National Center for Nuclear Research

Status of Molybdenum Program in National Centre for Nuclear Research

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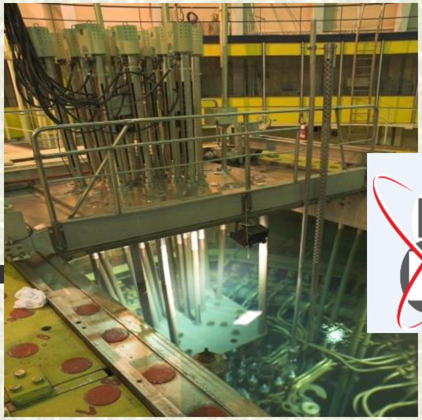
MARIA RESEARCH REACTOR

Molybdenum Program



- **NCBJ is willing to provide solution ensuring sustainable production and distribution Mo-99 in both <u>mid and long terms</u> based on irradiation HEU & LEU targets in MARIA RR and using the new MPF (Molybdenum Processing Facility)**

- **Molybdenum Program provided in NCBJ includes:**

  1) **Technology of irradiation targets in MRR: HEU/LEU-based,**
  2) **Molybdenum Processing Facility (MPF) located on NCBJ site: LEU-based production Mo-99 & Mo-99/Tc-99m generators;**
  3) **Participation on existing programs including "*Developing techniques for Molybdenum-99 production using neutron activation*" (collaboration with JAEA, MURR and IAEA)**

BACKGROUND INFORMATION: ^{99}Mo Production

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- European production was based on HEU target irradiation on five reactors: HFR (Petten, NL), BR2 (Mol, B), MARIA (PL), LVR-15 (Rez, CR) andd OSIRIS (Sacley, FR);
- Reactors were operated as a supply network within Europe in conjunction with two Mo-99 processing facilities operated by Mallinckrodt (Petten, NL) and IRE (Fleurus, B);
- Supply elsewhere in the world is not-worked and exist as a number of single supply lines of geographically isolated reactor processing facilities (Canada, South Africa and Australia, Argentina);
  - single break in the supply chain completely stops Mo-99/Tc-99m supply
- With the ageing of the European supply network it is necessary to consider new reliable supply sources.

BACKGROUND INFORMATION:
^{99}Mo Irradiators World Net

Reactor	Country	Operating days	Forecasted date of operation
HFR	Netherlands	280	2022
BR-2	Belgium	140	2022
MARIA	Poland	180	2030
OSIRIS	France	200	2015
LVR-15	Czech Republic	200	2029
NRU	Canada	300	2016
OPAL	Australia	290	2015
SAFARI-1	South Africa	300	2027
RA-3	Argentina	330	2022

Radioisotope production Mo-99
Main irradiation facilities

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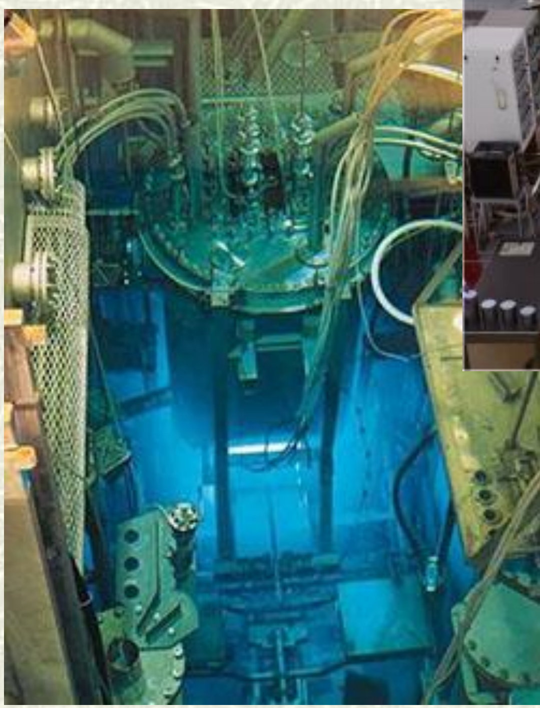
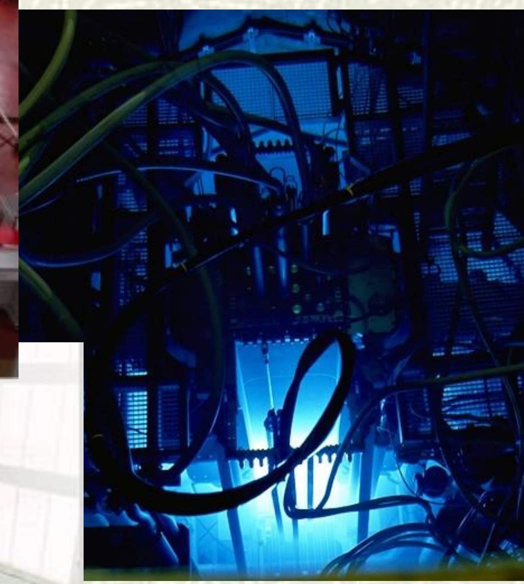
SAFARI-I (1965)
South Africa



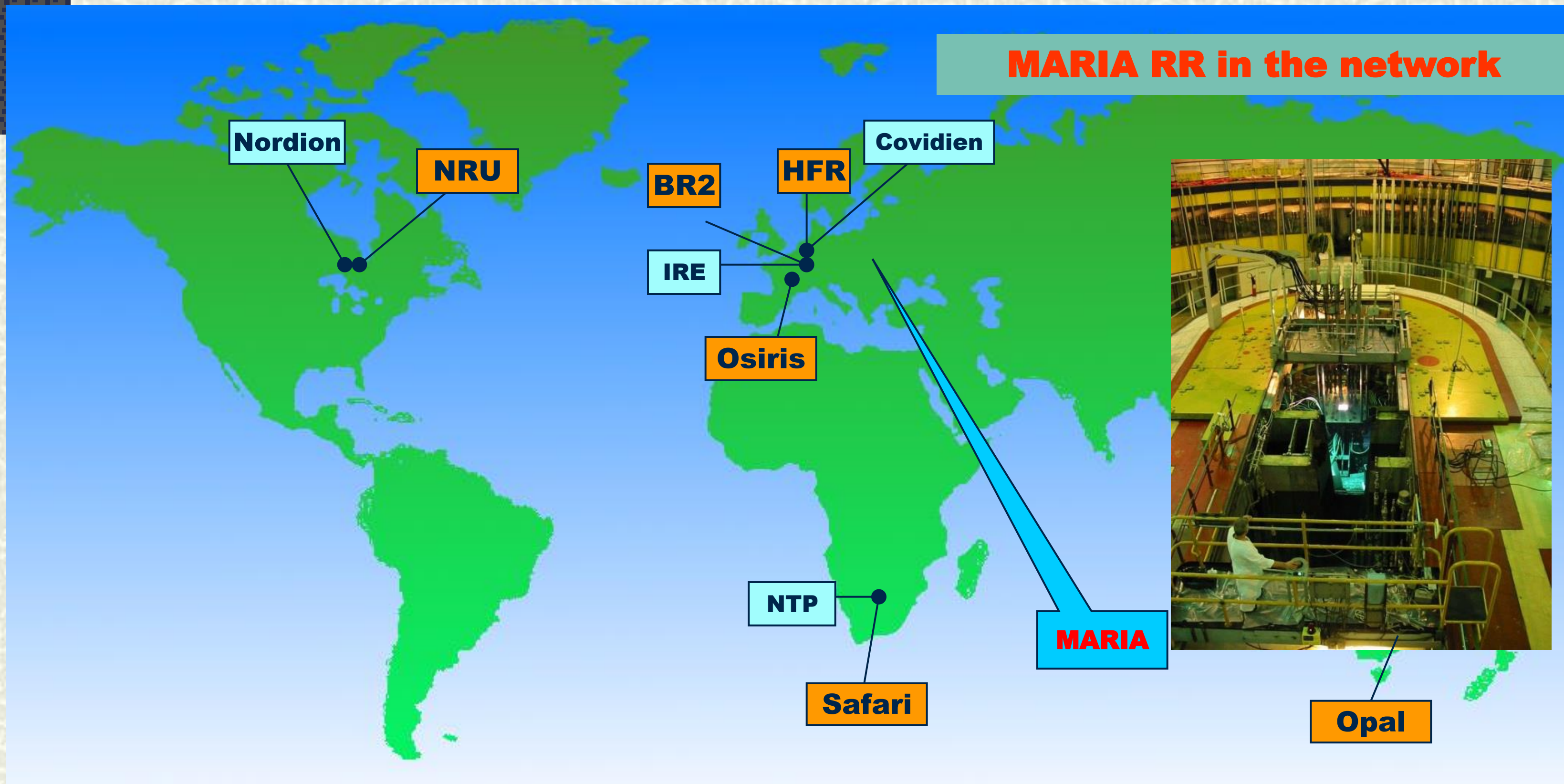
BR2 (1961)
Belgium



HFR – 45 MW
Netherlands

NRU – 135 MW
Canada

Reactors and Mo-99 Processing Facilities around the world



RR in operation

- BR2, Belgian Nuclear Radiopharmacy Centre, Belgium
- OSIRIS, France, French Atomic Energy Commission (CEA)
- NRU, National Research Universal Reactor, Canada
- HFR, Nuclear Research & Consultancy Group (NRG), The Netherlands
- SAFARI-1, South African Nuclear Energy Corporation (NESCA), S.Africa
- OPAL – ANSTO, Australia

Mo-99 Processing Facilities

- COVIDIEN, USA / The Netherlands
- MDS Nordion, Canada
- Nuclear Technology Products (NTP), S. Africa
- The Institute for Radio Elements (IRE), Belgium

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- **General assumption**: production rate of ^{99}Mo should be proportional to fission power generated from uranium targets in irradiation rig:

A – ^{99}Mo activity, P – fission power, λ - decay constant ^{99}Mo,
γ = 0.0611 – production efficiency of ^{99}Mo per one fission act;
$E_f = 3.244 \cdot 10^{-11}$ J – generated energy per one fission act:

$$\frac{dA}{dt} = \alpha P - \lambda A \qquad \alpha = \gamma\lambda / E_f \qquad (1)$$

- Alfa constant based on physical properties and ORIGEN code calculation:

$$\alpha = 5.47E3\left[Bq/Ws\right] \qquad (2)$$

- Integrating equation (1) within the irradiation time (0,t) we receive a relation of activity of ^{99}Mo to be formed from the fission power generation in the plate.

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Molybdenum Program

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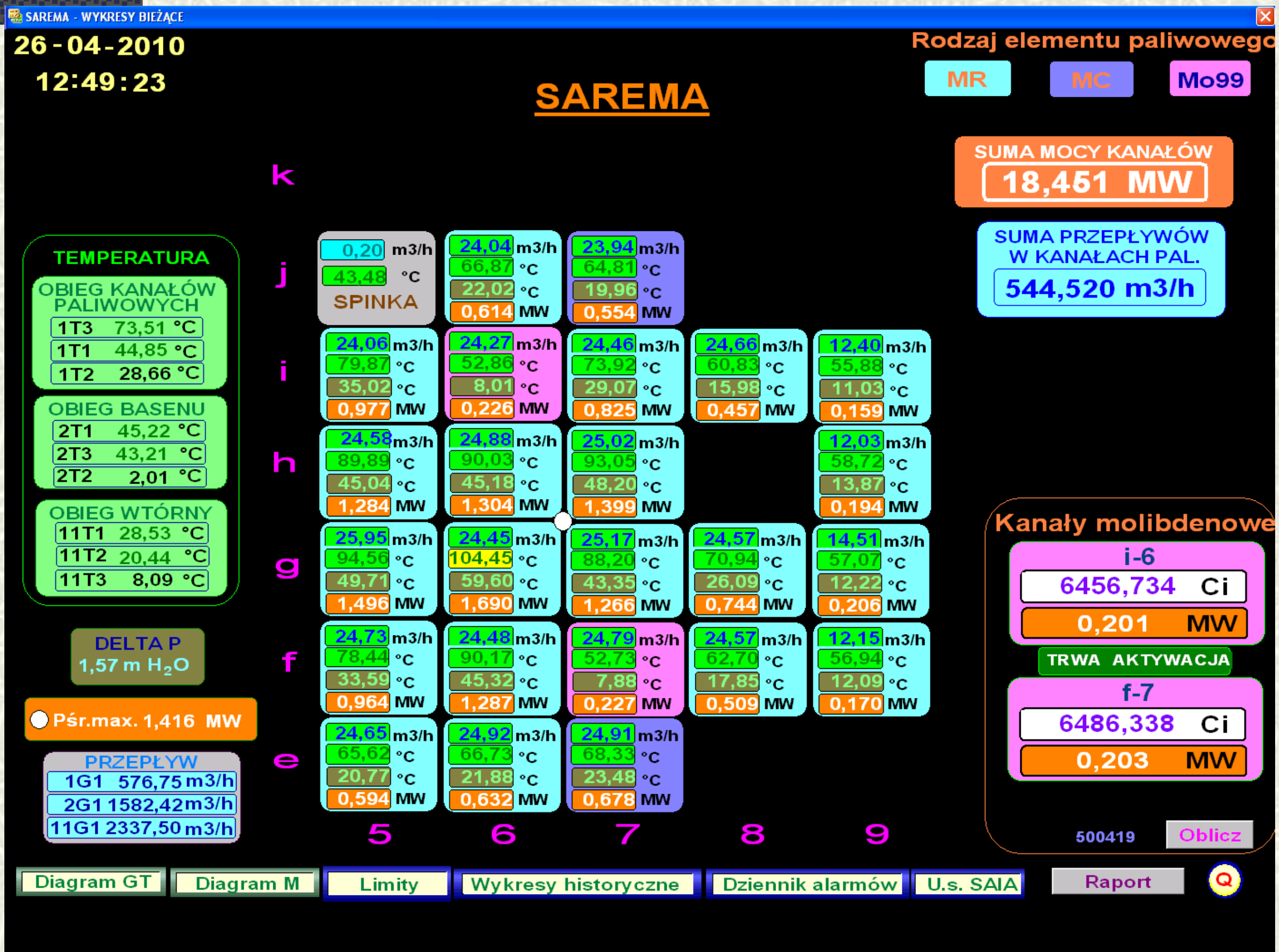
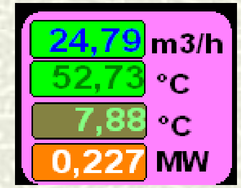
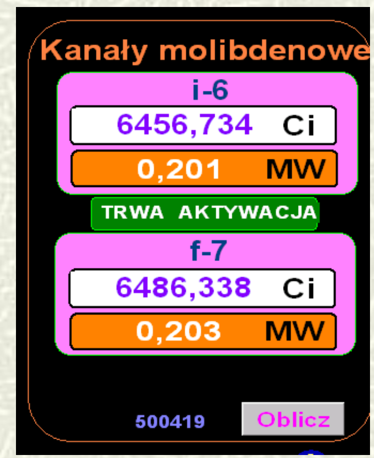


Moly channel f-7





Screen of SAREMA system – reactor MARIA

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The Safety Analysis, Test & Manufacturing for Certification of new HEU targets

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Target qualification & technical specification

Safety analyses & Design

Design and Safety Analysis Report

Manufacturing and commissioning

Hot test with dummy targets

Hot test with HEU / LEU targets

Safety Analysis Report

Safety Commission Approval

National Regulatory Body Approval

Domestic & Foreign Licenses

Transport container

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Molybdenum Program

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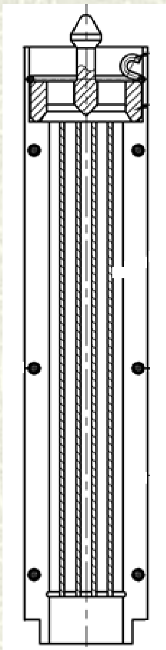
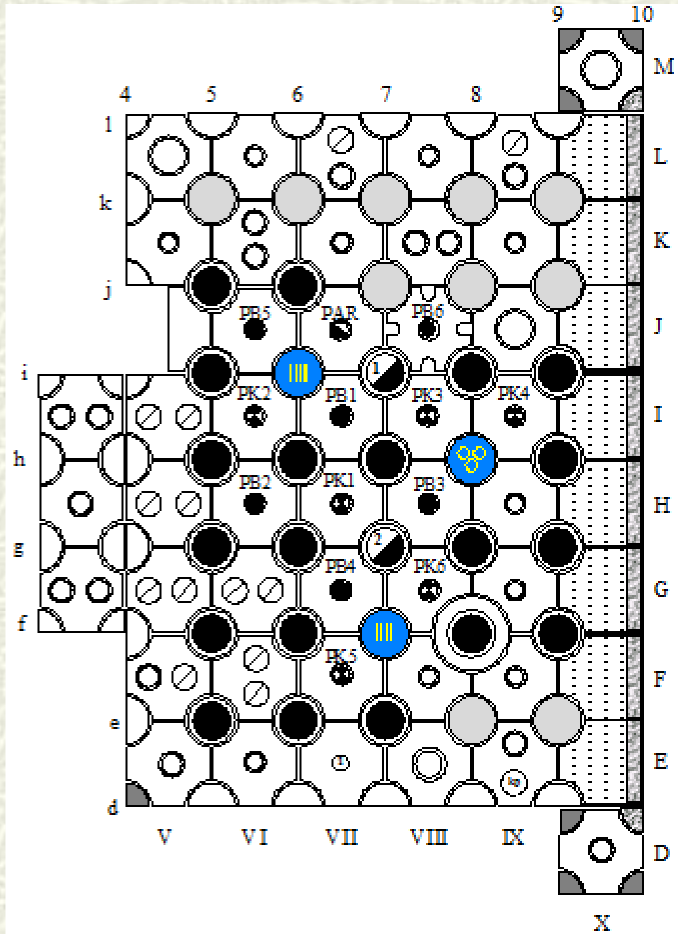
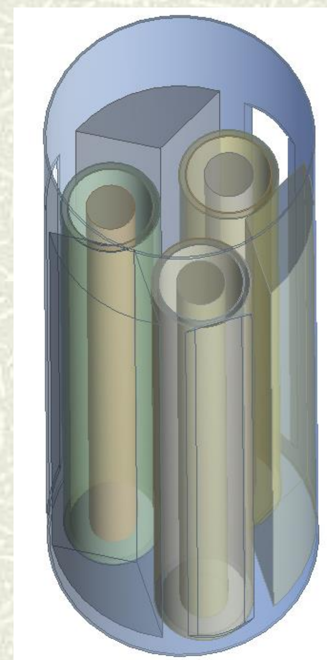


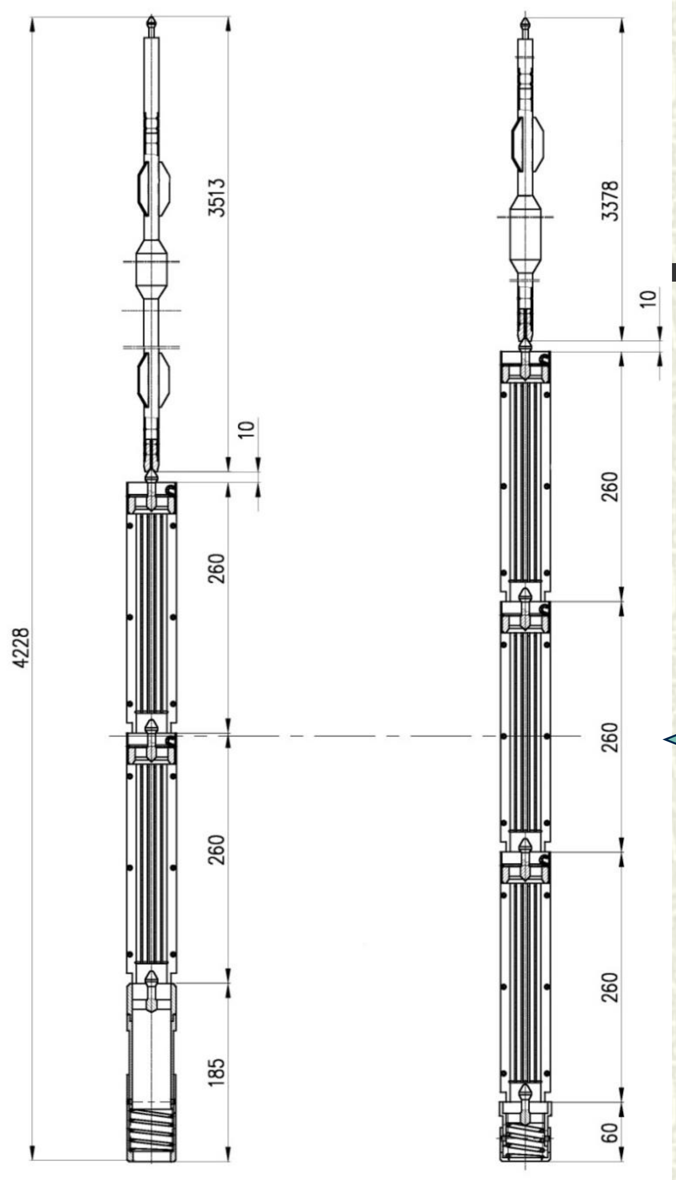
Irradiation container
for plate targets

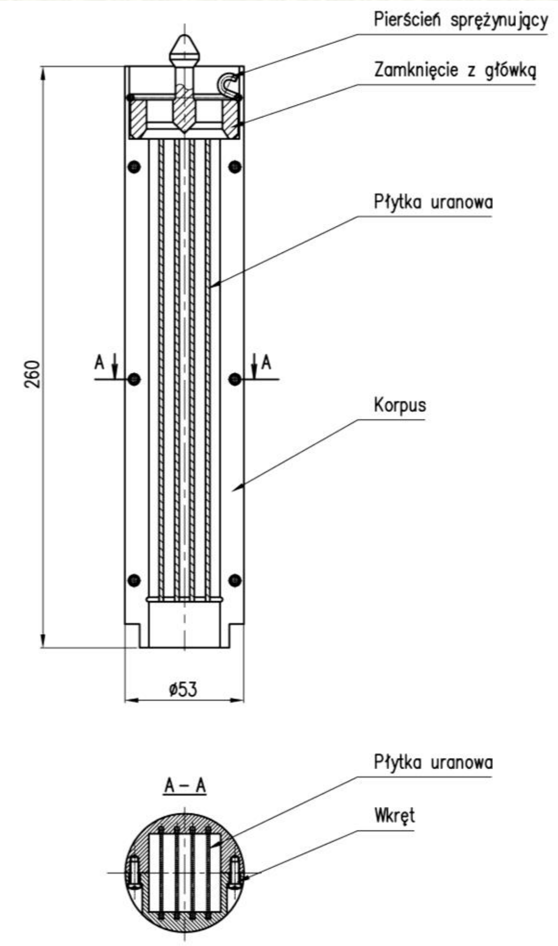


Irradiation container
for tubular targets



MARIA Research Reactor
Irradiation facility



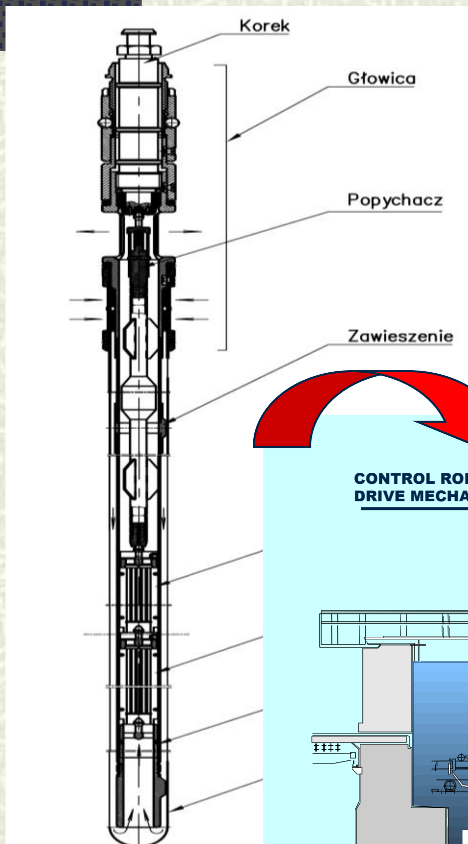


Irradiation rigs: (1) - 2 containers x 4 targets

and 2 containers x 4 LEU targets

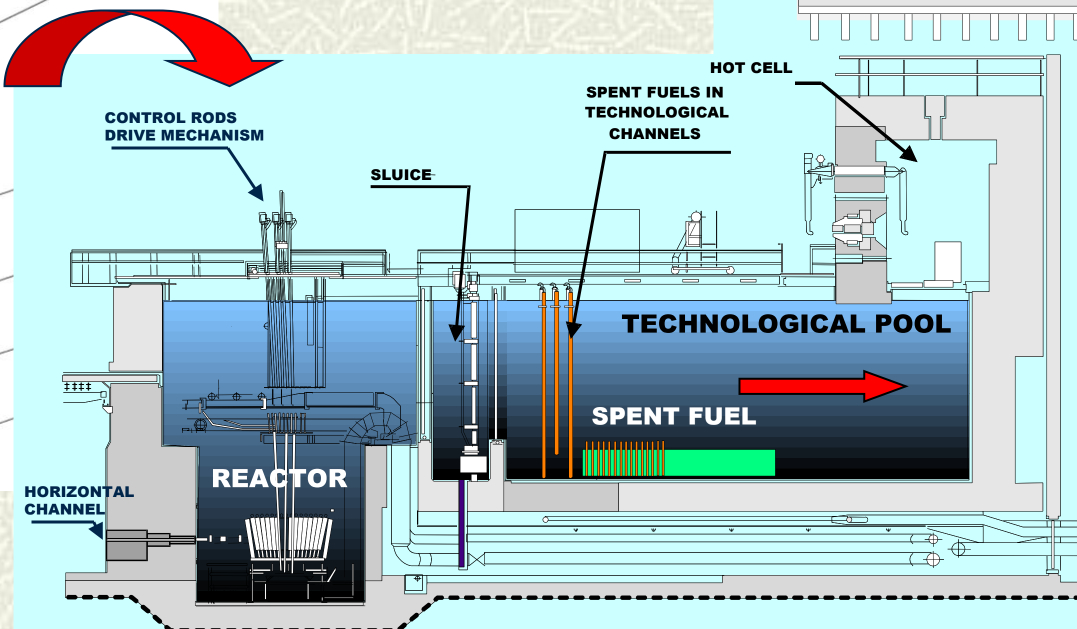
Molybdenum Program

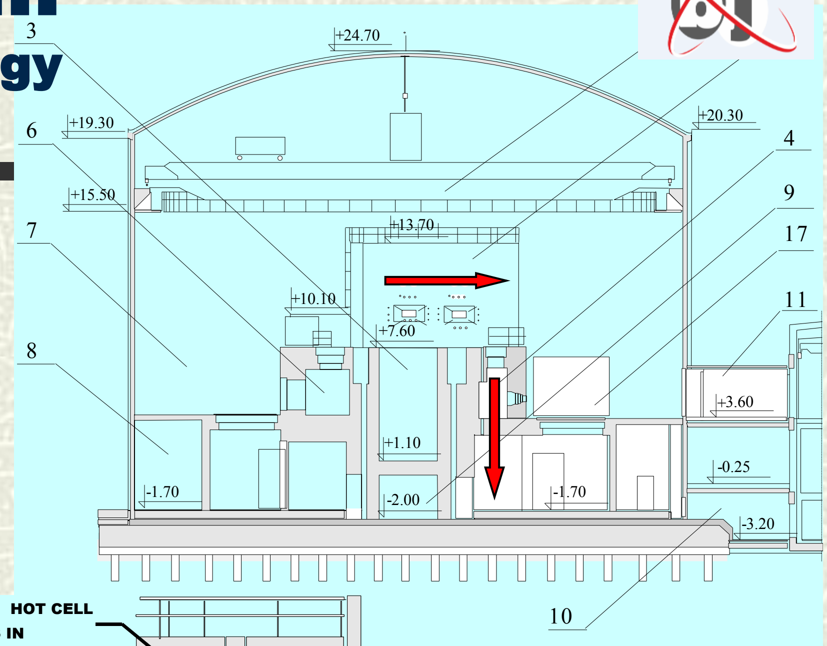
Base steps of irradiation technology



Irradiation Rig

Irradiation & transport targets to Hot Cell





Reloading operation in Hot Cell

Transportation container

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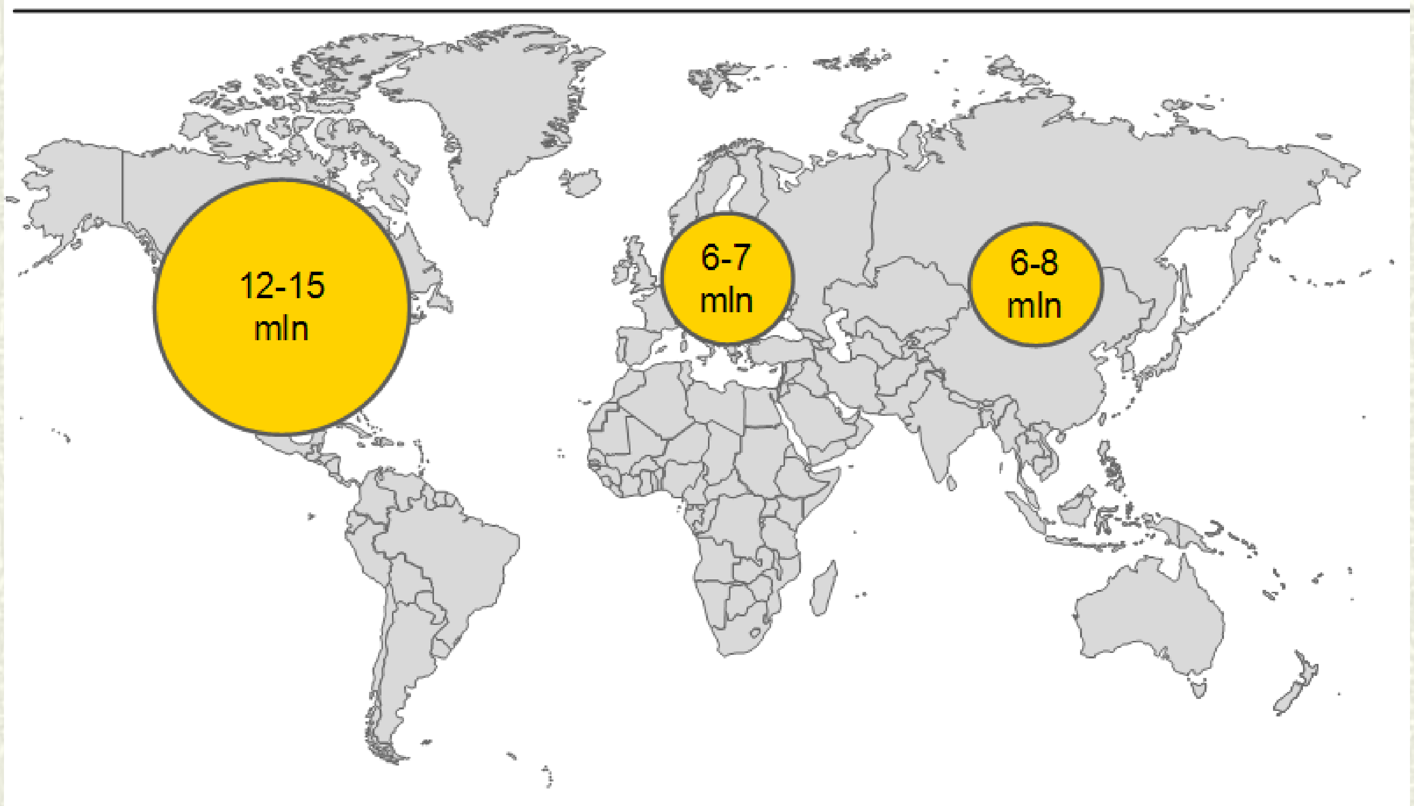
Molybdenum Program

Number of medical procedure around the world based on ^{99}Mo/ ^{99m}Tc generators (2009 y)



Source: Prelminary report on supply of radioisotopes for medical use and current developments in nuclear medicine, EC 2009

BACKGROUND INFORMATION:
^{99}Mo Production

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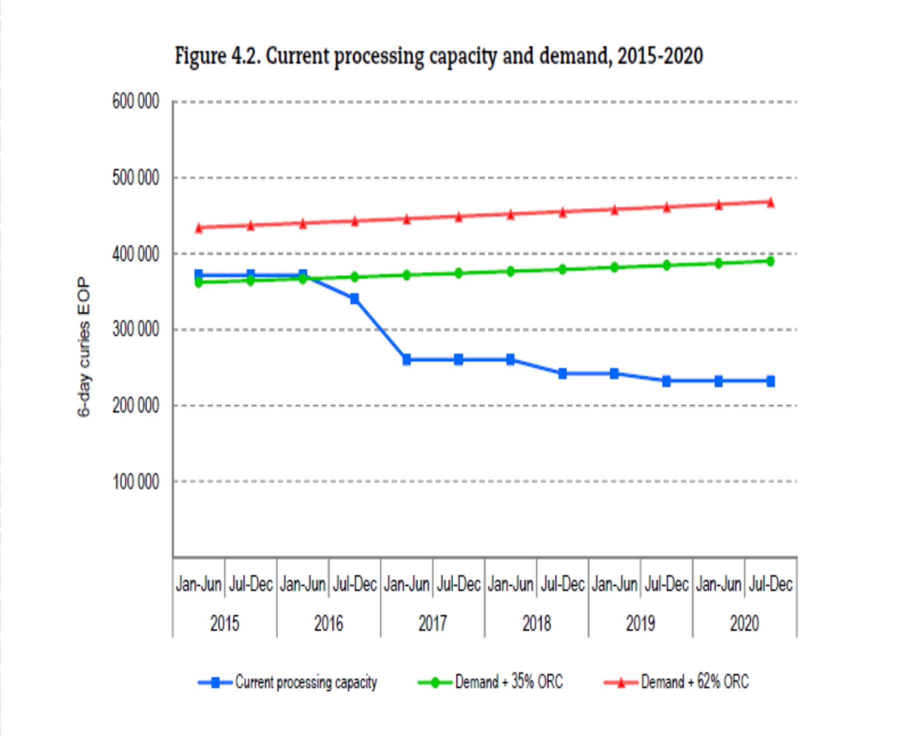
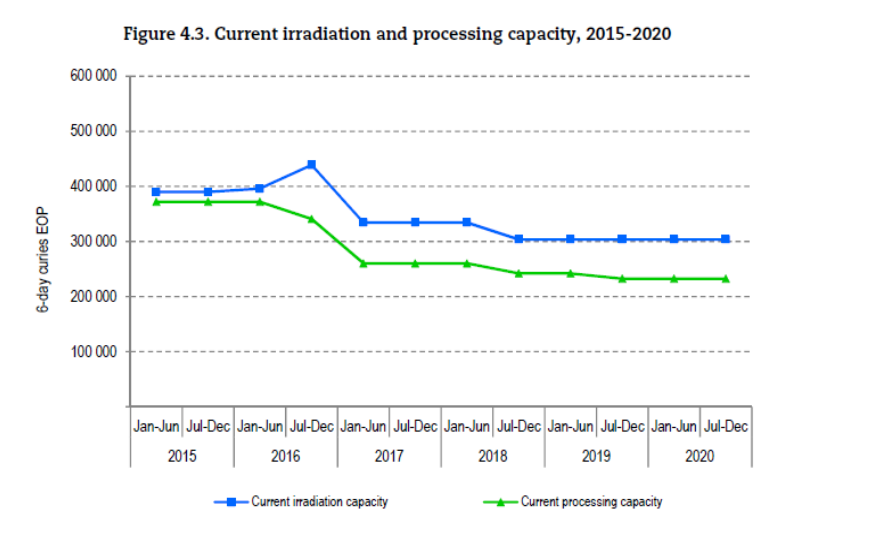




BACKGROUND INFORMATION: ^{99}Mo Production

- **Processing facilities should be located close to the reactors:**
  - the primary reasons for this is minimize the transport of high activity fissile nuclear materials;
  - reduce as much as possible the decay loss of Mo-99 (the quantity of Mo-99 produced decay by 1% per hour from the EOB);
  - the processing site should be licensed for waste management.
- **The main European Mo-99 producers: COVIDIEN and IRE plants are located at reactor site or on reasonable distance:**
  - COVIDIEN plant is located at the HFR site; PALLAS location will be same
  - IRE plant is located close to BR-2; MYRRAHA location will be same,
  - Plans for new plant be located in Munich (TUM site next to FRM II) and / or Cadarache (CEA site next to JHR).

„Molibden – Świerk" Project

Project defined as follows:

- **Design and construction of the two parallel technological lines for Mo-99 production with LEU targets (UAl_xAl) irradiated in reactor MARIA (2x500 Ci /w 6-days Mo-99) will be placed in a new building near reactor;**

- **Establishing of the new line for Mo-99/Tc-99m generators manufacturing, which will be placed inside the POLATOM building (capacity of 500 units /week)**

„Molibden – Świerk" Project

Uranium targets irradiation

HEU/LEU

LEU

Mo-99

Technetium generators production

Mo-99/Tc-99m

Mo-99

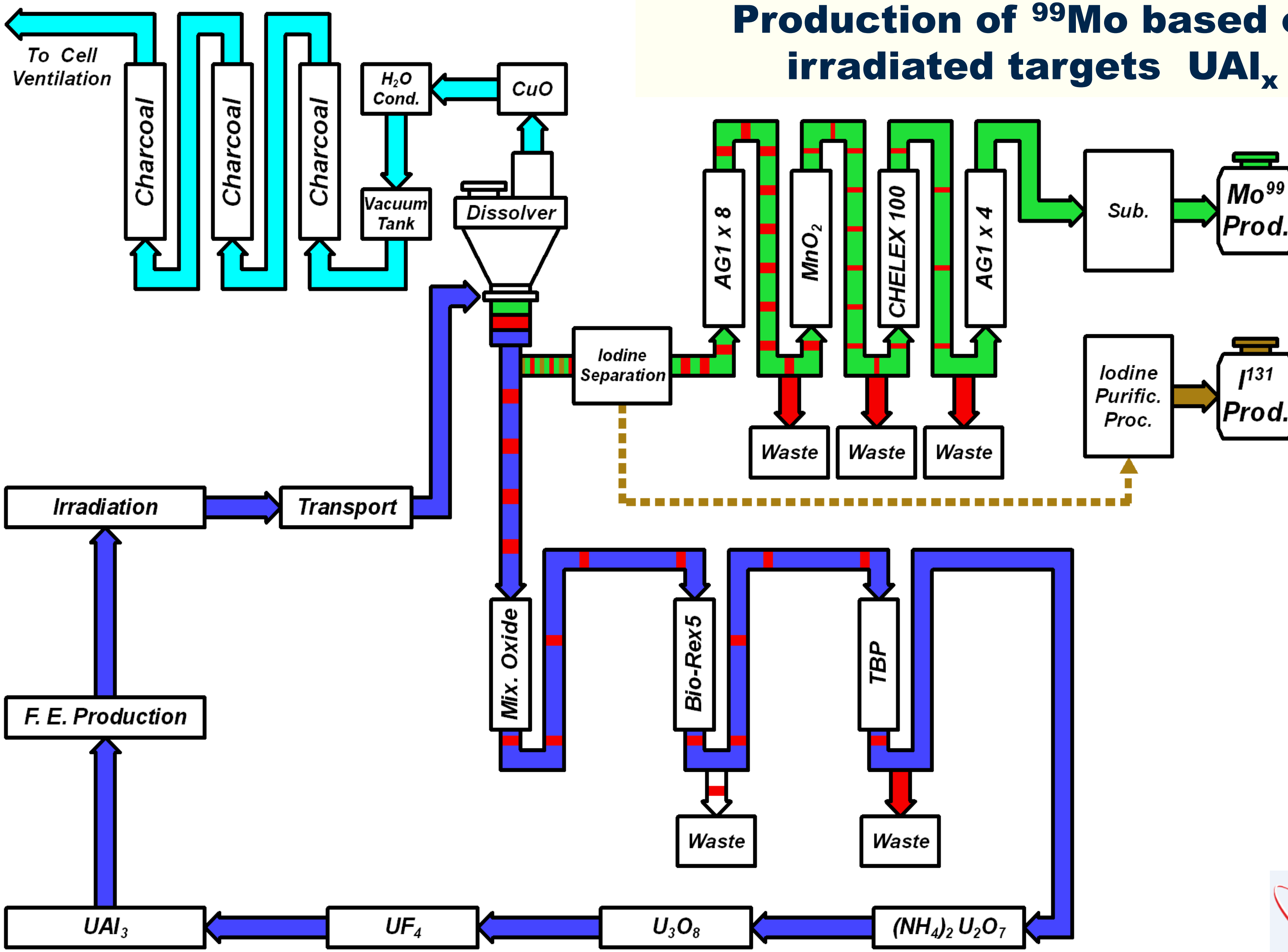
Mo-99 production (MPF)

„Molibden – Świerk" Project

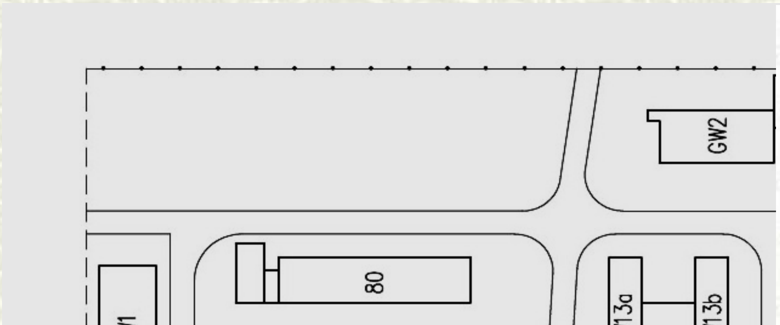
Target Specification: "MOLIBDEN 2010" Program

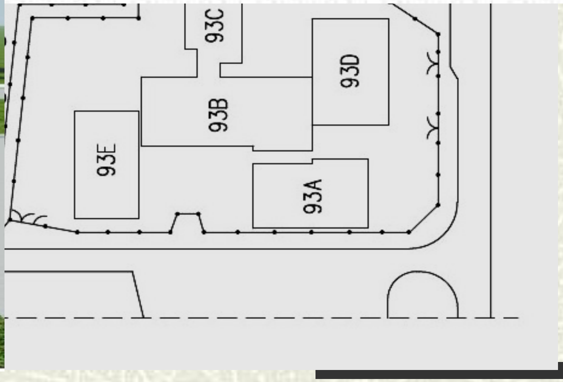
target specification		HEU	LEU	LEU	LEU
target core material		UAlx-Al	U_3Si_2-Al	UAlx-Al	UO_2-Al
type of target		plate	plate	plate	cylinder
target dimension	mm	203 x 40 x 1.45	203 x 40 x 1.35	203 x 40 x 2.00	$Ø_{out}$ = 25.0
core meat dimension	mm	191 x 27.5 x 0.85	186 x 29.5 x 0.75	186 x 29.5 x 1.4	$Ø_{in}$ = 24.4
meat thickness	mm	0.85	0.75	1.4	0.6
enrichment	%	93	19.75	19.75	19.75
U density	gU_T/cm^3	1.1	4.8	2.6	3.8
U_{total} loading	g	5.1	23.8	11.7	11.7
^{235}U loading	g	4.7	4.5	2.3	5.3
amount of Al in the core	g	11.6	6.9	10.4	bd.
amount of Al in the target	g	20.3	20.3	20.3	bd.
number of targets (batch)		8	8	8	6
total mass of ^{235}U (batch)	g	37.6	36.0	31.6	37.6

Production of ^{99}Mo based on irradiated targets UAl_x



Location of the building for ^{99}Mo and ^{99m}Tc generators production

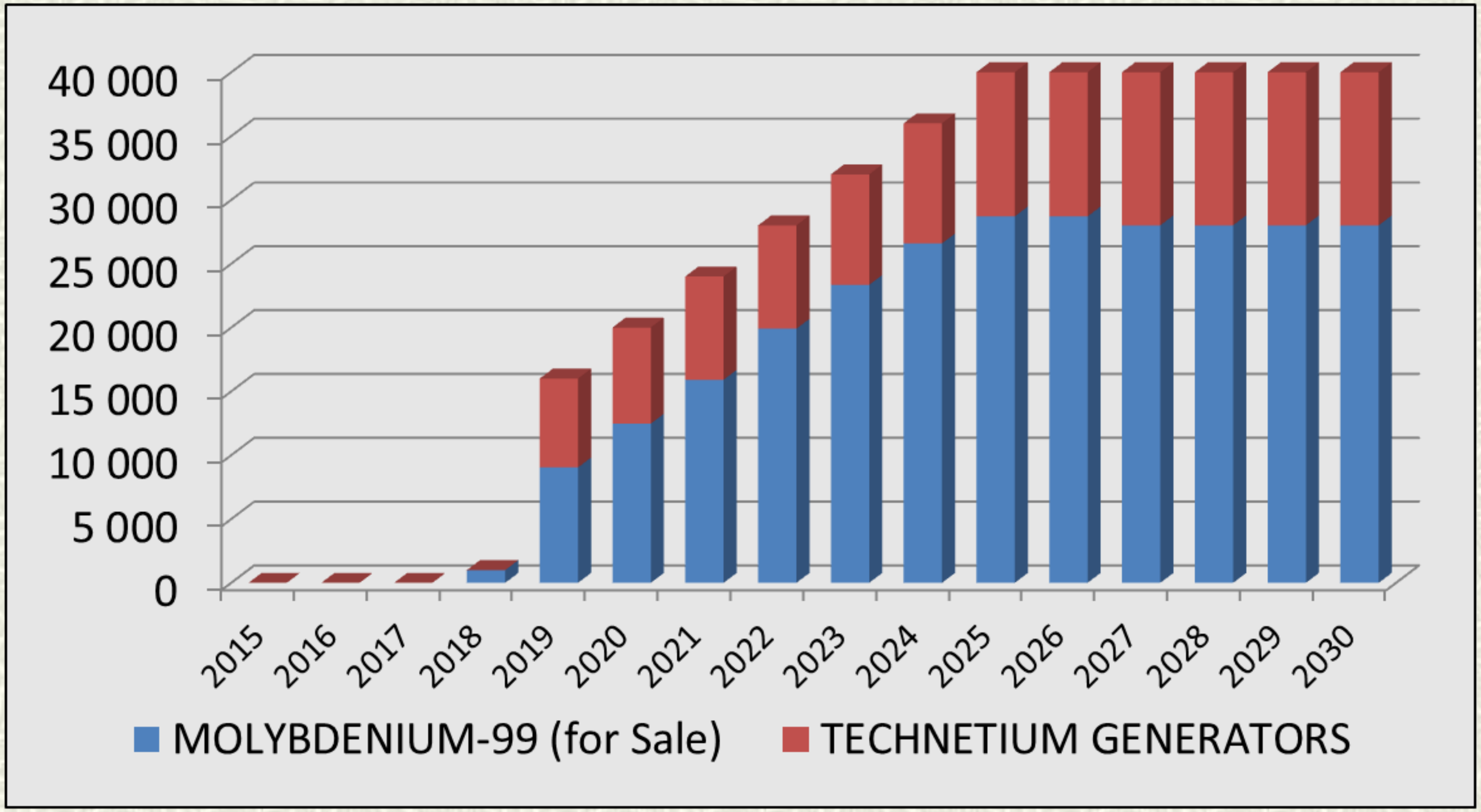




„Molibden – Świerk” Project

Financial Model

Chart 1: Production Output: Technetium Generators and Mo-99 (Ci Mo)



Source: Business Plan by NCBJ


THANK YOU
for Your Attention

Determining the activity of ^{99}Mo in irradiated uranium targets

- The measurements of temperatures and flow rate of coolant in reactor fuel channels are conducted by standard reactor measuring system SAREMA;
- Using the quantities measured the total reactor power (P) to be sum of thermal powers of fuel channels and reactor pool is calculated;
- These measurements, don’t supply direct information on current fission power, to be generated in fuel channel; they are taking into account additionally heat generation due to gamma radiation from FE and the heat exchange between FE and reactor pool;
- To estimate the ^{99}Mo activity in molybdenum channel it is necessary to get information on real fission power to be generated in uranium plates.

Technical characteristic of uranium targets & irradiation rig

- The uranium targets: plates with dimension of 203x40x1.45 mm; the core including fission material in the shape of dispersion in aluminum: UAl_x ($x \cong 3$) in Al (> 90% ^{235}U);
- Container for irradiation of uranium target includes 8 plates positioned in special cans (four plates on each);
- Irradiation of uranium plates set takes place in the adopted for this goal fuel element of MARIA reactor;
- The internal structure of the molybdenum channel preserve the construction principle of the *Field's tube*;
- The construction of the internal fuel structure allows after reactor shutdown and removing the fuel channel head to take out and transportation of the irradiation container.

Alternative Molybdenum-99
IAE / NCBJ experience

Irradiation molybdenum targets using neutron capture method

- **Irradiation facility:** EWA & MARIA RRs
- **Target:** MoO_3 (powder)
- **Batch:** 3 x vials inside Al container
- **Irradiation container:** Θ 25 mm / L=100 mm
- **Container closing:** cold weld able
- **Mass:** 3x2,5g
- **Neutron flux density:** $1x10^{14}$ [n/cm^2 s] (MARIA)
- $8x10^{13}$ [n/cm^2 s] (EWA)
- **Yield at EOI:** 2.0 Ci/g (MARIA)
  1.2 Ci/g (EWA)
- **Time of irradiation:** 87 h (MARIA)
  1 week (EWA)

Alternative Molybdenum-99 IAE / NCBJ current status

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- Most of ^{99}Mo is produce using fission method: 95% of the world demand is covered by this method;
- The extremely low specific activity of ^{99}Mo from neutron capture method makes its use less convenient;
- Difficulties in terms of safety & waste management are limitation for production fission ^{99}Mo;

Current status:

- NCBJ plans continuation of irradiation of targets HEU & LEU
- NCBJ plans design, construct & operate own production facility based on irradiated in the MARIA RR LEU targets
- RR MARIA is ready to restart irradiation ^{98}Mo targets & participate on program neutron of (n,γ) method

Alternative Molybdenum-99 IAE / NCBJ experience

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Processing procedure

- Irradiated cans are opened using special cutters;
- Targets has been transferred to a solution flack containing 4N NaOH solution;
- Solution has been heated up to 60-70 ^{o}C to fascilate dissolution;
- Solution was stirred by passing compressed air;
- Solution was cooled and passed through a filter to remove any impurities;
- Result: sodium molibdate in sodium hydroxide solution;
- ^{99}Mo was used as a row material for conversion into medical product for extraction ^{99m}Tc.