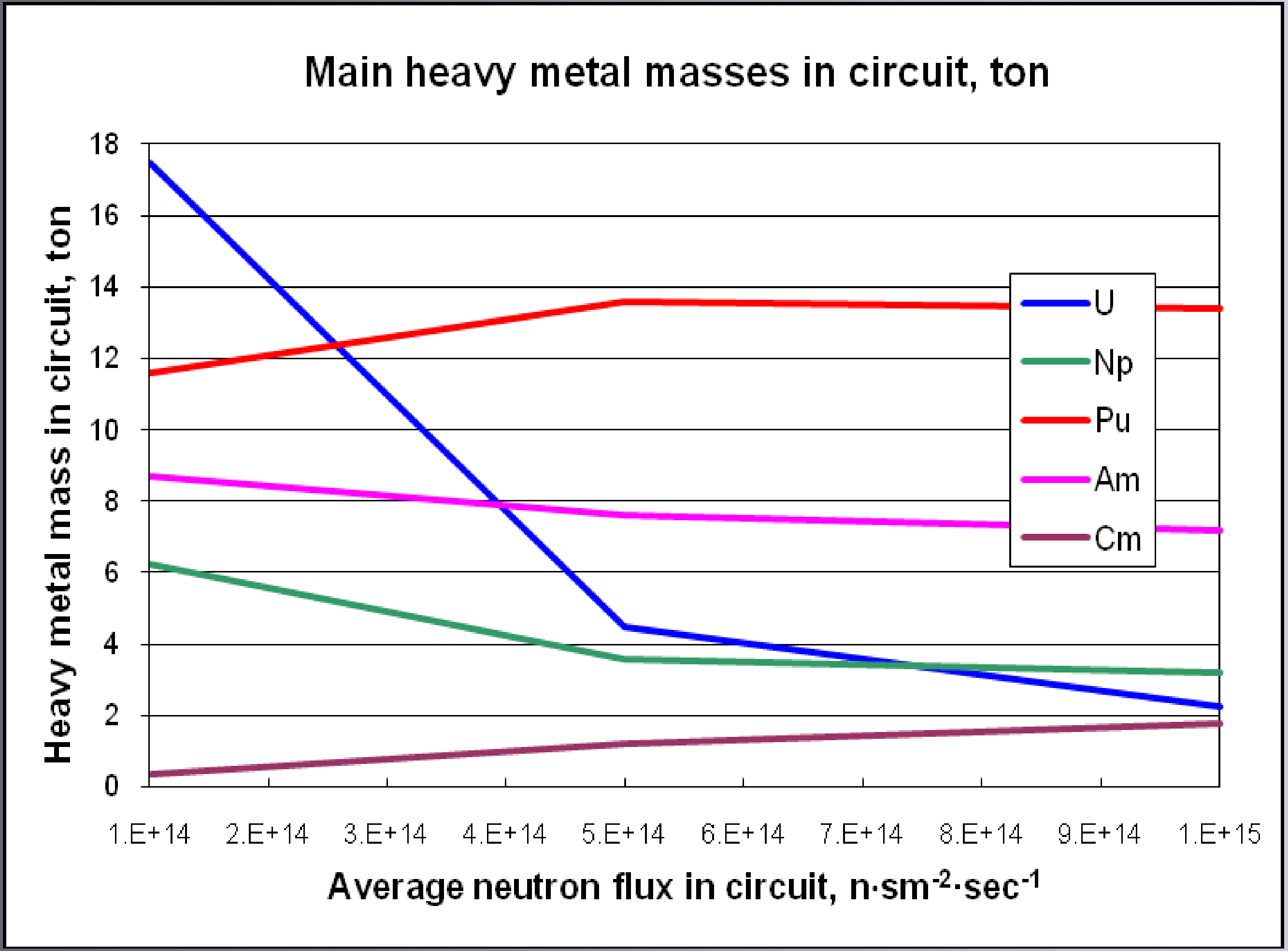


Blanker diameter, m	2		
Blanket height, m	2		
Blanket volume, m^3	6.28		
Average neutron flux in circuit, $n \cdot sm^{-2} \cdot sec^{-1}$	$1 \cdot 10^{14}$	$5 \cdot 10^{14}$	$1 \cdot 10^{15}$
Heavy metals fraction in salt, % mol.	21.8%	13.8%	12.4%
Heavy metals mass in circuit, ton	44.4	30.5	27.8
Heavy metals mass in blanket, ton	13.3	9.2	8.4
MA consumption, ton/year	0.1	0.4	0.8
Thermal power, GW	0.3	1.2	2.3

HM mass and thermal power in dependence of average neutron flux in circuit



HM masses in dependence of average neutron flux in circuit

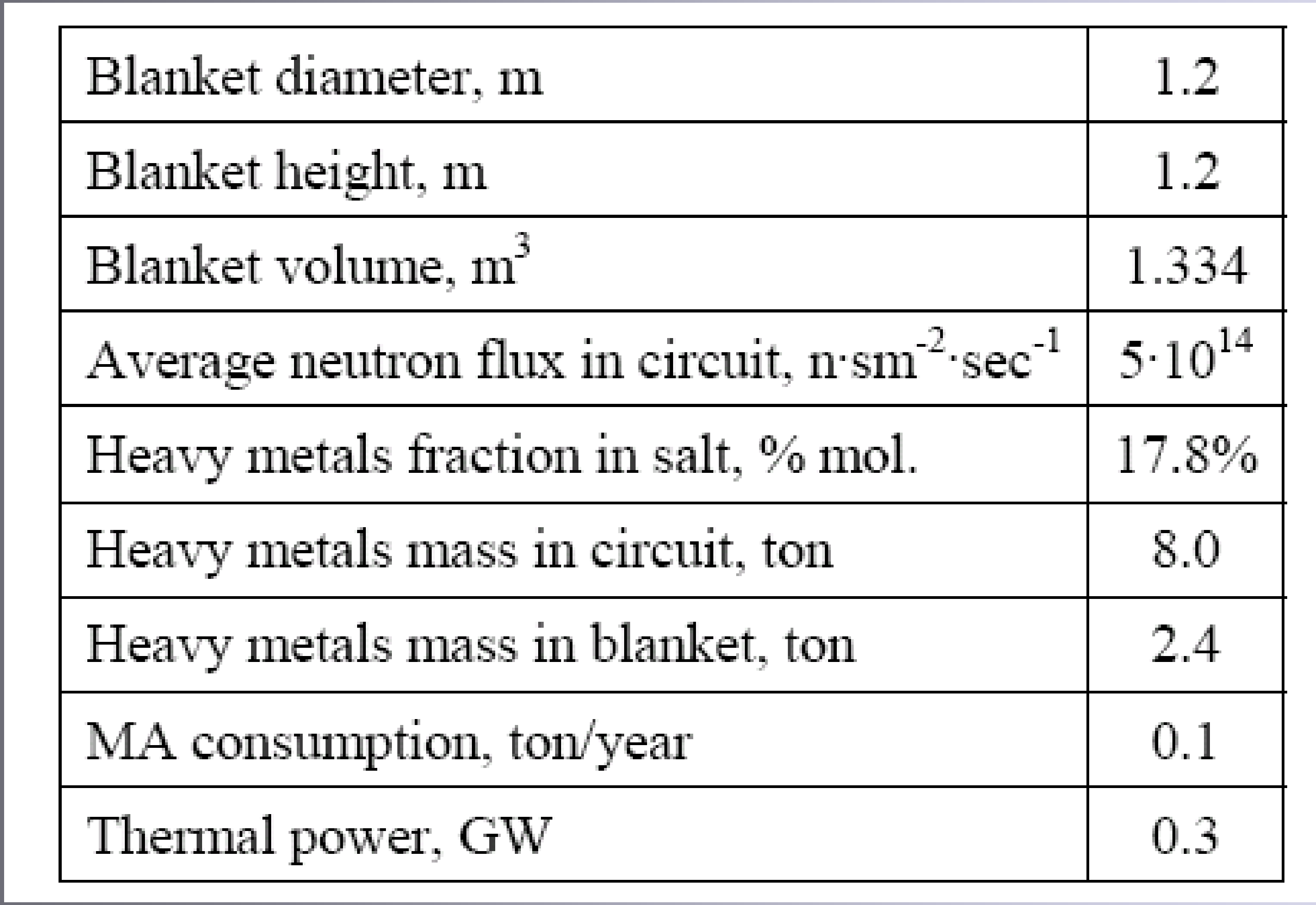


- **Reactor VVER-1000 produces about 40 kg/year MA.**
- **In equilibrium station reactor model-1 can contain about 26÷44 tons MA.**
- **There is little likelihood that such amount of spent fuel can be processed in a needed time.**

So Model-1 project cannot be realized due to large amount of VVER-1000 spent fuel needs to reprocessed simultaneously

- **Calculations show that neutron flux increase from $1{\cdot}10^{14}$ to $5{\cdot}10^{14}$ $n{\cdot}sm^{-2}{\cdot}sec^{-1}$ results in significant decrease of HM mass in circuit, at the cost of uranium mainly; consumption of MA and thermal power increase.**
- **Further increase of neutron flux is not so profitable. However HM mass in circuit (several tens of tons) seems to be rather large.**
- **Only blanket volume decrease permits to keep the necessary level of neutron flux and to decrease loading mass. Therefore SMSR Model-2 with lesser blanket dimensions was considered.**

Parameters of SMSR Model-2 with external neutron source



Blanket diameter, m	1.2
Blanket height, m	1.2
Blanket volume, m^3	1.334
Average neutron flux in circuit, $n \cdot sm^{-2} \cdot sec^{-1}$	$5 \cdot 10^{14}$
Heavy metals fraction in salt, % mol.	17.8%
Heavy metals mass in circuit, ton	8.0
Heavy metals mass in blanket, ton	2.4
MA consumption, ton/year	0.1
Thermal power, GW	0.3

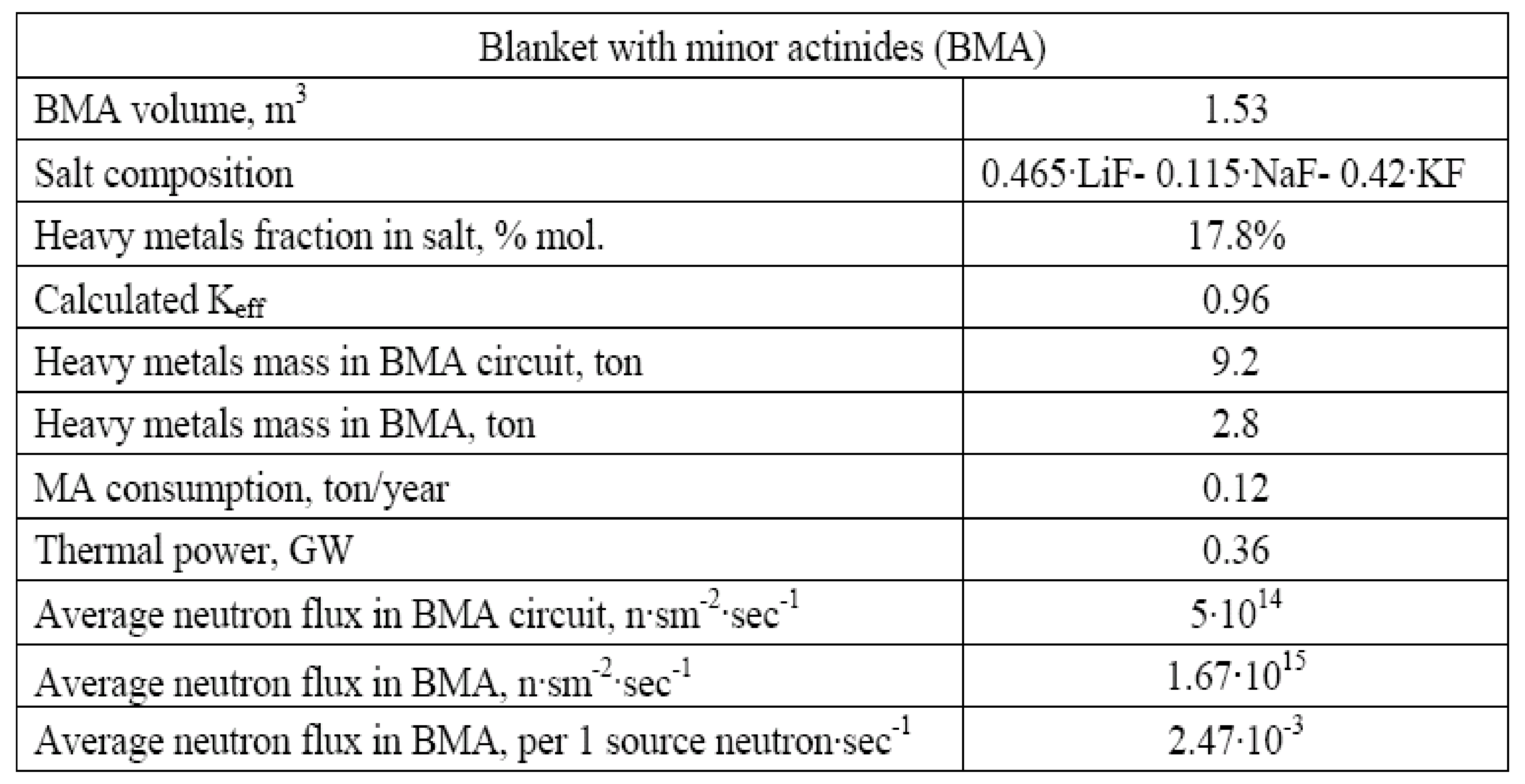
Results of Computational Analysis

Considered SMSR Model with accelerator proton beam target unit as external neutron source can utilize about 120 kg MA per year (the annual production of 3 reactors VVER-1000 type).

It should be noted that demonstration SMSR at thermal power 360 MW can produce about 100 MW electricity for accelerator supply.

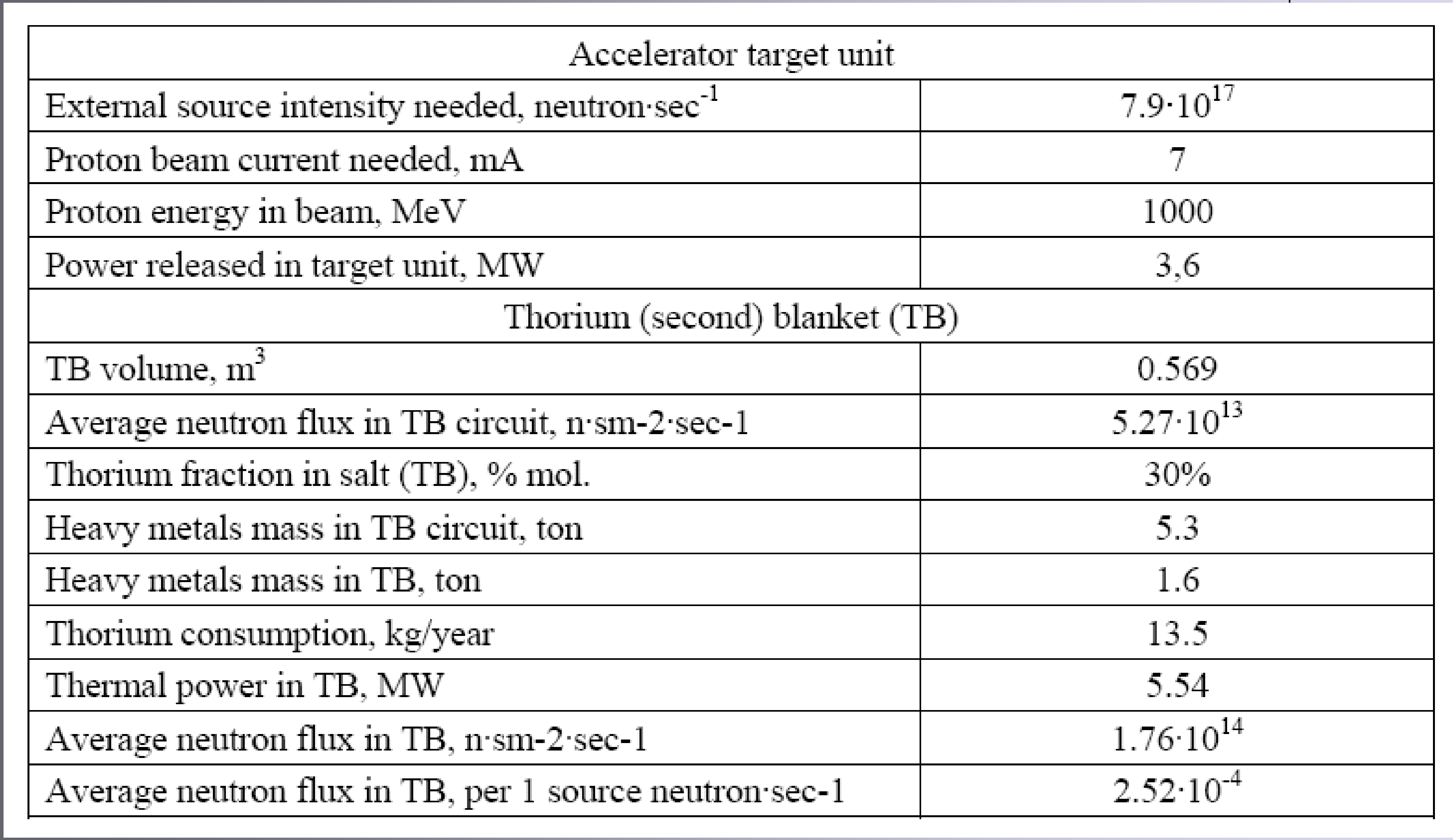
Also in thorium blanket it is possible to produce reasonable amounts of U-233 (10 kg/year) and Pa-233 (1.3 kg/year) for technological researches on their separation from molten salt.

Results of Computational Analysis (2)



Blanket with minor actinides (BMA)	
BMA volume, m^3	1.53
Salt composition	$0.465 \cdot LiF$- $0.115 \cdot NaF$- $0.42 \cdot KF$
Heavy metals fraction in salt, % mol.	17.8%
Calculated K_{eff}	0.96
Heavy metals mass in BMA circuit, ton	9.2
Heavy metals mass in BMA, ton	2.8
MA consumption, ton/year	0.12
Thermal power, GW	0.36
Average neutron flux in BMA circuit, $n \cdot sm^{-2} \cdot sec^{-1}$	$5 \cdot 10^{14}$
Average neutron flux in BMA, $n \cdot sm^{-2} \cdot sec^{-1}$	$1.67 \cdot 10^{15}$
Average neutron flux in BMA, per 1 source $neutron \cdot sec^{-1}$	$2.47 \cdot 10^{-3}$

Results of Computational Analysis (3)



Accelerator target unit	
External source intensity needed, neutron·sec^{-1}	$7.9 \cdot 10^{17}$
Proton beam current needed, mA	7
Proton energy in beam, MeV	1000
Power released in target unit, MW	3,6
Thorium (second) blanket (TB)	
TB volume, m^3	0.569
Average neutron flux in TB circuit, n·sm-2·sec-1	$5.27 \cdot 10^{13}$
Thorium fraction in salt (TB), % mol.	30%
Heavy metals mass in TB circuit, ton	5.3
Heavy metals mass in TB, ton	1.6
Thorium consumption, kg/year	13.5
Thermal power in TB, MW	5.54
Average neutron flux in TB, n·sm-2·sec-1	$1.76 \cdot 10^{14}$
Average neutron flux in TB, per 1 source neutron·sec-1	$2.52 \cdot 10^{-4}$

Conclusion

Considered SMSR Model with accelerator proton beam target unit as external neutron source can utilize about 120 kg MA per year (the annual production of 3 reactors VVER-1000 type).

Heavy metals mass in BMA circuit is equal 9.2 ton

It is consistent with industrial scale and opens up possibilities to design, construction and using this type SMSR as a component of spent fuel processing plants.