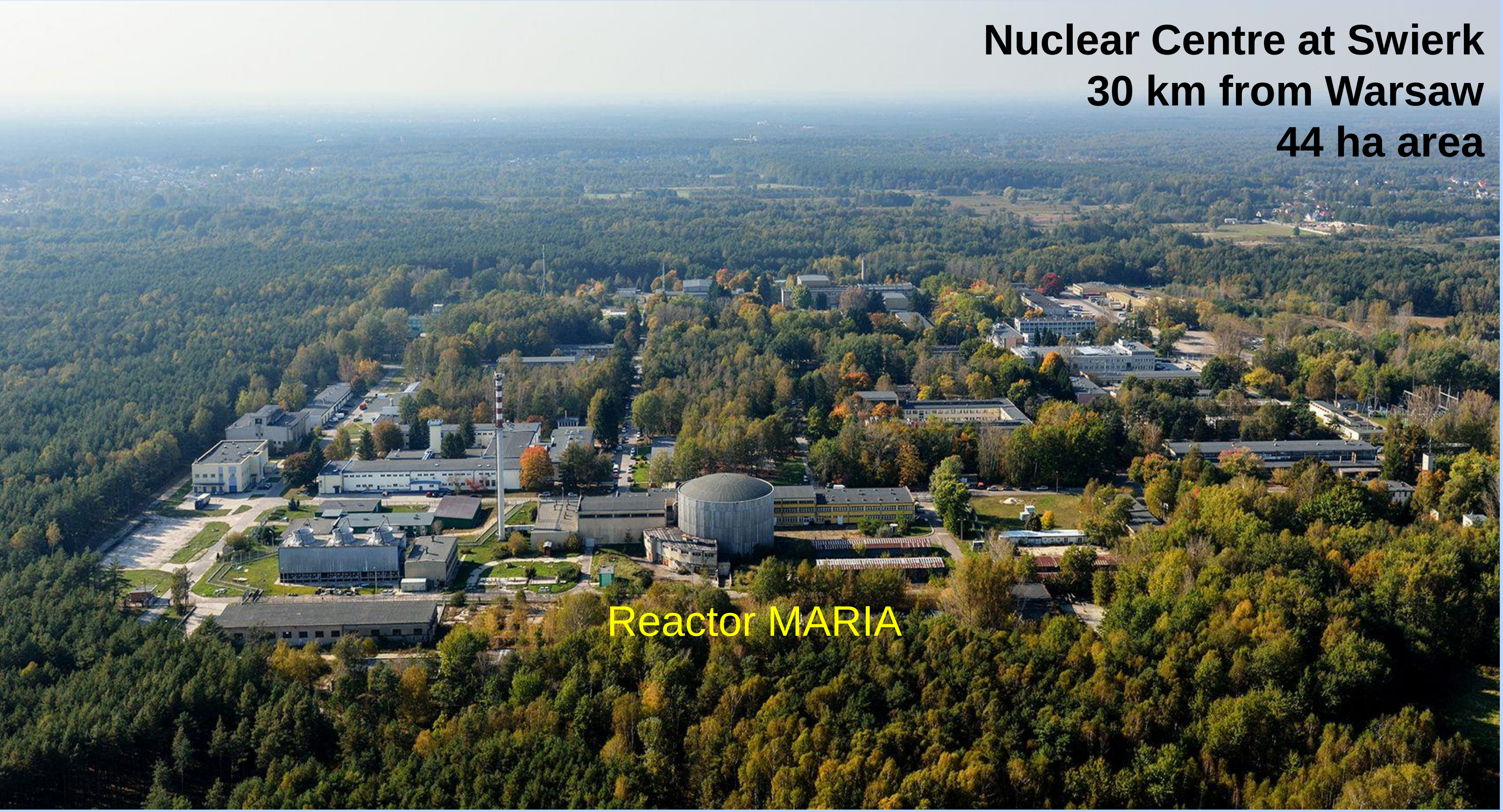
National Centre for Nuclear Research
ul. A. Sołtana 7
05-400 Otwock, Poland

Maria research reactor in supply chain of Mo-99

G. Krzysztoszek

August 31 – September 3, 2015, Boston, USA

NATIONAL CENTRE FOR NUCLEAR RESEARCH



INTRODUCTION

- In the half of 2009 a decision was taken on cooperating between MARIA reactor and COVIDIEN,
- MARIA reactor and COVIDIEN agreed to initiate an irradiation of high-enriched uranium plates in MARIA reactor for production of molybdenum Mo-99,
- There was developed the Mo-99 irradiation and transport technology in MARIA reactor facility and then its expedition to the processing facility in Petten (Holland),

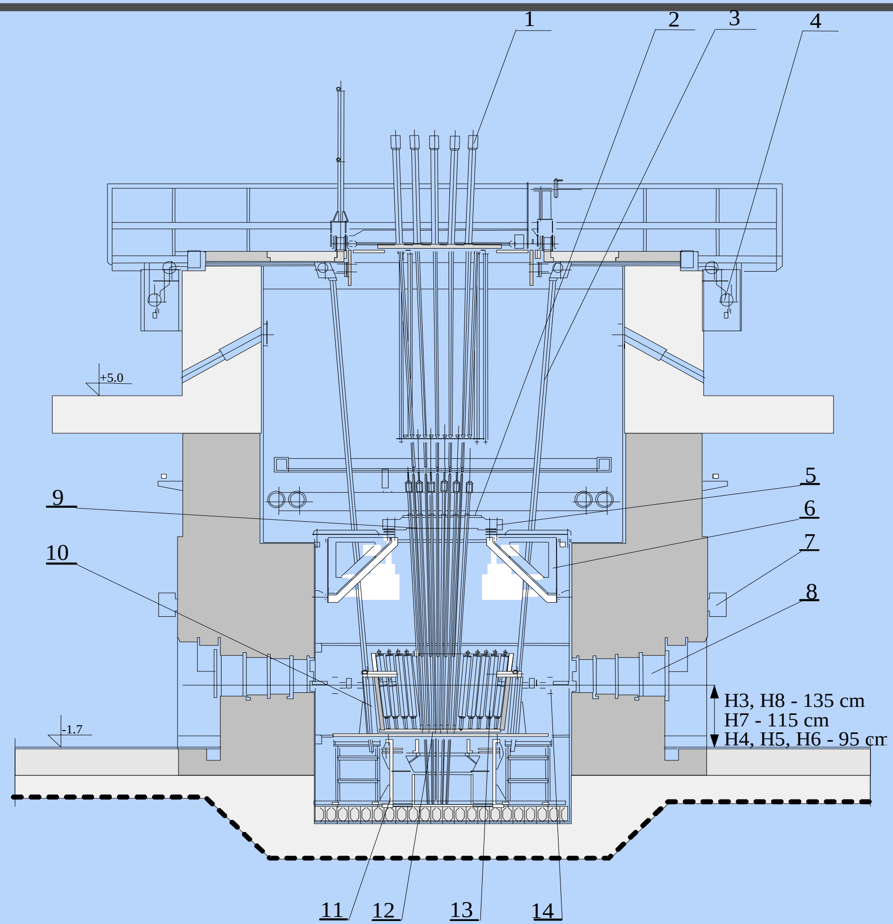
- MARIA reactor prepared:
  - physical calculation,
  - safety analyses,
  - technical designs and manufacture of equipment for irradiation and transport,
- We received the positive opinion of the Nuclear Safety Committee of IAE and approvals released by the National Atomic Energy Agency;
- The first irradiation of uranium plates has been taken place in the MARIA reactor in February 2010;
- In 2010 in MARIA reactor we have made 21 cycles of U-targets irradiation for Mo production;
- The reactor fully converted from HEU to LEU fuel in the end of August 2014;
- March 2015 – new license for reactor operation till the end of March 2025.

MARIA RESEARCH REACTOR DESCRIPTION

- The research reactor MARIA is operated at the National Centre for Nuclear Research;
- It is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels;
- The fuel channels are situated in a matrix containing beryllium blocks;

- Main characteristics and data of MARIA reactor are as follows:

• maximum power	30 MW (th)
• thermal neutron flux density	3.0×10^{14} n/cm^2 s
• moderator	H_2O, beryllium
• reflector	graphite in Al
• cooling system	channel type
• fuel assemblies:	
- material	U_3Si_2
- enrichment	19,75%
- cladding	aluminium alloy
- shape	five concentric tubes
- active length	1000 mm
• output thermal neutron flux at horizontal channels	$3 \div 5 \times 10^9$ n/cm^{2}s



1. control rod drive mechanism
2. mounting plate
3. ionization chamber channel
4. ionization chamber drive mechanism
5. fuel and loop channels support plate
6. plate support console
7. horizontal beam tube shutter drive mechanism
8. beam tube shutter
9. fuel channel
10. ionization chambers shield
11. core and support structure
12. core and reflector support plate
13. reflector blocks
14. beam tube compensator joint

Fig 1. Vertical section of the MARIA reactor.

- The main areas of reactor application are as follows:
  - production of radioisotopes,
  - research in neutron and condensed matter physics,
  - neutron radiography,
  - neutron activation analysis,
  - neutron transmutation doping,
  - testing of fuel and structural materials for nuclear power engineering.

DEVELOPING THE URANIUM TARGETS IRRADIATION TECHNOLOGY, SAFETY ANALYSIS, MEASUREMENTS AND TESTS:

In the period from June 2009 up to January 2010 was developed the technology for U-targets irradiation;

Calculations and safety analyses at steady states were as follows:

- safety analysis and design of irradiation rig,
- safety analysis of transport of plates into MARIA hot cell to processing facility using special transportation container,
- calculations of molybdenum activity,
- neutronic calculations,
- thermal-hydraulic calculations at steady states,
- activity of fission products and thermal power of the uranium plate batch.

Program of examinations and installation tests consisted of:

- hydraulic measurement of channel for irradiation of containing the mock-ups of plates,
- cold trials of reloading and transport operations with a batch of dummy plates,
- calibration measurements of calorimeter for measuring of thermal power of 4 plate batch,
- measurement of the heat balance in molybdenum installation with the dummy plates,
- test irradiation of uranium plates and their dispatching,
- measurements of temperatures of uranium plates in the air.
- handling and loading of plates into the transport Marianne cask,

CURRENT STATUS OF MO-99 PRODUCTION IN THE MARIA REACTOR

- In the period from February 2010 to the end of 2014, 76 irradiation cycles in in the MARIA reactor were conducted;
- In all cycles were irradiated 1112 plates;
- Irradiations were conducted in two different locations of molybdenum channels (f-7 and i-6);
- The typical configuration of the core for irradiations of molybdenum channels is shown in Fig.2;

NATIONAL CENTRE FOR NUCLEAR RESEARCH

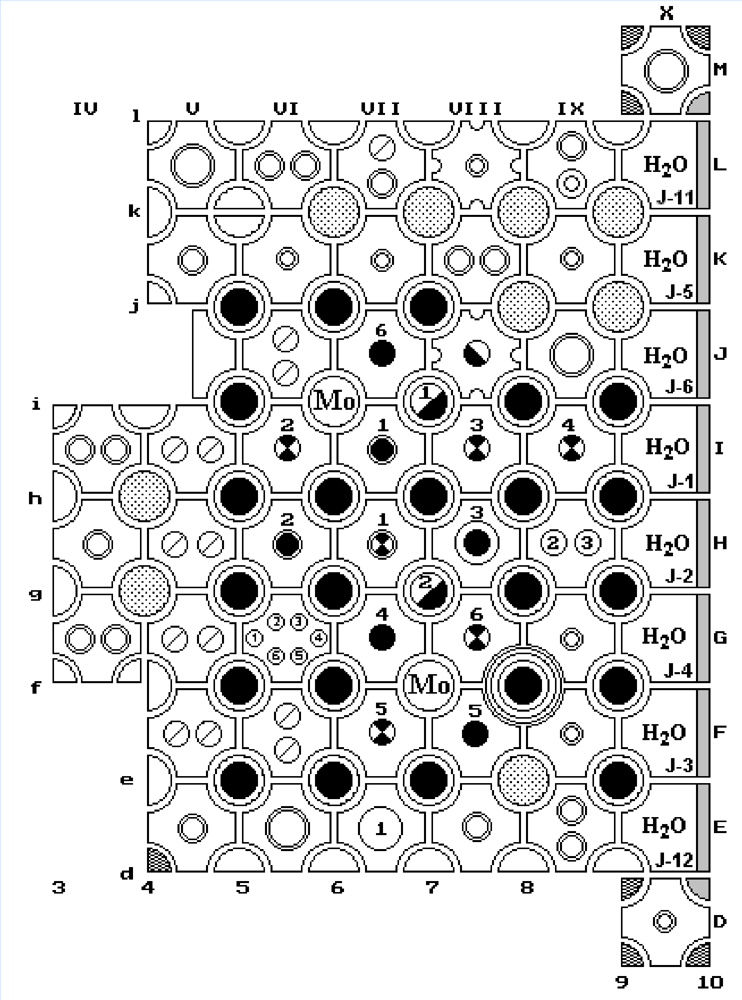


Fig 2. A typical configuration of the MARIA reactor core with molybdenum channels.

- The details of irradiation cycles of uranium plates in the Maria reactor are presented below:
  - time of irradiation – 120 [hours]
  - average power – 180 ÷ 200 [kW]
  - Mo-99 activity at the end of irradiation (EOI) – 7000 ÷ 8000 [Ci]
- The technological parameters of MARIA RR core are shown in Fig.3;
- In the beginning of July 2015 we increased Mo production capacity by increasing the number of plates in the channel (from 8 to 12 pcs).

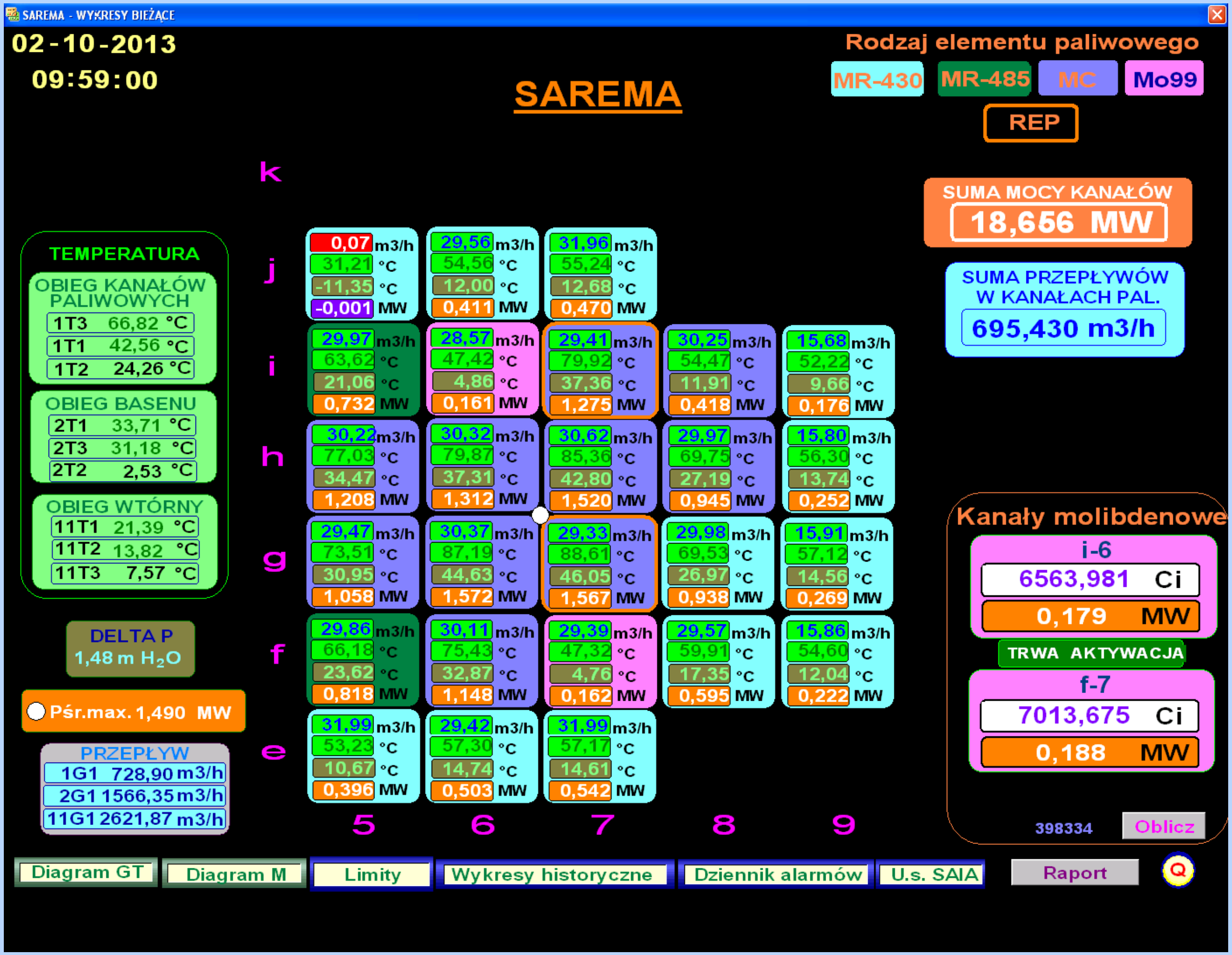


Fig 3. Diagram of MARIA RR core.

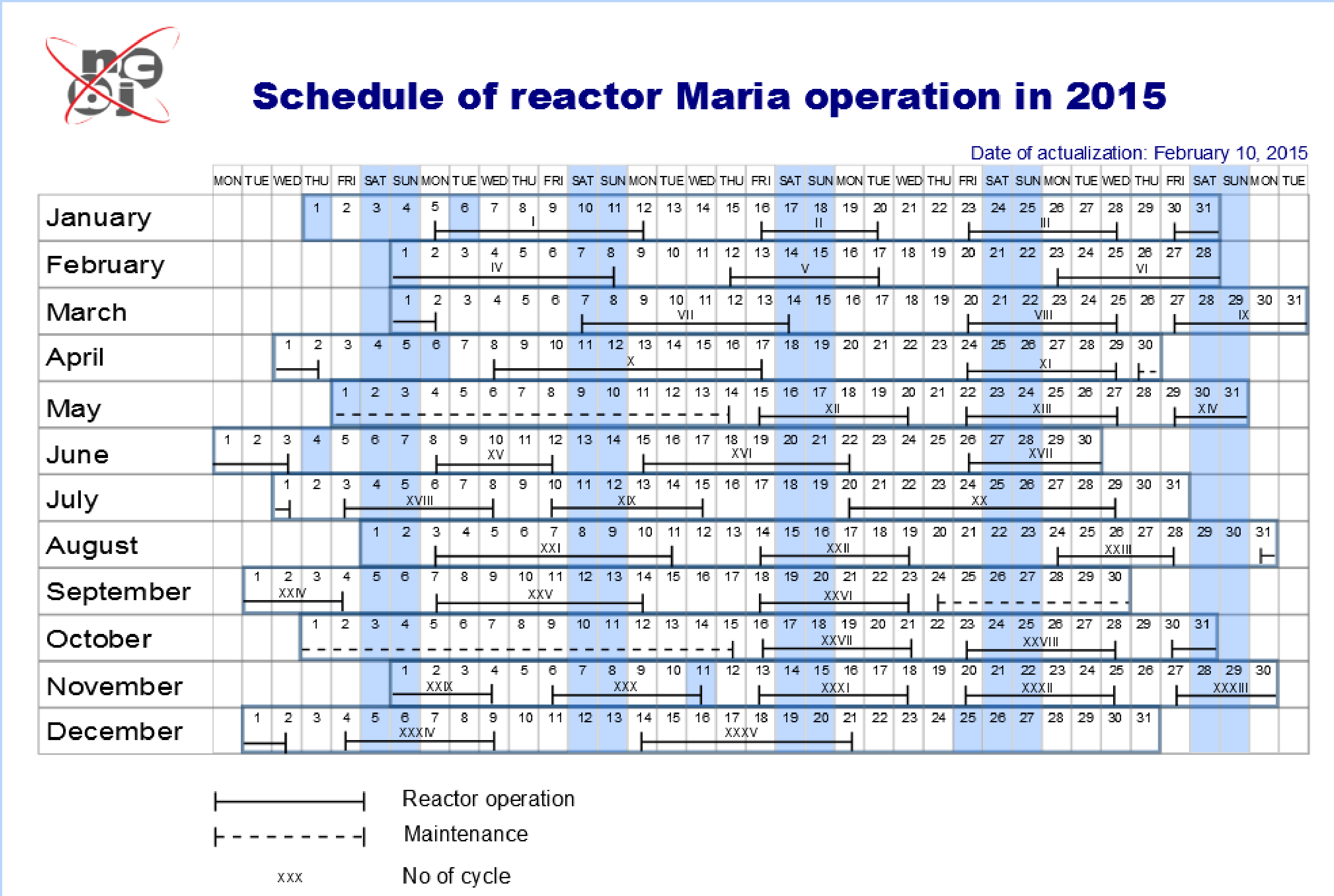


Fig. 4. Schedule of reactor MARIA operation in 2015.

IRRADIATION OF HEU IRE TARGETS IN MARIA

Cooperation between NCBJ and IRE, Belgium:

- safety analysis (neutronic, thermohydraulic in steady states, transient and emergency situation),
- technology of irradiation handling and reloading of irradiated targets:
  - manufacturing and commissioning of an irradiation facility,
  - licensing process (interaction between NCBJ and Regulators Authority),
  - training of MARIA reactor operators,
  - hot tests.

QUALIFICATION OF THE NEW LEU TARGETS

Under supervision of the Mallinckrodt Pharmaceuticals and with collaboration with HFR and BR2 reactors we are developing irradiation and transport technology of a new designed Low Enriched Uranium (LEU) targets for molybdenum production.

The first step of works comprised of development of technology and neutronic and thermal-hydraulic calculations;

Technology over irradiation, reloading and transport of LEU plates comprise of:

- irradiation of plates and preliminary cooling in the channel,

- calorimeter measurement of the residual power generation,
- transport of plates to the hot cell,
- measurement uranium plates temperature,
- reloading handling operation in the hot cell,
- emergency procedure in case of damaging the uranium plates in the cell.

Neutronic and thermal-hydraulic calculations at the steady-states and analysis of transients consist of:

- reactor kinetic parameters: λ_{eff} and β_{eff}
- hydraulic characteristics,
- forced coolant flow,
- natural convection,
- cooling of low enrich uranium LEU in the can for irradtion under natural convection in the air,
- an assessment of radiological hazard during transport handling operation,

- influence of the reactor transient states linked with insertion of positive reactivity on irradiation conditions over LEU plates,
- lose of leek tightness of the LEU plate during irradiation in the channel,
- analysis of abnormal states during discharging and transport of cans from the channel for irradiation into the hot cell,
- analysis of abnormal states during handling operations in the hot cell,

- analysis of radiological hazard associated with damaging LEU plates in the hot cell,
- limits relevant to LEU uranium plates,
- thermal hydraulic limits over uranium HEU and LEU plates' irradiation,
- thermal limits during execution of reloading and transport operations,
- constraints and limits associated with radiological hazard during the relocating and transport operations.

The second step will be modification of the design existing molybdenum channel and manufacturing the new parts of the irradiation rig;

The third step will be licensing process (interactions with the Regulatory Authority);

The fourth step will be:

- upgrading of expedition devices including modification inner transportation container,
- modification of existing equipment in the Hot Cell,
- adaptation of the hoisting device for MARIANNE container with new inner container;

The final step will be test irradiation of 8 LEU plates and its expedition to Petten facility.

CONCLUSION

- From the 2010 MARIA research reactor is in the supply chain to ensure a reliable supply of molybdenum-99 for nuclear medicine.
- After upgrading of the pumps in the primary cooling system we increased capacity of Mo-99 irradiation in MARIA reactor around 50%.
- In the near future we will start to irradiate HEU targets for the new partner.

- The specific activity of U-targets reached in MARIA is very high and the period December 2012 – April 2013, we delivered for market Mo-99 covered about 15% of global demand.
- We are working on qualification of LEU target irradiation and transport technology in MARIA reactor and than its expedition to the processing facility in Petten (The Nederlands).