Institute of Atomic Energy POLATOM
OTWOCK-SWIERK
POLAND

Irradiations of HEU targets in MARIA RR

for Mo-99 production

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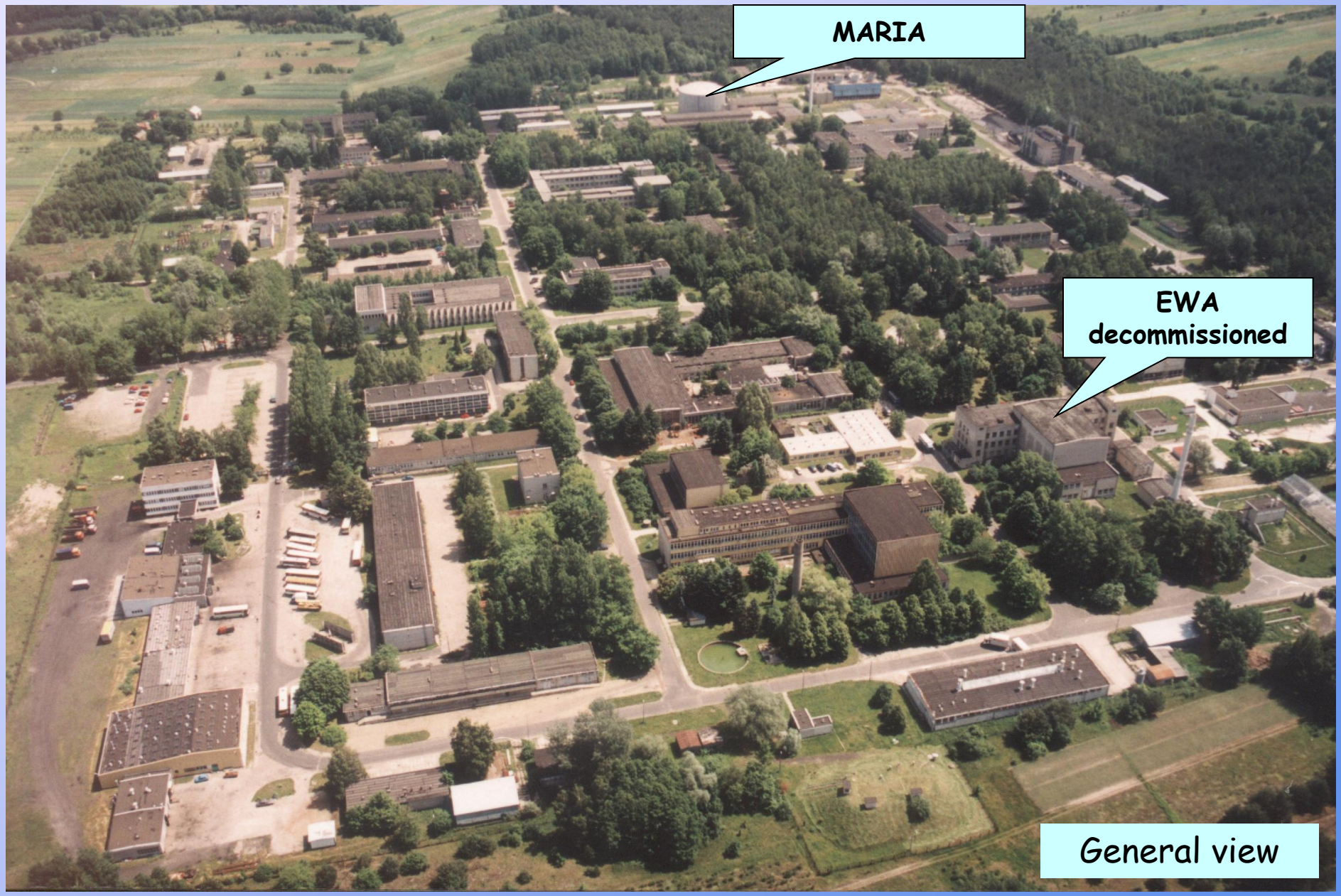
IAEA TM on Commercial Products and Services of Research Reactors

Vienna, 28 June - 2 July 2010

Instytut Energii Atomowej POLATOM



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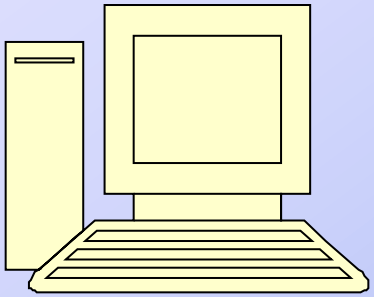
INTRODUCTION

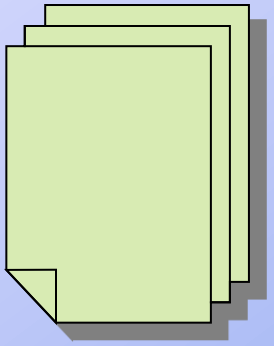
- In May 2009 the NRU reactor (Canada) was shutdown and was planned for scramming the HFR reactor (Holland),
- In the half of 2009 a decision was taken on cooperating between IAE and COVIDIEN,
- IAE and COVIDIEN initiative cover an irradiation of high-enriched uranium plates in MARIA reactor for production of molybdenum Mo-99 in Petten,
- There was developed the Mo-99 irradiation and transport technology in MARIA reactor facility and then its expedition to the reprocessing factory in Petten (Holland).

INTRODUCTION

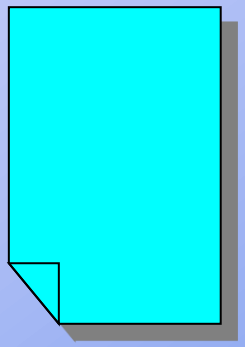
Safety analyses & Design



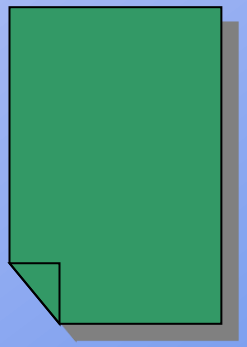
Safety Commission Approval

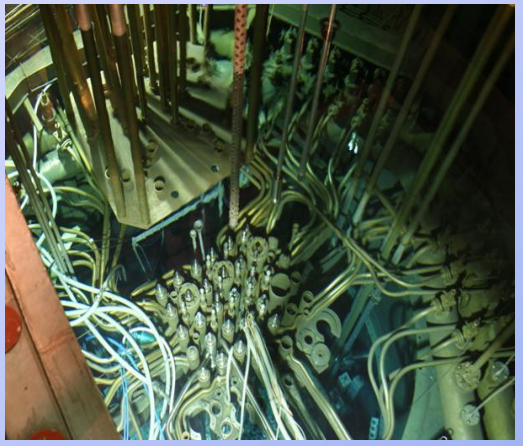


National Regulatory Body Approval



Domestic & Foreign Licenses





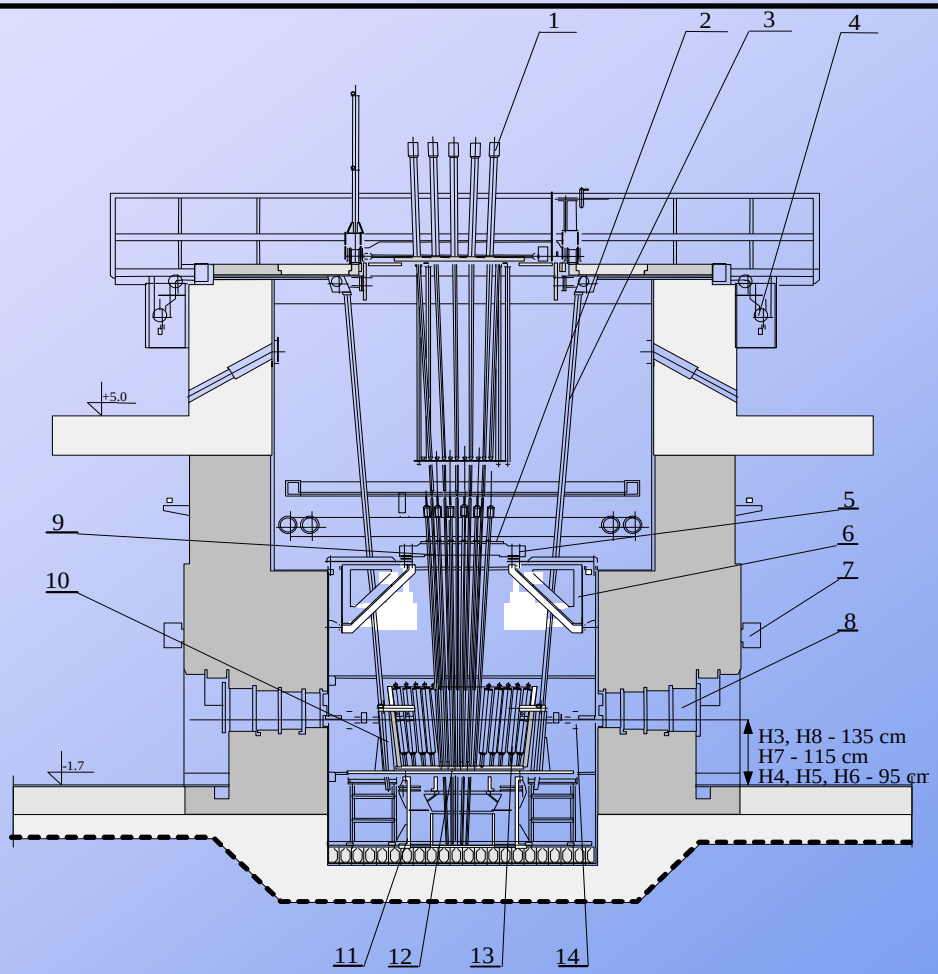
Irradiation facility manufacture

- **Tests and reactor out-core experiments: Dec. 2009**
- **Test with dummy plates: Jan. 2010**
- **Test irradiation uranium plates: Feb. 2010**
- **Commercial irradiation (HEU): Mar 2010**

MARIA RESEARCH REACTOR
Facility description

- The high flux rector MARIA is a water and beryllium moderated reactor of 30 MW power level;
- Pool type reactor with pressurized fuel channels containing concentric tube assemblies of fuel elements;
- Fuel channels are situated in matrix containing beryllium blocks surrounded by graphite reflector;
- Main characteristics and data of MARIA reactor:

• maximum power	30 MW (th)
• thermal neutron flux density	$2{,}5\times10^{14}$ n/cm^2 s
• moderator	H_2O, beryllium
• reflector	graphite in Al
• cooling system	channel type



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

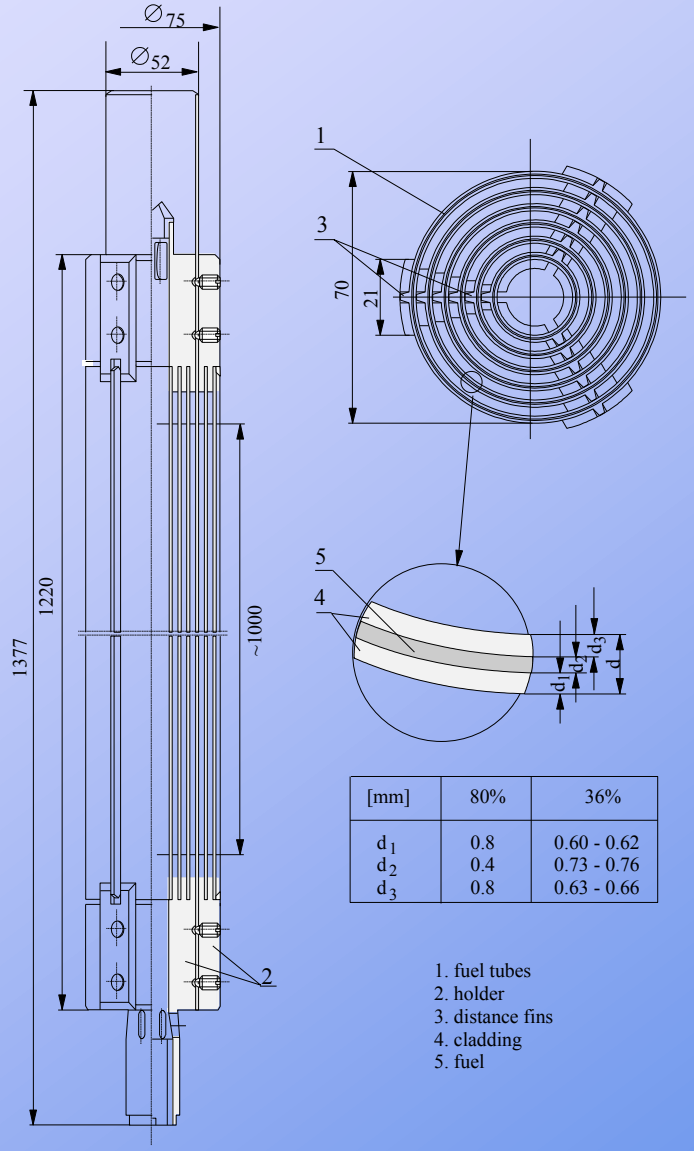
FIG. 1. Vertical section of the MARIA reactor.

The main areas of reactor application are as follows:

- production of radioisotopes,
- testing of fuel and structural materials for nuclear power engineering,
- research in neutron and condensed matter physics,
- neutron radiography,
- neutron activation analysis,
- neutron transmutation doping.

FUEL ELEMENT - MR

- Material UO_2-Al. Alloy clad in aluminium
- Enrichment 80% / 36% U-235 (from 1999)
- Shape concentric tubes
- Dimensions 1000 mm height / 79 mm diameter
- Cooling under pressure flow
- Power limited to 1.8 MW
- 2 Lead Test Assemblies MC-LEU (19,7% U-235) are irradiated for qualification



[mm]	80%	36%
d_1	0.8	0.60 - 0.62
d_2	0.4	0.73 - 0.76
d_3	0.8	0.63 - 0.66

1. fuel tubes
2. holder
3. distance fins
4. cladding
5. fuel

FIG. 2. MR - Fuel element

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

Technology for irradiation and handling of uranium plates comprise of:

- Irradiation of plates and initial cooling in the irradiation channel
- Calorimetric measurement of heat generation in the capsule with plates
- Transport of plates into the hot cell
- Handling operations in the hot cell
- Loading of plates into the transport cask MARIANNE

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

Calculations and safety analyses at steady states are as follows:

- Calculations of molybdenum activity
- Neutronic calculations
- Thermal-hydraulic calculations at steady states
- Activity of fission products and thermal power of the uranium plate batch
- Cooling of uranium plates in the capsule for irradiation during natural convection in the air
- Shielding calculations and an assessment of radiological hazard for personnel pending reloading – transport operations

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

Program of examinations and installation tests consist of:

- Hydraulic measurement of channel for irradiation of capsules containing the mock-ups of plates
- Cold trials of reloading and transport operations with a bath of dummy plates
- Calibration measurements of calorimeter for measuring of thermal power of 4 plate batch
- Measurement of axial distributions of the neutron flux density in the capsule containing dummy plates
- Measurements 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

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

Technical Assumptions for developing the uranium targets technology:

- Irradiation is held in containers, containing 4 plates each, loaded into the molybdenum channel.
- Irradiation of the containers is held in installations which are converted fuel channels of the MARIA reactor.
- Loading and discharge of the containers with plates from the installation is possible without the necessity of the evacuation of the irradiation channel from the reactor core.
- The nominal flow of coolant is maintained in the irradiation installation.

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

Technical Assumptions for developing the uranium targets technology:

- The cooling is ensured by the circuit of cooling fuel channels.
- Opening of the molybdenum channel and the evacuation of the containers with uranium plates are held of not earlier than 10 hours after the reactor shutdown.
- Handling operations in the hot cell are conducted in the air.
- Cooling plates with the natural convection in the air is less efficient than cooling convection in water.

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

Technical Assumptions for developing the uranium targets technology:

- The recipient of uranium plates determines two thermal limits for the set of 8 uranium plates (residual power 548 W and 450 W).
- The procedure of the uranium plates dispatch includes the possibility of conducting calorimetric measurements of the residual heat generated in a single container with plates.
- The measurements of plate's temperature were conducted in hot cell during test irradiation.
- These measurements showed that temperatures of uranium plates in the air were below 200 ˚C.

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

Technical Assumptions for developing the uranium targets technology:

- The total activity of fission products in uranium plates during transport operations in the hot cell is ca. 100 kCi.
- Test measurements showed that the shielding of the hot cell is sufficient for safe performing handling operation of irradiated uranium plates.
- After the process of irradiation and cooling plates has ended the plates are loaded into a special shielding container MARIANNE

MO-99 PRODUCTION IN THE MARIA REACTOR – CURRENT STATE

- Between 8th ÷ 14th February the test irradiation of 8 plates has been conducted.
- In the period from 11th March to 2nd June 2010 eight irradiation cycles in molybdenum channels in the MARIA reactor were conducted.
- In all cycles 12 sets of uranium plates (8 plates in each) were irradiated.
- Irradiations were conducted in three different locations of molybdenum channels (f-7, h-7 and i-6) and different configurations of the core, introduced in *FIG.3*.

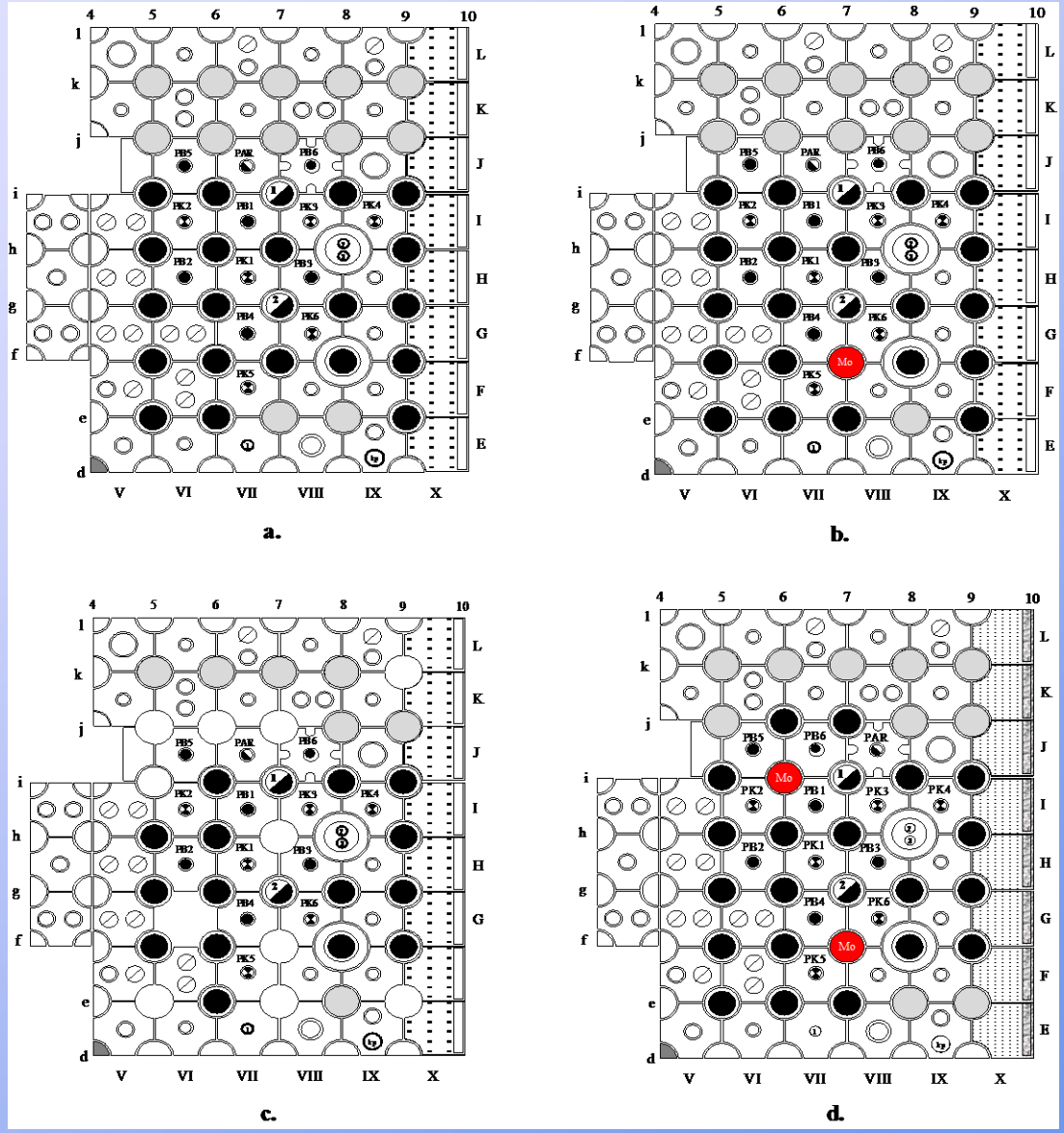


FIG. 3. Configurations of the MARIA reactor core with molybdenum channels.

MO-99 PRODUCTION IN THE MARIA REACTOR – CURRENT STATE

- The details of irradiation cycles of uranium plates in the Maria reactor (along with test irradiation) are presented below:

– time of irradiation	– 135÷ 145 [hours]
– average power	– 180 ÷ 200 [kW]
– Mo-99 activity at the end of irradiation (EOI)	– 7500 ÷ 8000 [Ci]

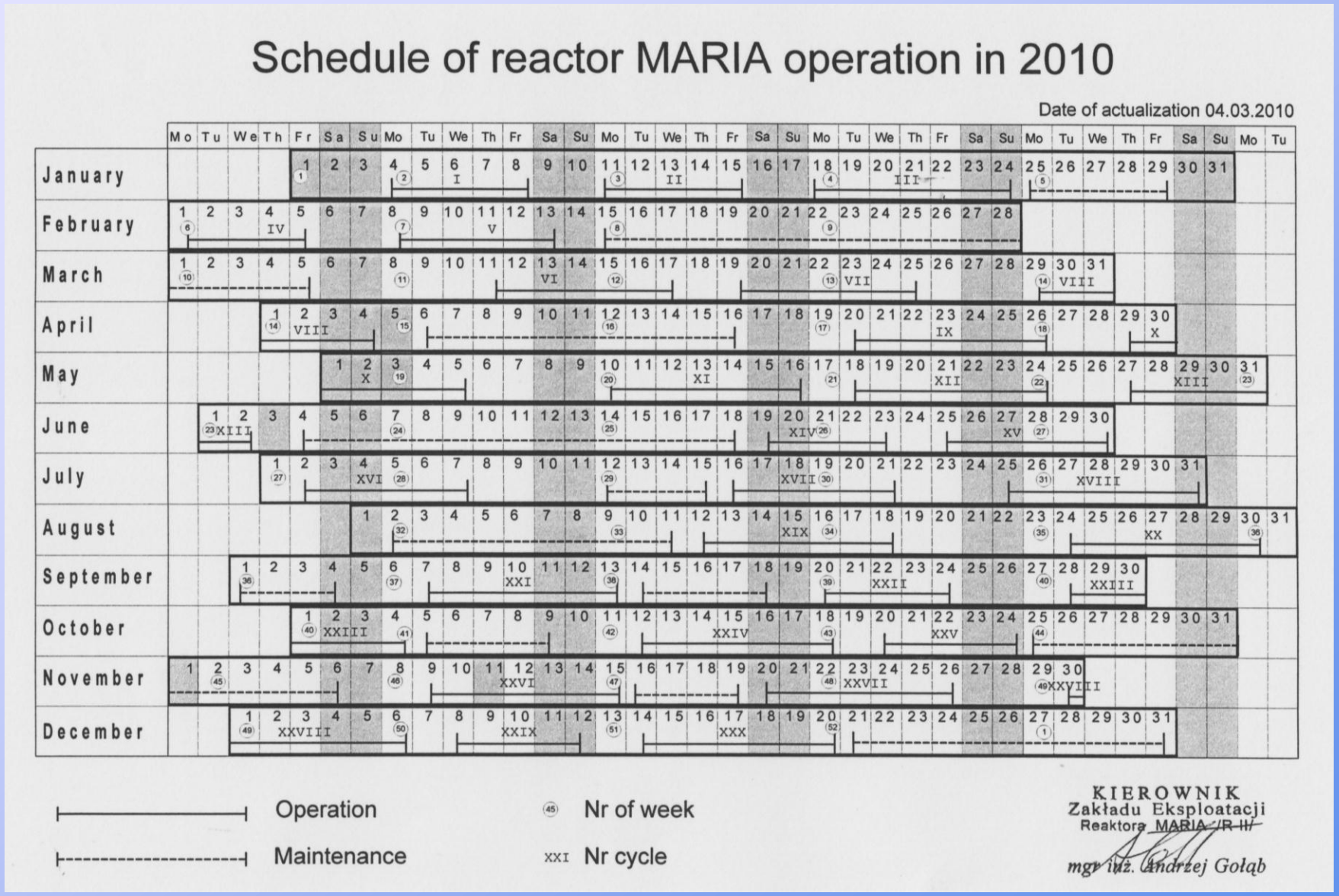


FIG. 4. Schedule of reactor MARIA operation in 2010.

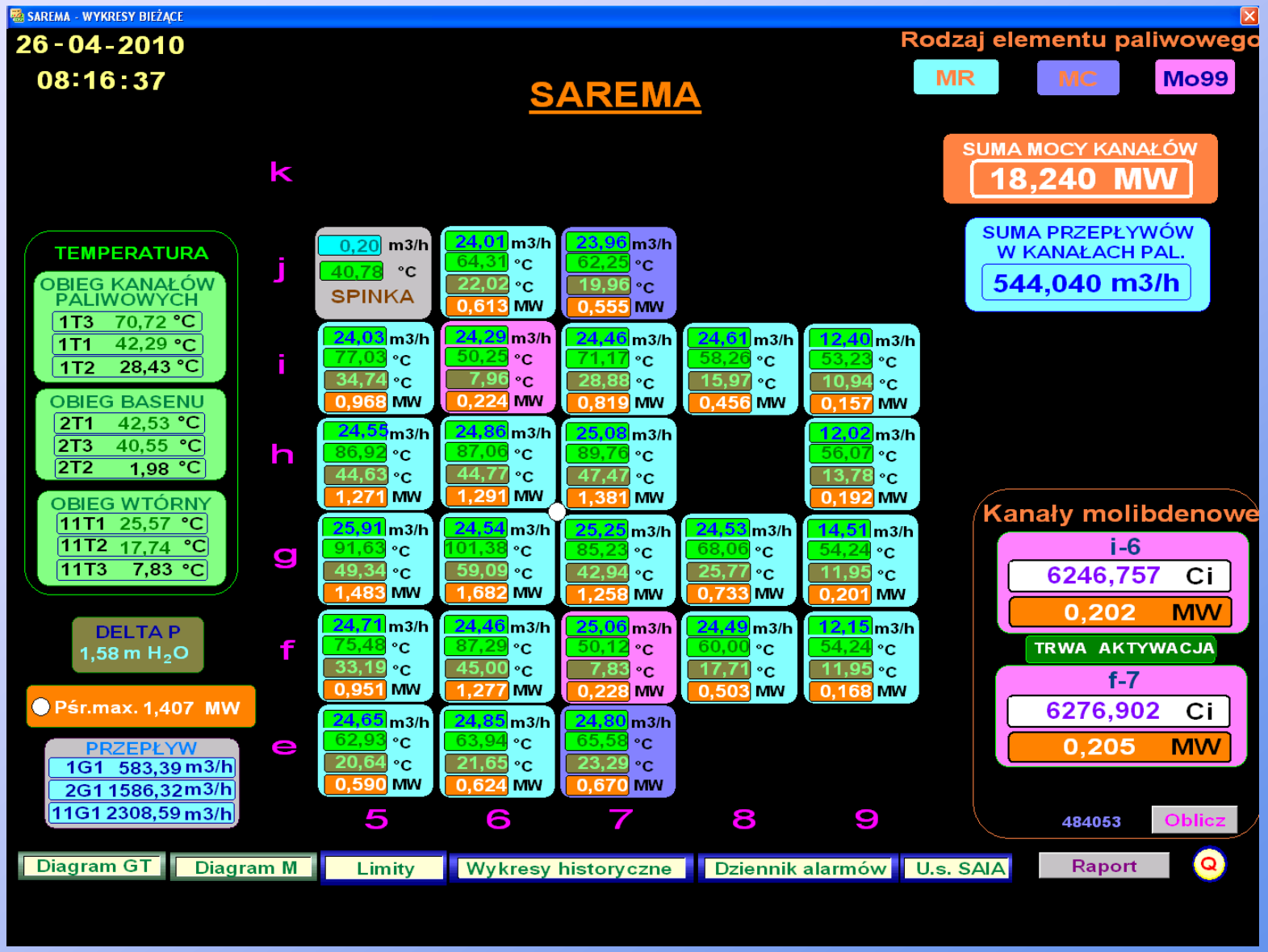
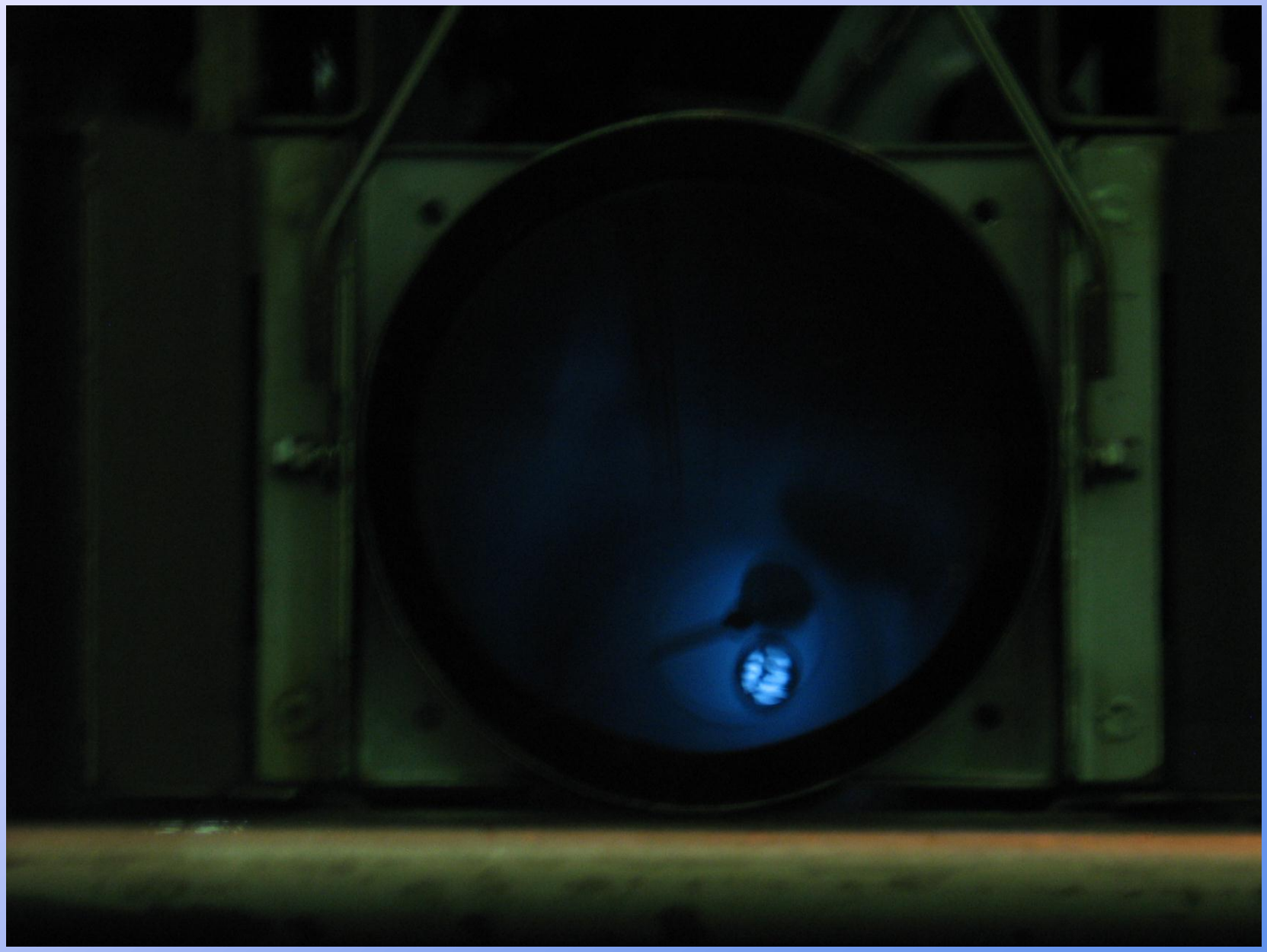


FIG. 5. Diagram of MARIA RR core.

HANDLING OF IRRADIATED TARGET IN MARIA REACTOR BUILDING

- After reactor shut down and cooling time minimum 12 hours the irradiation holders are unloading from the channels and handling to the dismantling cell.
- Calorimetric measurements conducted directly before the dispatch of plates showed residual powers in the range of 320 ÷ 410 W, that is below limit 450 W of power.
- Measurements of the temperature of plates in the container in conditions of the natural convection in the air were made after test irradiation has ended.
- The measurement was performed directly before plates were loaded into the shielding container MARIANNE.
- The temperature of plates didn't achieve the value of 200 ˚C.

FIG. 6. Handling of irradiated target in MARIA reactor building.



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Świerk, 03 June 2010

CERTIFICATE OF RADIOACTIVE SOURCE
no. 15/10

1. Preparation: 8 uranium targets / irradiation container: 29/10 and 30/10
2. Irradiation Rig: channel i-6
3. Batch: 2010.13/311205

Position holder	Target number
LOWER	NRGA3911
	NRGA3912
	NRGA3913
	NRGA3914

Position holder	Target number
UPPER	NRGA3915
	NRGA3916
	NRGA3917
	NRGA3918

4. Radionuclide: Mo-99
5. Mo-99 activity/batch: 7773 Ci on EOI
6. Residual power: < 410 W
7. Container type: MARIANNE no. 01
8. Dose rate equivalent on the outer surface of container: 0,02 mSv/h
9. Time of irradiation:

   Start of irradiation: 27 May 2010 – at 18:20
   Stop of irradiation: 02 June 2010 – at 14:45

11. Total 140h 25'

Dosimetry
DOZYMETRYSTA Reaktora MARIA
Janusz Surowiecki

Laboratory
KOORDYNATOR PROGRAMÓW NAPROMIENIOWANIA W REAKTORZE MARIA
mgr inż. Janusz Jaroszewicz

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CONCLUSION

- The realization of the molybdenum program confirmed the correctness
  - of the irradiation technology,
  - handling operations in the reactor pools and in hot cell,
  - loading operation into the transport container MARIANNE.
- Experience acquired made it possible to implement additional technical and organizational solutions.
- The achieved very good results of production is an important step in increasing of commercial products and services of MARIA research reactor.


THANK YOU