Malé modulárne reaktory spása alebo nádej

Ján Haščík,
jan.hascik@stuba.sk
ÚJFI

Obsah

- Hlavne znaky MMR
- Počiatky prace MMR
- Príprava nového paliva
- Vhodne typy
- Rýchle reaktory a ich význam
- Záver

Hlavné znaky

1. Pokročilé reaktory s výkonom do 300 MW(e)
2. Výroba modulov v závode a následný transport celkov.
3. Kombinované využitie popri výrobe elektriny (priemyselné teplo, vodík, odsoľovanie morskej vody, petrochémia, oceliarstvo,....)
4. Inštalácia hlavne na miestach bez dostupnej verejnej siete
5. Ekonomika prevádzky je dôležitá, nie však prvoradá

Hlavné znaky 2

1. Vysoká miera pasívnej bezpečnosti
2. Minimalizácia modulov (integrovanie komponentov primárneho okruhu do jedného modulu)
3. Jednoduchá obsluha s minimálnou údržbou a dlhými (viacročnými) kampaňami na výmenu paliva
4. Skrátenie výstavby a investičnej akcie

JE MH-1A STURGIS

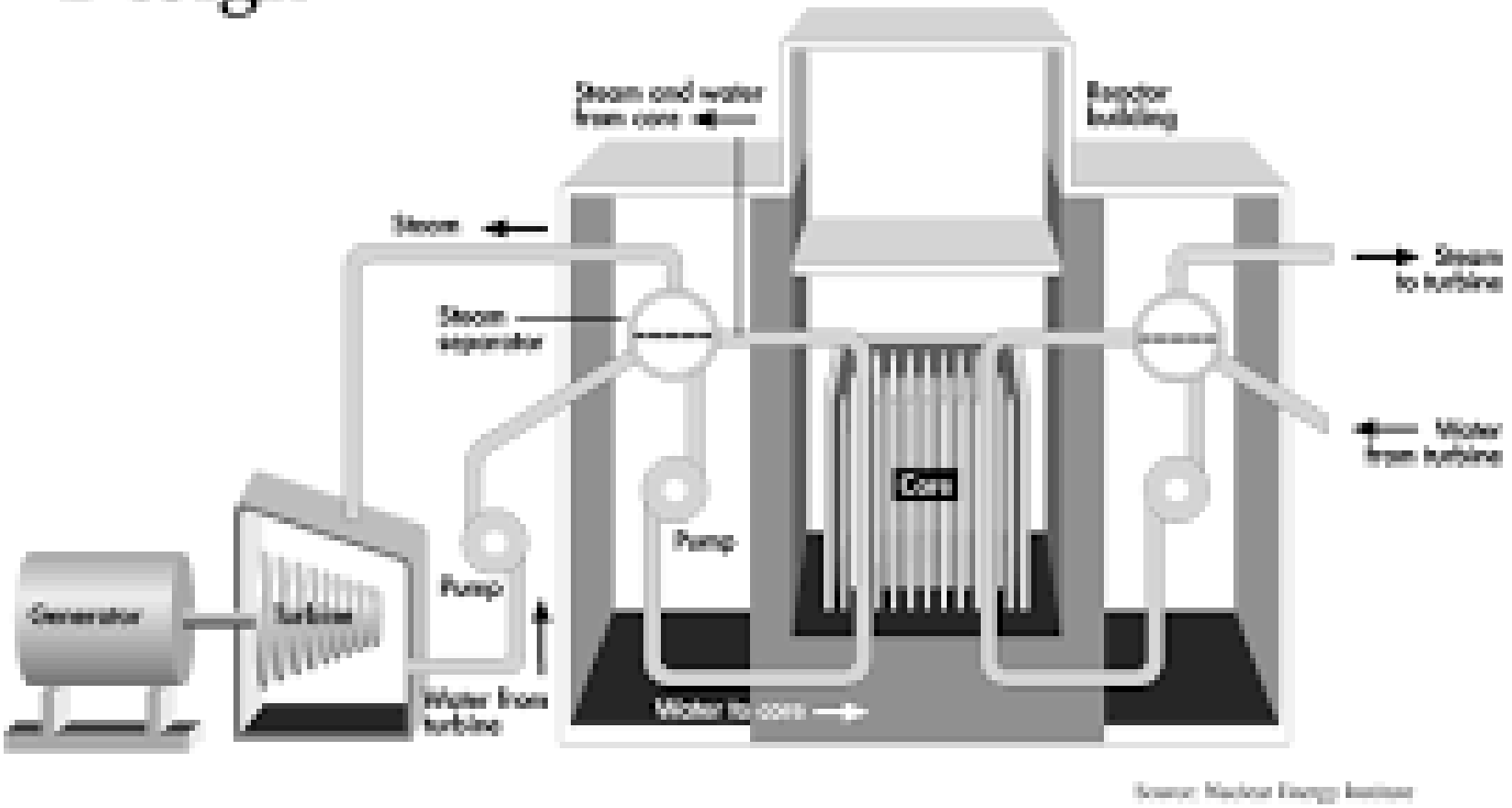
Nasadená v roku 1967 v zóne Panamského prieplavu, kde dodávala 10 MW_e elektrickej energie od októbra 1968 až do roku 1975.
Tlakovodný reaktor na lodi Liberty, palivo obohatenie ^{5}U 4-7%.

Bilibino 1-4

V rokoch 1973-76 boli v lokalite Bilibino na Čukotke postupne spustené 4 jadrové bloky konštrukčne na báze reaktorov RBMK s výkonom cca 12 MW_e na blok. V odľahlých miestach, kde nie je žiadna verejná sieť sa stali základom pre existenciu priemyslu, ktorého základom bola energeticky náročná ťažba diamantov. Dôležitá bola i kombinovaná výroba tepla na úrovni do 25 Gcal/hodinu (cca 29 MW_t). Obohatenie centrálnej časti paliva dosahovalo 3,3% U^{235} , na periférii aktívnej zóny 3,0% U^{235}.
Koeficient využitia bloku dosahoval 77%. Dnes sú bloky už odstavené.

Bilibino

RBMK Reactor Design



Akademik LOMONOSOV Pevek

Akademik Lomonosov nahradil kapacitu odstavenej JE Bilibino na Čukotke (prístav Pevek). Na plavidle s výtlakom 21 000 ton sú dva ruské reaktorové bloky KLT-40S s elektrickým výkonom 35 MW_e.

Mechanizmus vzniku nových štiepnych izotopov (paliva)

- ^{238}U > ^{239}Pu

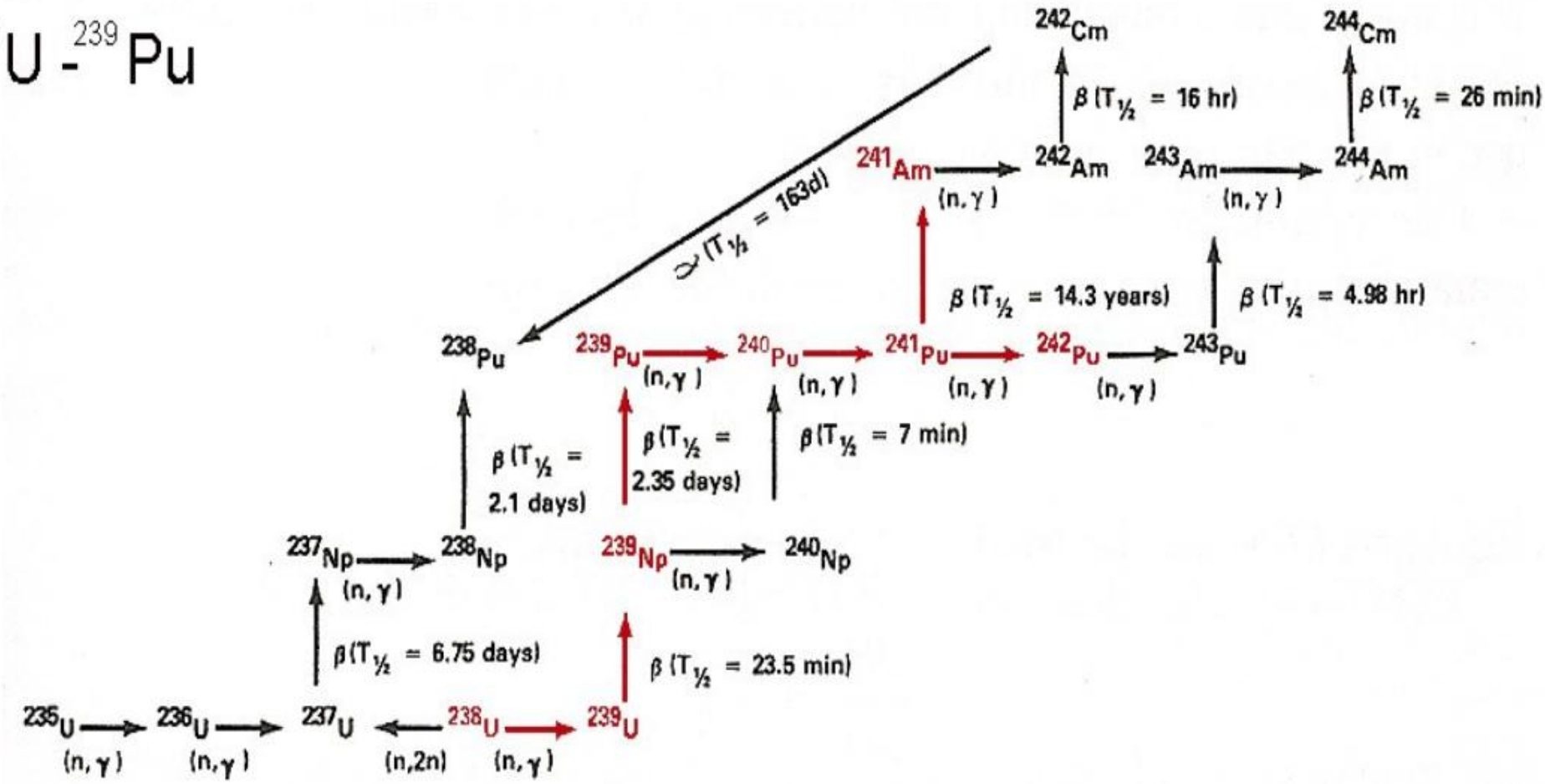
$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U \xrightarrow{\beta^-\,(23{,}45\,\mathrm{min})} ^{239}_{93}Np \xrightarrow{\beta^-\,(2{,}36\,d)} ^{239}_{94}Pu$$

- ^{232}Th > ^{233}U

$$^{232}_{90}Th + ^{1}_{0}n \rightarrow ^{233}_{90}Th \xrightarrow{\beta^-\,(22{,}3\,\mathrm{min})} ^{233}_{91}Pa \xrightarrow{\beta^-\,(26{,}97\,d)} ^{233}_{92}U$$

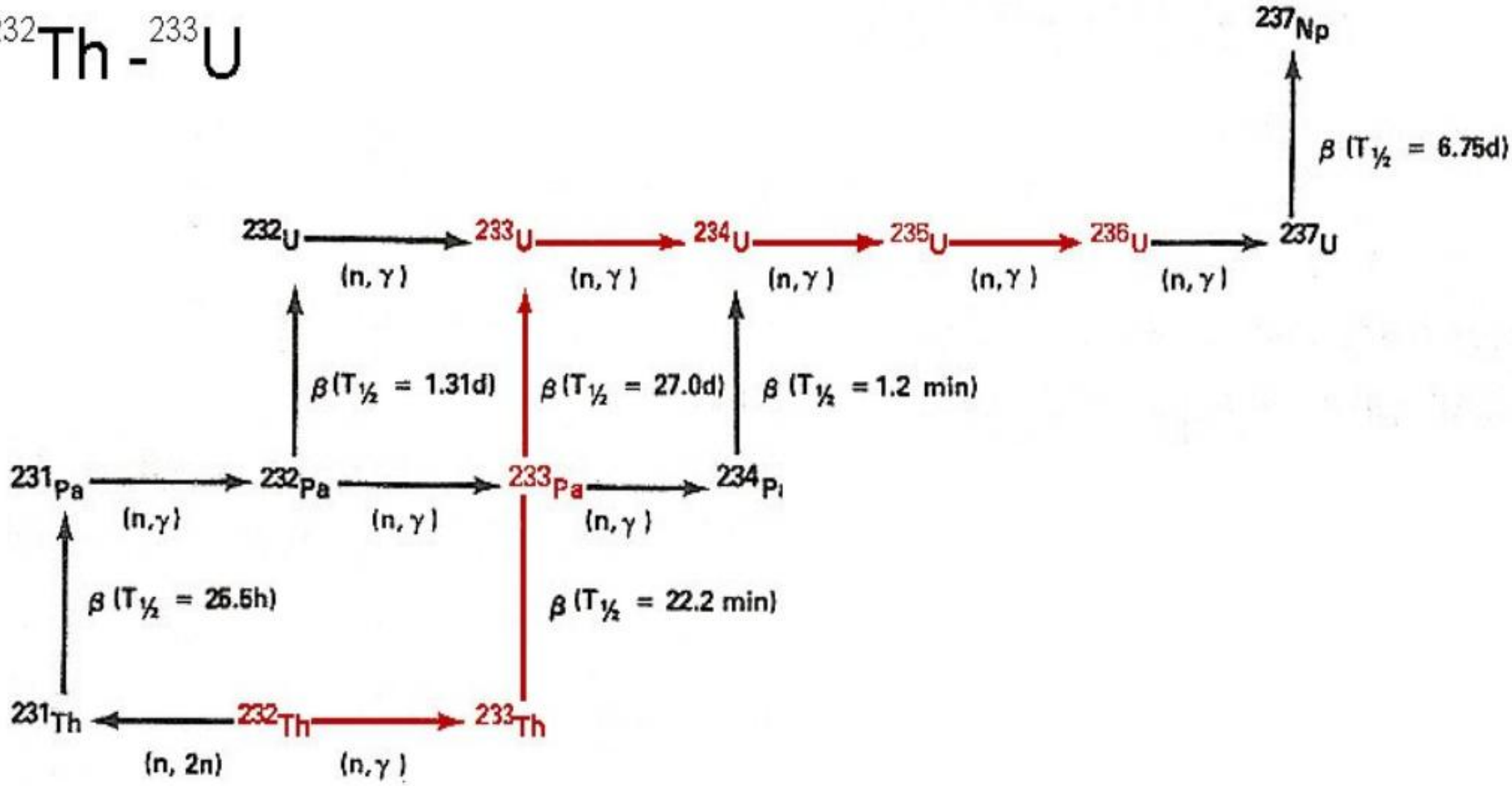
Vznik Pu

^{238}U - ^{239}Pu



Vznik U

^{232}Th - ^{233}U



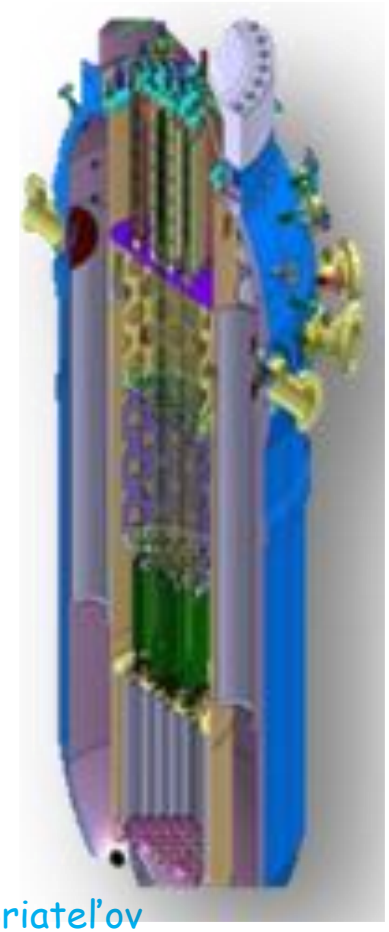
Palivo a množivý materiál

- Urán - ^{233}U; ^{235}U
- Plutónium - ^{239}Pu
- Chemická forma - kov; UO_2; UC_2;UN; U_2SiO_3
- Množivý materiál
- Urán - ^{238}U
- Tórium - ^{232}Th

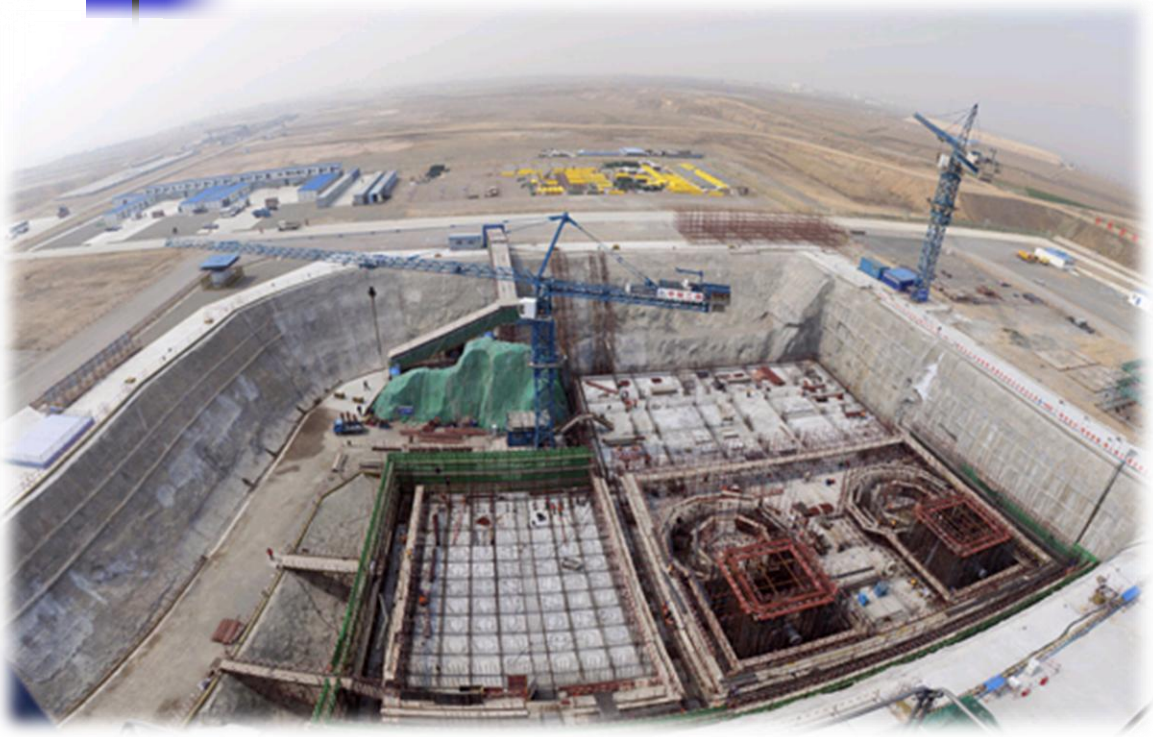
SMR vo výstavbe a na okamžitú dodavku

Country	Reactor Model	Output (MWe)	Designer	Number of units	Site, Plant ID, and unit #	Startup Construction
Argentina	CAREM-25	27	CNEA	1	Near the Atucha-2 site	2018
China	HTR-PM	250	Tsinghua Univ./Harbin	2 mods, 1 turbine	Shidaowan unit-1	2018
Russian Federation	KLT-40S *(ship-borne)*	70	OKBM Afrikantov	2 modules	Akademik Lomonosov units 1 & 2	2018
	RITM-200 *(Icebreaker)*	50	OKBM Afrikantov	2 modules	RITM-200 nuclear-propelled icebreaker ship	2019

CAREM 25

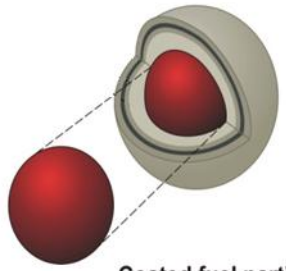


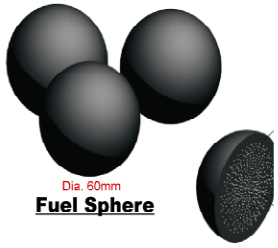
HTR - PM

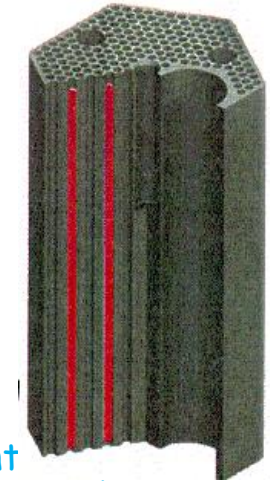


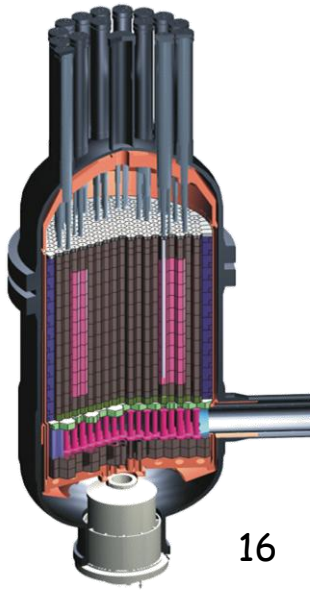
HTGR Charakteristiky

- Vyššia účinnosť (↑40-50%) vo výrobe elektriny
- Vyššie teploty chladiva na priemyselné aplikácie (750-1000°C)
- Využitie guličkového paliva
- Helium ako chladivo; Grafit ako moderator
- Výkon (~100 - 650 MWt)
- Vysoká modularita
- Nižšia výkonová hustota (3-6 W/cc v porovnaní s 60-100W/cc pre LWR)
- Možnosť dvoch variantov (Prismatic and pebble bed)









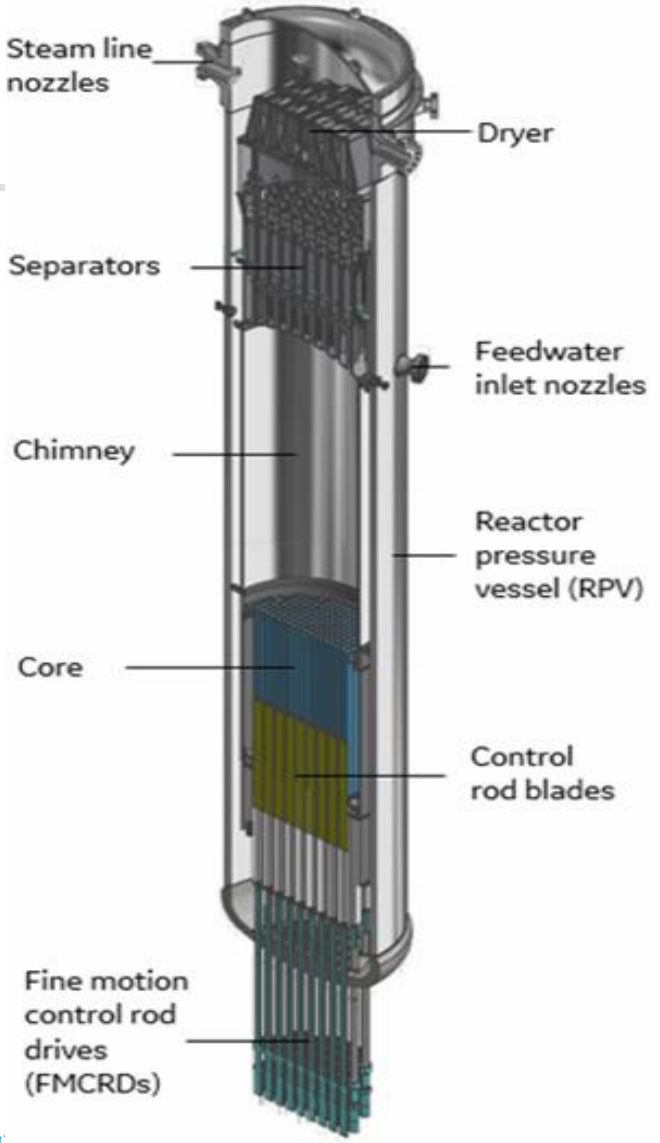
Uvažovane typy pre Európu

1. GE-Hitachi, BWRX-300
2. Rolls Roys, SMR-470
3. NuScale, SMR-77
4. Westinghouse, AP-300
5. KHNP, I-SMART-170
6. Holtec, SMR-300; SMR-160
7. Newcleo, LFR-AS-200

GE-Hitachi, BWRX-300

Základne parameter BWRX-300

- Reactor description: boiling water reactor
- Thermal power (MW_t): 870
- Electric power-gross (MW_e): 300
- Outlet temperature (°C): 288
- Spectrum (thermal/fast): Thermal
- Fuel type: UO_2 pellets
- Fuel: LEU
- Supplier: GE-Hitachi
- Locality: Darlington-CANADA
- Operator: Ontario power group (now-in build), ORLEN (Poland) and Fermi Energia (Estonia)

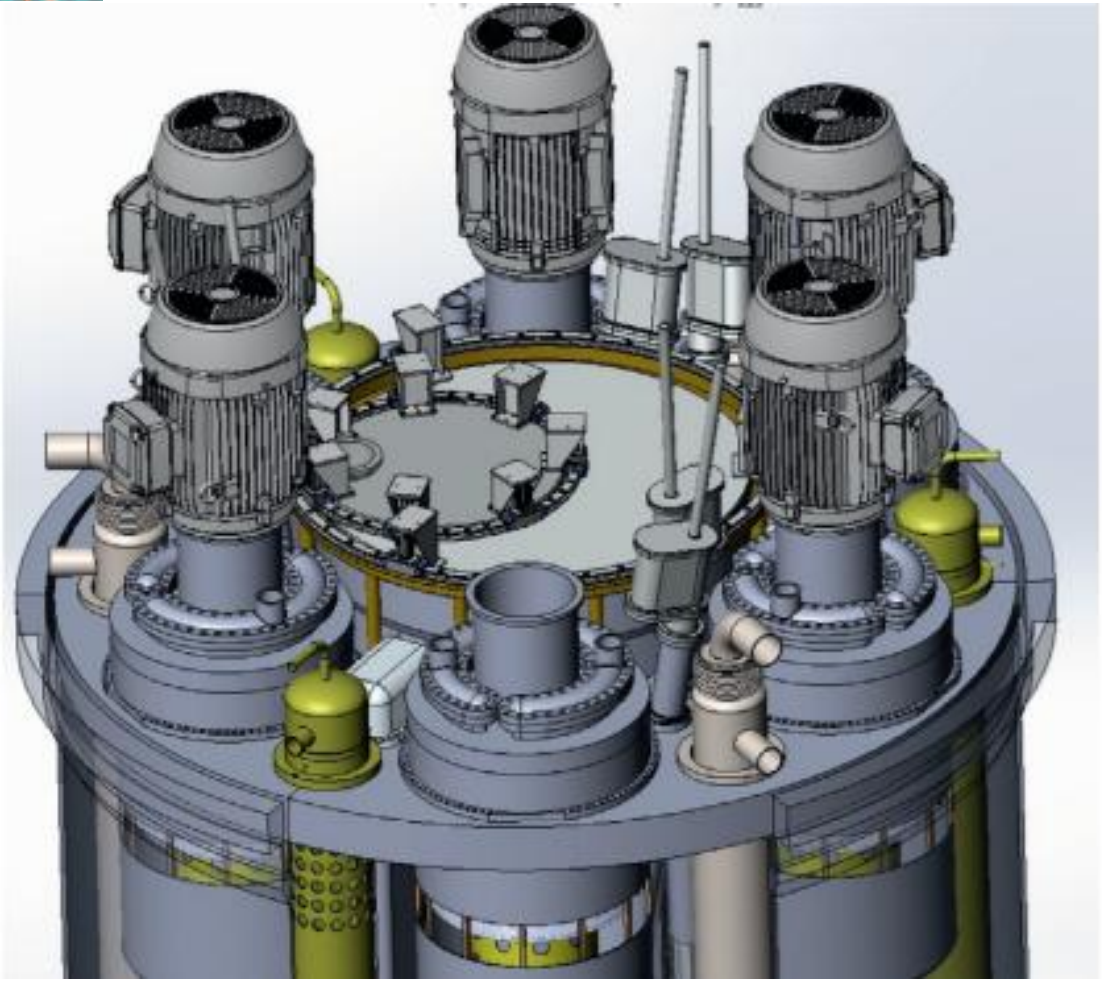


Westinghouse AP300

Hlavne parameter AP300

- Reactor description: One-loop pressurised light water reactor based on the proven AP1000 design
- Thermal power (MW_t): 990
- Electric power-gross (MW_e): 300
- Outlet temperature (°C): 325
- Spectrum of neutrons: Thermal
- Fuel type: UO_2 pellets
- Fuel: LEU
- Supplier: Westinghouse
- Potentional locality: Ohio and West Virginia-USA

LFR-AS-200

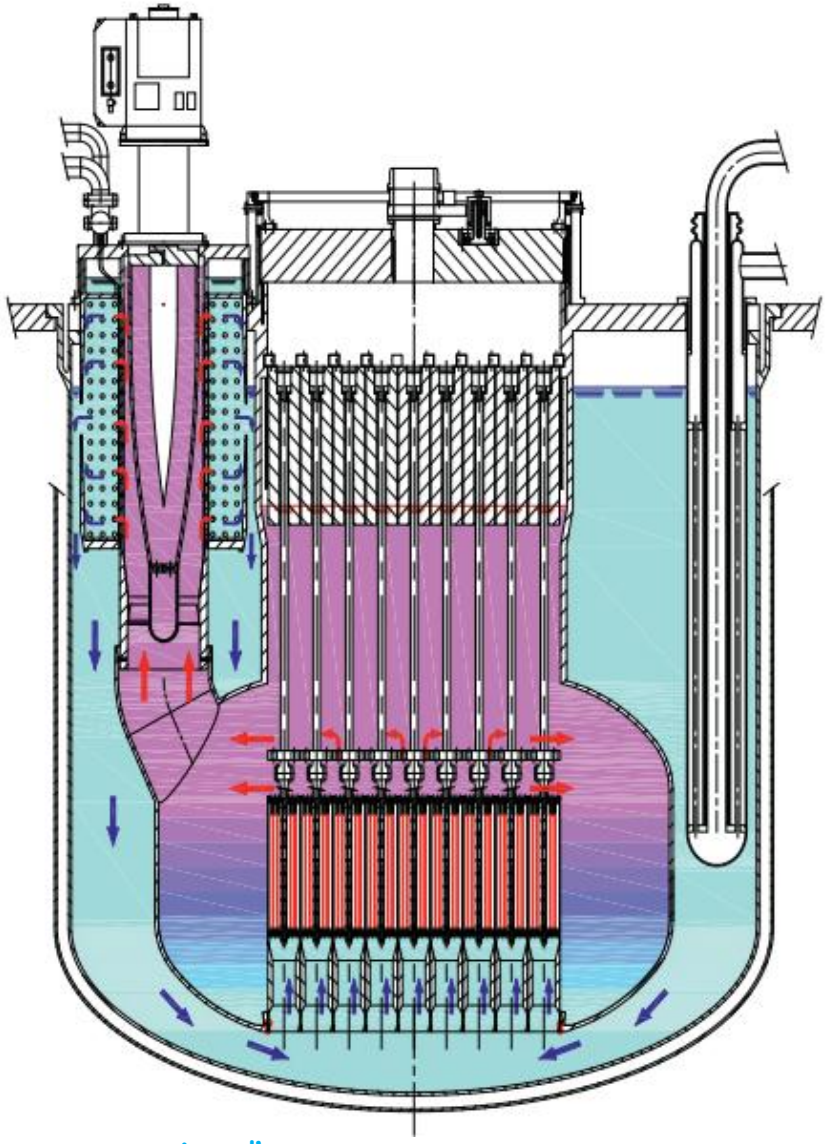


Hlavne parameter LFR AS200

- **Neutron energy spectrum:** fast
- **Coolant:** Lead or Lead-Bismuth (as alternative)
- **Moderation:** Lead and LBE (weak moderation)
- **Boiling point of coolant:** 1737°C
- **Pressure of coolant:** 2.9×10^{-5} Pa
- **Fuels:** UO_2; MOX; U+PU
- **First implementation:** reactors OK-550 and BM-40a in nuc-submarines (USSR)
- **Projects:** LFR-AS-200 (Newcleo, UK); BREST-OD-300 (NIKIET, Russia); MYRRHA (SCK-CEN, Belgium); ALFRED (Ansaldo, Italy-Romania)

Konštrukcia LFR-AS-200

- Power (MW_t/MW_e): 480/200
- Core inlet/outlet temperature (°C): 420/530
- Primary side pressure loss (bar) 1,3
- Turbine inlet pressure (bar) 180
- Feed water /steam temperature (°C) 340/500
- Reactor vessel height/diameter (m) 6,2/6
- Core active height (cm) 85
- Type of fuel MOX
- Mass of fuel (t) 12,8



Konštrukcia LFR-AS-200

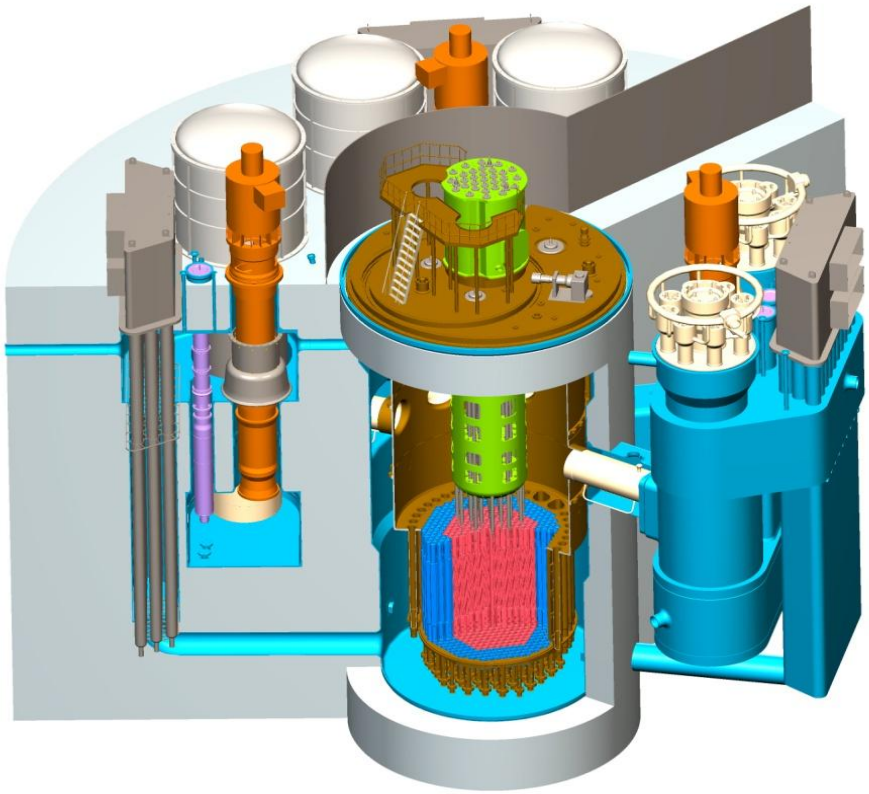
- The LFR-AS-200 is an integral pool-type fast reactor with all the primary components installed inside the Reactor Vessel (RV).

- The main primary components are six innovative Spiral-Tube Steam Generators (STSGs), six Mechanical Pumps (MPs), flag-type control rods and three + three dip coolers belonging to two diversified, passive, redundant DHR systems.

Konštrukcia LFR-AS-200

- Thanks to the properties of lead, intermediate loops are not required with several special precautions intended to deterministically eliminate any risk of important primary system pressurization: among them are water and steam collectors that are located outside the RV and short in-vessel Spiral-Tube Steam Generators (STSGs) partially raised above the lead-free level of the cold collector.
- The FAs extend with a stem above the lead-free level eliminating the necessity of an in-vessel refueling machine. Refueling is performed under visual control and sealed conditions by means of two rotating plugs and an ex-vessel refueling machine.

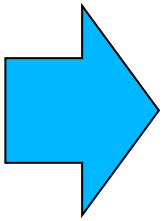
BREST-OD-300



- *BREST is a lead-cooled fast reactor with uranium-plutonium mononitride fuel that has a two-circuit heat transport system*
- *BREST-OD-300 fast reactor and on-site fuel cycle facilities are to be built at the Siberian Chemical Plant near Tomsk*

BREST-OD-300: Design Basis

- Exclusion of severe accidents at nuclear power plants requiring people evacuation
- Closed NFC to fully exploit the energy potential of uranium feedstock
- Consistent approach to radiation equivalence of definitively buried RAW with respect to the originally used natural uranium raw materials
- Technological strengthening of non-proliferation
- Phased justification of resource characteristics of the reactor elements for creating commercial NPP with LFR



- Use of low-activated coolant with sufficiently high boiling temperature, without rough interaction with water and air
- Core with mixed uranium-plutonium nitride fuel. Full breeding of fissionable materials, capability of transmutation of minor actinides
- Integral-type arrangement with multilayer reinforced concrete vessel
- No overpressure in the primary circuit (hydrostatic only)
- Emergency coolant system with natural circulation, transferring heat directly from the first contour to the final absorber – atmospheric air
- No lock fittings in the first circuit
- Double-circuit design with steam overheating

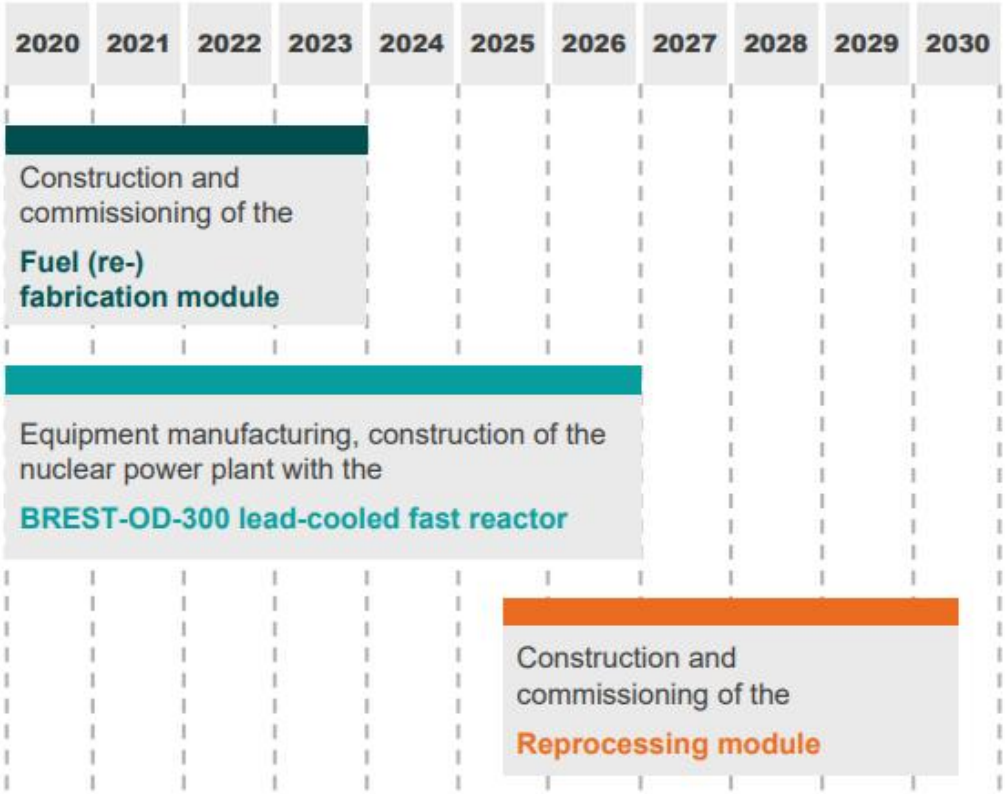
BREST-OD-300: základne parametre

Thermal power, MW	700
Electric power, MW	300
Fuel	Mixed uranium-plutonium nitride
Primary circuit coolant	Lead
Average temperature of the lead coolant (core inlet/outlet), °C	420/535
Steam pressure (SG outlet), MPa	17.0
Average temperature of the coolant on the steam generator entry/ exit, °C	340/505
FA number in the core	169
Loop number	4

Výstavba BREST-OD-300

Proryv project: practical demonstration of all elements of the closed nuclear fuel cycle (CNFC) at the Pilot Demonstrational Energy Complex (PDEC)

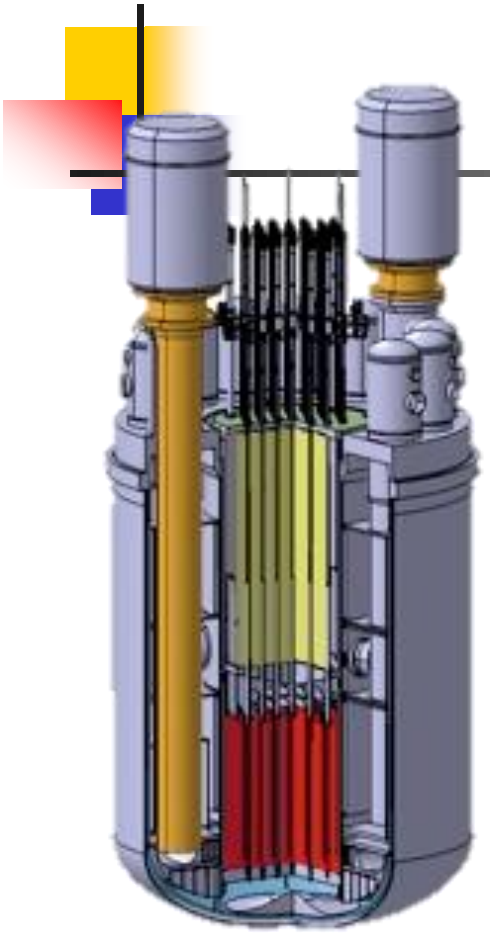
Pilot Demonstrational Energy Complex (PDEC), in construction © SCC



newcleo

11

SVBR-100



- *SVBR-100 is an innovative, small, modular fast reactor with lead–bismuth coolant. The project is carried out by JSC AKME-engineering - a 50/50 joint venture of the State Corporation Rosatom and private partner En+ Group*
- *In February 2015, JSC AKME-engineering got a license granting the right to place a nuclear power plant facility with SVBR-100 reactors in Ulyanovsk region (Dimitrovgrad)*
- *In October 2015, the Scientific and Technical Council of Rosatom approved the results of the expert review for the design of the SVBR-100 reactor facility and the design of a pilot production power unit with an SVBR-100 reactor*

SVBR-100 – základne parametre

Thermal power, MW	280
Electric power, MW	101
Fuel/enrichment, %	UO_2/16
Primary circuit coolant	Lead-Bismuth
Fuel campaign duration, year	7-8
Reactor module dimensions (diameter/height), m	4,5/8,2

Záver

- MMR sú vhodne pre neštandardne riešenia
- Nadej do budúcnosti