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RESEARCH REACTOR CENTRE

Operational characteristics of research reactor MARIA after modernisation.

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Abstract

Polish high flux research reactor MARIA is a pool type reactor moderated with beryllium and water and cooled with water. The fuel is 80% enriched uranium, in the shape of multitube fuel elements, each tube made up of Ual_x alloy in aluminum cladding.

MARIA reactor has been operated in the year of 1977-85 and then it was modernised and again put into operation in December of 1992.

Reactor is used for radioisotope production and physical research on neutron beams.

Nominal power of the reactor is 30 MW_{th} and its maximum thermal neutron flux is equal to $4{,}5 \cdot 10^{14}$ $n \cdot cm^{-2}s^{-1}$.

After modernisation the reactor core was extended from 12 to 18 fuel channels. Within the frame of nuclear fuel burn-up optimisation the high burn-ups of fuel up to ca. 45% have been reached.

Irradiation of the target materials is linked mostly with the production of - P-32, J-131 and Ir-192.

Material investigation and dynamics of the crystal lattice by means of neutron spectrometer at the neutron beams outlets of the reactor are conducted.

Radioactive products releases to the atmosphere were on the minimal level and they were contained within one several percent of the annual release limit.

1. INTRODUCTION

High flux research reactor MARIA is situated at Świerk near Warsaw and operated by the Institute of Atomic Energy.

Maria has been designed and constructed by Polish industry. It is water and beryllium moderated, water cooled reactor of a pool type with pressurised fuel channels containing concentric multi-tube assemblies of fuel elements.

MARIA has been designed with a high degree of flexibility to provide possibilities of production of radioisotopes, of physical and irradiation experiments. Operational power is 30 MW and thermal neutron flux in the centre of the core $4x10^{18}$ n/m^{2}s.

The main reactor possibilities are as follow:

- testing of fuel and material for nuclear power stations,
- production of radioisotopes,
- neutron physics,
- neutron activation analysis,
- neutron radiography.

First criticality of the MARIA reactor was reached in December 1974. The reactor was in operation since 1975 until 1985. In July 1985 it was shout down for modernisation. Modernisation of the MARIA reactor as related to the core was connected with extension of beryllium matrix from 20 to 48 blocks which was accomplished by the substitution of the retired graphite reflector blocks with the new beryllium ones. MARIA reactor was put again into operation in 1993.

2. DESCRIPTION OF REACTOR MARIA

A vertical cross section across the reactor pool is shown in. Fig. 1. The reactor core fuel and loop channels, headers, and connections between the headers and fuel channels are all submerged in the pool under a layer of water ensuring sufficient radiation shielding above the core.

The characteristic design feature of the core is a conical arrangement of fuel channels. The fuel channels are situated in beryllium matrix made of blocks of 110 cm height and enclosed by a lateral reflector made of graphite blocks in aluminium cans. Some of the blocks contain horizontal holes for extraction of neutron beams from the reflector to the horizontal tubes penetrating the reactor lateral shield. A view of the reactor core and reflector from above is shown in Fig. 2.

In area of reactor core and reflector there is a number of vertical irradiation channels, made of aluminium tubes. The reactor core layout, shown in Fig. 3, gives an example of core management, which fulfils the needs of radioisotope production and several experimental programs.

Fuel assembly is shown in Fig. 4. It contains six tubes with uranium enriched to 80 % U-235 content in the fuel assembly is 350 g. In future the enrichment will be changed to 36 % U-235.

Fuel assemblies are placed in the pressurised channels. Each channel is individually connected to the primary cooling circuit.

The main moderating element in the core is water, which also provides cooling of fuel channels and core materials. Its volumetric fractions in the core is only 20 %, but its contributions to neutron slowing down is 70 %.

The other moderating materials is beryllium, constituting the matrix which fill up the space between the fuel channels. The reflector is assembled of graphite blocks canned in aluminium and cooled by water flowing in the separate pool cooling circuit.

The control rod units divided into two section, connected with disconnectable joints. The upper section are supported on the upper support plate above the water level and contain drive mechanism, the lower sections, containing active portions of the rods as well as connections and control rod followers, move inside the tubes placed in 28 mm dia. holes in the beryllium matrix blocks. The control rods are cooled with pool water flowing down the core along the gaps in the control rod channel.

3. REACTOR CHARACTERISTIC

The basic characteristics data for the MARIA reactor are presented on the vertical cross section of reactor pool, Fig. 1, on the core and reflector view., Fig. 2, on the cross section of the fuel assembly, Fig. 3, on the core layout, Fig. 4 and in Table I.

The reactor core power distribution and reactor MARIA parameters of water cooling the fuel channels are presented in Appendix 1.

3.1. Neutron flux densities in the channels for irradiation.

In Fig. 4 the 20 - fuel channels' reactor core configuration has been shown and for this case the following densities of thermal neutrons' fluxes in the irradiation channels have been demonstrated in Table II.

3.2. Thermal neutron flux densities at horizontal channels' outlets.

In accordance with Fig. 1 and Fig. 2 the MARIA reactor has got six horizontal channels for neutrons beams output from the reactor core.

The thermal neutron flux densities at the horizontal channels outlets are within the range of $3 - 8 \cdot 10^9$ [n/cm^2 s].

3.3. Reactor operation cycles.

Depending on the radioisotopes production programme the reactor can be operated in 100 hr, 120 hr or 264 hr cycles.

Due to the need of the apparatus maintenance, periodic probes and checks as well a repairs, there are envisaged appropriate breaks in the reactor operation.

The reactor operation schedule for 1998 is presented in Appendix 2.

4. REPORT ON OPERATION OF THE MARIA RESEARCH REACTOR IN 1997.

The Maria research reactor used at the Institute of Atomic Energy in 1997 was operated 3856 hours on power of about 20 MW_{th}.

The reactor operation was aimed for:

- irradiation of target materials for the Isotope Research and Development Centre and the Institute of Chemistry and Nuclear Technique,
- usage of neutron beams for physics research.

There have been irradiation 200 cans with sulphur, 74 cans with TeO_2, 32 cans with Sm_2O_3 as well as iridium, ytterbium, potassium bromide, potassium chloride, alkaline and biological substances. The received specific activities of isotopes, in particular the Ir-192 (650 Ci/g) have proved the large possibilities of Maria reactor for radioisotope production.

The four out of the six reactor neutron beams were being used:

H-4 - materials testing by means of the neutron scattering spectrometer,

H-5 - identification of atomic magnetic moment values by usage of polarised neutron spectrometer,

H-6 - research of dynamics of crystalline and magnetic lattice by means of triaxial neutron spectrometer,

H-7 - measurements of thermal neutron current.

Nuclear fuel of the MR-6 type (80 % enrichment of U-235) has been tested which allowed to increase its burn-up to 45 % and simultaneously more effective its usage in the reactor.

During the reactor operation the minimal releases of radioactive substances to the atmosphere occurred e.g., emission of noble gases (mainly Ar-41) was equal to $9{,}3 \cdot 10^{13}$ Bq (i.e., about 10 % of the limit value), emission of iodine - $4{,}5 \cdot 10^{7}$ Bq (i.e., 1 % of the limit value).

TABLE I

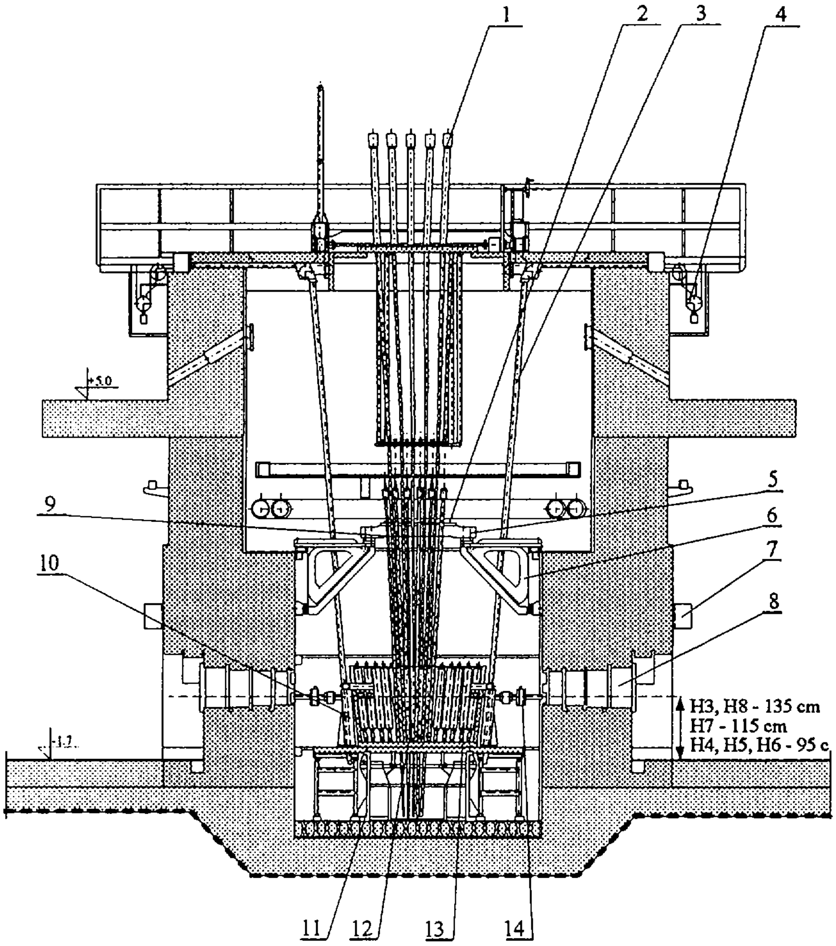
General characteristics of MARIA reactor

Nominal power	30 MW
Maximum thermal neutron flux:	
in fuel	2,5. E18 n/m^{2}sec
in beryllium	4,5. E18 n/m^{2}sec
Moderator	water and beryllium
Reflector	graphite (blocks in Al. Cans) and water
Fuel element:	
material	U-Al. Alloy clad in Al.
enrichment	80% U-235
shape	six concentric tubes
overall dimensions	100 cm height
Primary fuel cooling system:	
type of fuel channel	field tube
pressure range	1,8 MPa
temperature, core inlet (outlet) water flow	
rate:	40 (90) °C
per channel	30 m^3/h
total	600÷700 m^3/h
Primary pool cooling system:	
pressure	atmospheric
temperature:	
at core matrix inlet	40°C
at core matrix outlet	45°C
water flow rate	1400 m^3/h
Secondary cooling system	
pressure	0,25 MPa
temperature:	
inlet	34°C
outlet	26°C
flow rate	2600 m^3/h

TABLE II

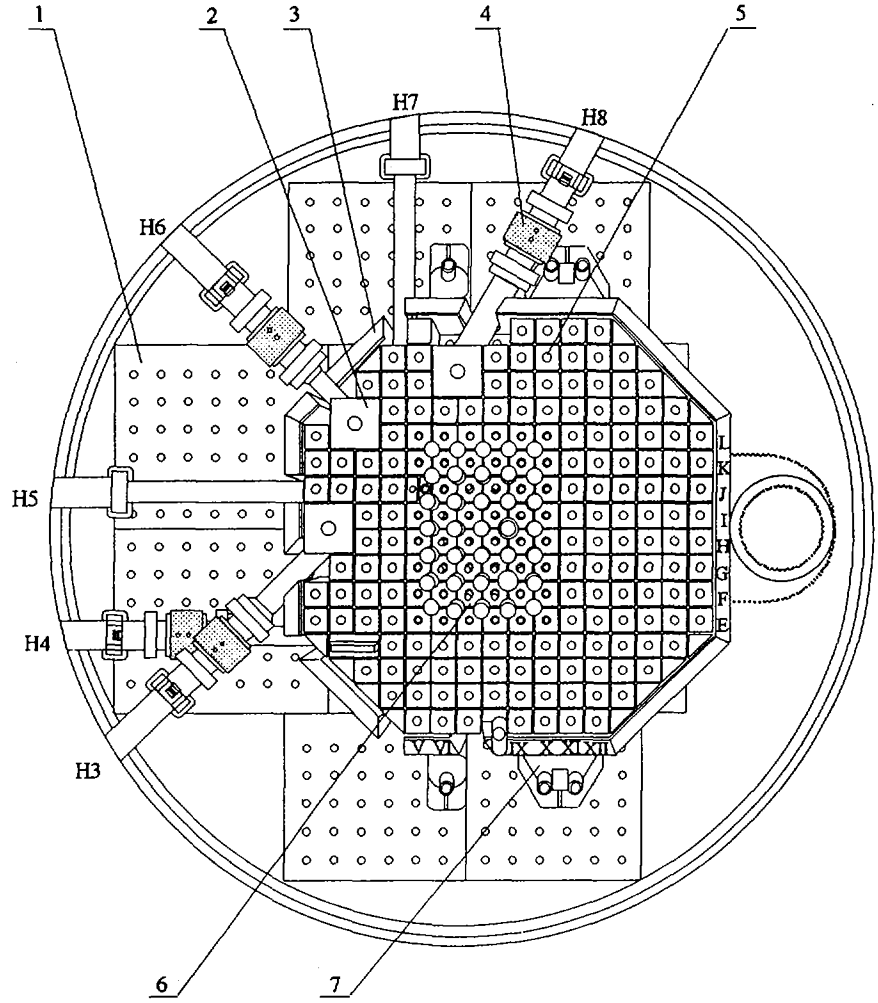
Characteristics of vertical channels for isotope production

Core co-ordinate	Diameter [mm]	Thermal neutron flux [n/cm^{2}s]
F-VB	28	2,2 E14
K-VIA	28	2,6 E14
H-VA	28	3,6 E14
G-VB	28	3,6 E14
F-VIB	28	3,6 E14
H-VB	28	4,0 E14
G-VIB	28	4,5 E14
E-VII	28	1,4 E14
h-8	28	3,4 E14
h-8	28	3,2 E14
I-V/1÷8	18	$2{,}6 \div 3{,}1 \cdot 10^{14}$
K-VIIIA	28	1,6 E14
H-XII	28	1,4 E13
I-XI	28	4,0 E13
H-XI	28	5,0 E13
I-XIII	28	1,0 E13



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 plants
13. reflector blocks
14. beam tube compensator joint

Fig. 1. Vertical cross-section of the MARIA reactor



1. core and reflector support plants
2. multiple graphite block
3. reflector support structure
4. beam tube compensator joint
5. graphite reflector block
6. beryllium block
7. ionization chambers shield

Fig. 2. Horizontal cross-section of the MARIA reactor

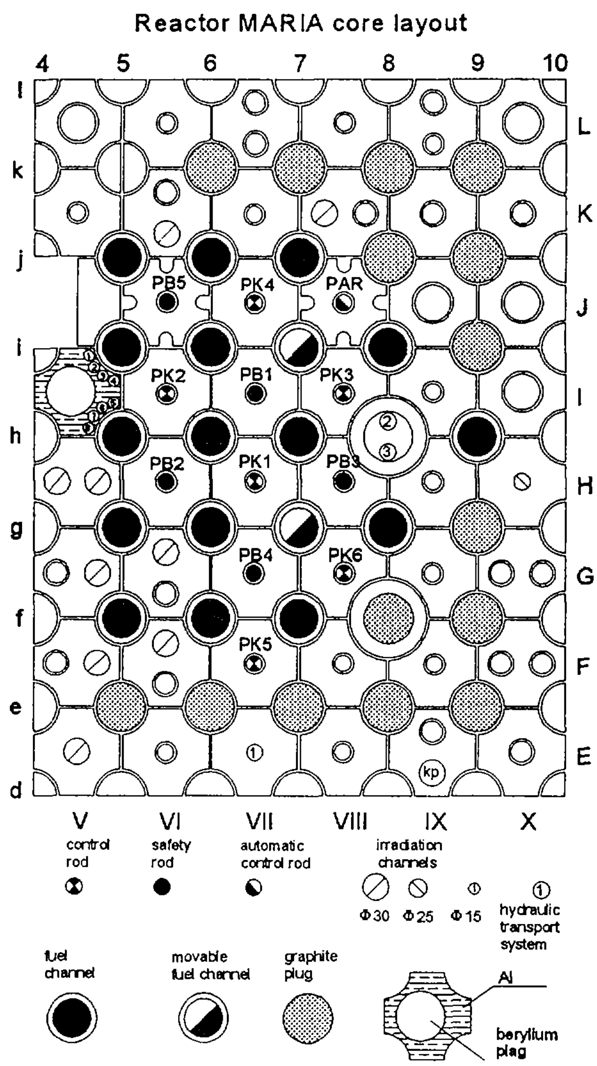


Fig. 3. Reactor MARIA core layout

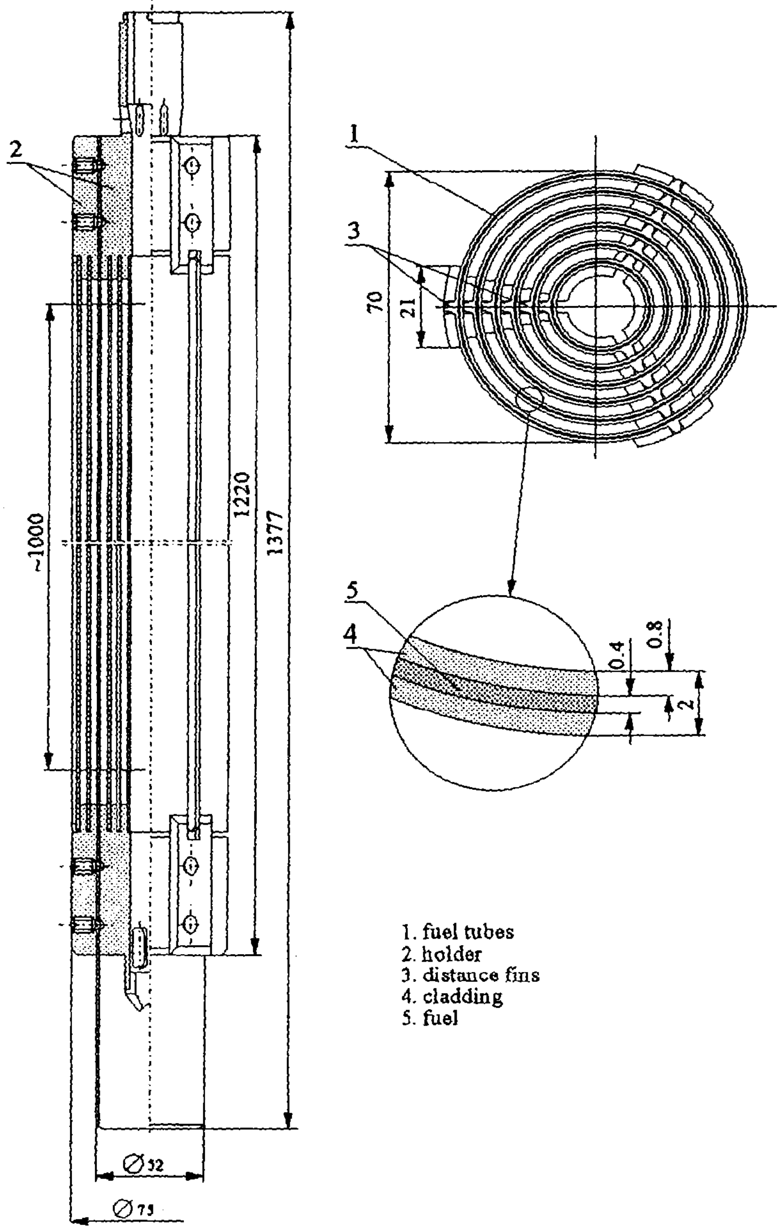


Fig. 4. Fuel assembly

Appendix 1

Data: 22.04.1998 Zmiana: I Godz.: 11:00 Nr. 23

SG = 571.2m3/h T11 = 56.9°C SP = 13.550MW CMM = 19.80 MW

	5	6	7	8	9
k		19.8 m3/h 0.0 °C spinka 0.000 MW	14.1 m3/h 54.3 °C spinka 0.000 MW		
j	12.1 m3/h 39.4 °C spinka 0.000 MW	28.4 m3/h 79.2 °C 22.2 °C 0.718 MW	28.9 m3/h 76.4 °C 19.4 °C 0.641 MW		
i	29.1 m3/h 83.7 °C 26.8 °C 0.890 MW	28.8 m3/h 92.4 °C 35.4 °C 1.164 MW	29.9 m3/h 75.7 °C 18.8 °C 0.640 MW	28.4 m3/h 74.0 °C 17.0 °C 0.551 MW	20.3 m3/h 55.0 °C spinka 0.000 MW
h	29.2 m3/h 87.7 °C 30.8 °C 1.025 MW	29.0 m3/h 98.9 °C 41.9 °C 1.386 MW	29.5 m3/h 95.4 °C 38.5 °C 1.293 MW		27.9 m3/h 63.7 °C 6.8 °C 0.217 MW
q	29.2 m3/h 85.2 °C 28.2 °C 0.941 MW	29.2 m3/h 93.7 °C 36.8 °C 1.225 MW	28.8 m3/h 87.1 °C 30.2 °C 0.991 MW	28.7 m3/h 74.5 °C 17.5 °C 0.572 MW	15.2 m3/h 53.6 °C spinka 0.000 MW
t	14.7 m3/h 55.0 °C spinka 0.000 MW	28.8 m3/h 78.5 °C 21.5 °C 0.707 MW	29.1 m3/h 75.0 °C 18.1 °C 0.600 MW		
e			12.1 m3/h 54.6 °C spinka 0.000 MW		

Przeplyw
Temperatura
Roznica temp
Moc

1G1 = 549.9 m3/h
2G1 = 1488.7 m3/h
11G1 = 2490.5 m3/h

delta p = 2.00 m H_2O

ΔP = 1.224 MW

Data: 22.04.1998 Zmiana: I Godz.: 13:00 Nr. 24

SG = 571.0m3/h T11 = 56.5°C SP = 13.478MW CMM = 19.62 MW

	5	6	7	8	9
k		19.8 m3/h 0.0 °C spinka 0.000 MW	14.0 m3/h 53.8 °C spinka 0.000 MW		
j	12.0 m3/h 39.2 °C spinka 0.000 MW	28.4 m3/h 78.5 °C 22.0 °C 0.714 MW	28.9 m3/h 75.7 °C 19.2 °C 0.634 MW		
i	29.2 m3/h 83.1 °C 26.7 °C 0.886 MW	28.8 m3/h 91.7 °C 35.2 °C 1.158 MW	29.9 m3/h 75.1 °C 18.6 °C 0.633 MW	28.3 m3/h 73.0 °C 16.5 °C 0.534 MW	20.3 m3/h 54.5 °C spinka 0.000 MW
h	29.1 m3/h 87.2 °C 30.7 °C 1.019 MW	29.0 m3/h 98.3 °C 41.8 °C 1.382 MW	29.5 m3/h 94.7 °C 38.3 °C 1.286 MW		28.0 m3/h 62.6 °C 6.2 °C 0.196 MW
q	29.3 m3/h 84.6 °C 28.2 °C 0.939 MW	29.2 m3/h 93.2 °C 36.7 °C 1.224 MW	28.8 m3/h 86.6 °C 30.2 °C 0.991 MW	28.7 m3/h 73.8 °C 17.3 °C 0.567 MW	15.2 m3/h 53.1 °C spinka 0.000 MW
t	14.7 m3/h 54.6 °C spinka 0.000 MW	28.8 m3/h 78.0 °C 21.5 °C 0.708 MW	29.1 m3/h 74.6 °C 18.1 °C 0.600 MW		
e			12.1 m3/h 54.0 °C spinka 0.000 MW		

Przeplyw
Temperatura
Roznica temp
Moc

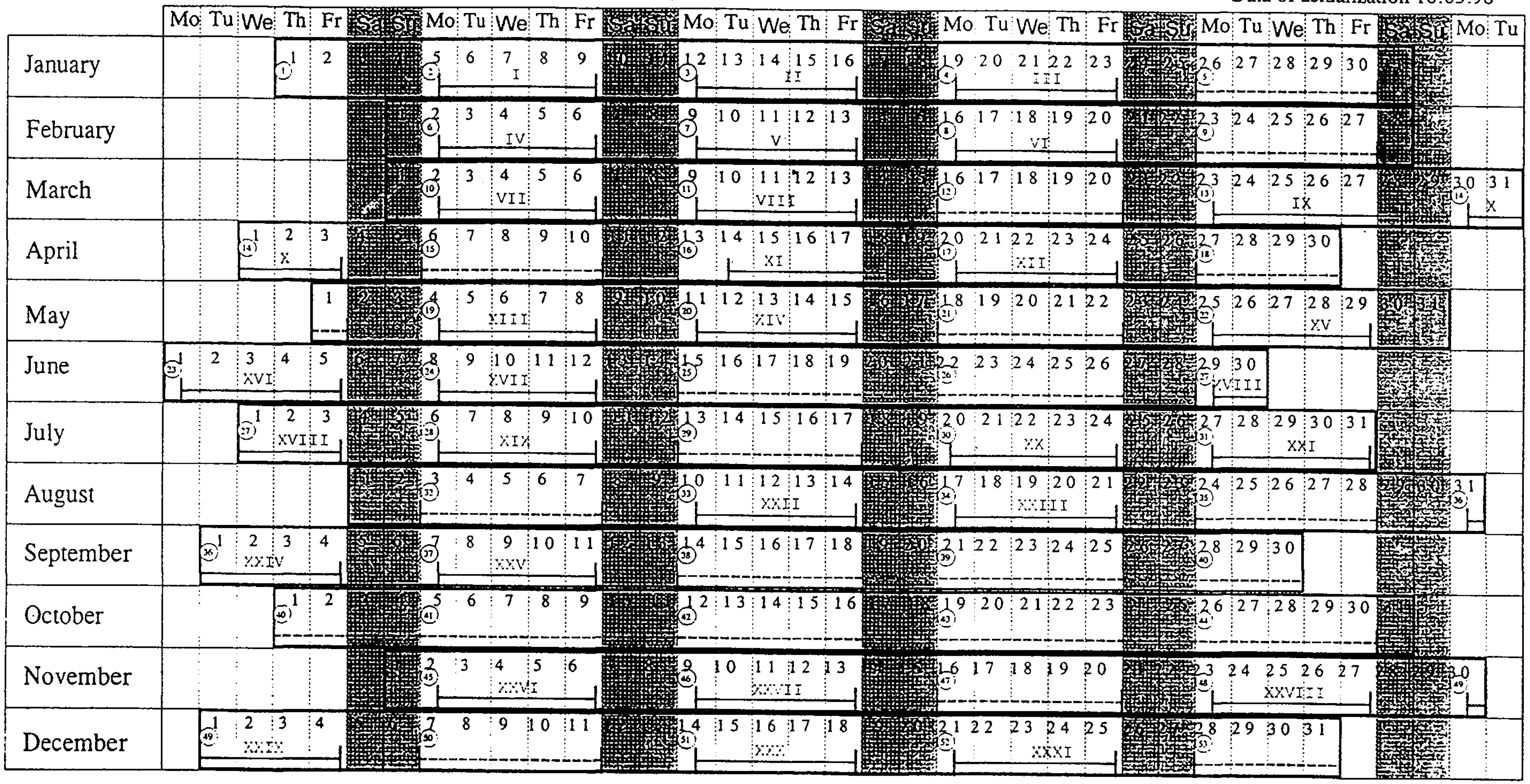
1G1 = 556.0 m3/h
2G1 = 1474.8 m3/h
11G1 = 2479.5 m3/h

delta p = 1.99 m H_2O

ΔP = 1.221 MW

Schedule of reactor MARIA operation in 1998

Data of actualization 16.03.98



Operation

Maintenance

KIEROWNIK ZAKŁADU
Eksploatacji Reaktora MARIA /R-II/