PRELIMINARY STUDIES FOR THE DECOMMISSIONING OF THE REACTOR COMPARTMENTS OF THE FORMER PALDISKI MILITARY NUCLEAR SITE AND FOR THE ESTABLISHMENT OF A RADIOACTIVE WASTE REPOSITORY

TASK 2 INTERIM REPORT

COLLECTION OF DATA AND OVERVIEW OF NATIONAL AND INTERNATIONAL REQUIREMENTS

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DESIGNATIONS AND ABBREVIATIONS

AC	Activated Crud
CFW	Control-Free Waste
CERS	Comprehensive engineering and radiation survey
D	Decommissioning
DCP	Donkey Centrifugal Pump
EDR	Exposure Dose Rate
eH	Oxidation-reduction potential (ORP)
ES	Energy Stand
EU	European Union
EURATOM	European Atomic Energy Community
EW	Exempt Waste
GSG	General Safety Guide
HLW	High Level Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IP	Industrial Packaging
IWPT	Iron-Water Protection Tank
LB	Left Board (Portside)
LILW	Low- And Intermediate Level Waste
LLW	Low-Level Waste
LRW	Liquid Radioactive Waste
LSA	Low Specific Activity
LTS RC	Long-Term Storage Of Reactor Compartments
MCP	Main Circulating Pump
MTS	Main Technological Section
N	Navy
NF	Nuclear Facility

NM	Nuclear Maintenance
NORM	Naturally Occurring Radioactive Material
NPS	Nuclear-Powered Submarine
NPU	Nuclear Power Unit
NS	Nuclear Submarine
Partition-off	part of the space bounded by the wall, usually designed for the individual machines, equipment, instrumentation and so on. (Russian – «выгородка»)
PPE	personal protective equipment (Russian - "средства индивидуальной защиты")
PS	Port Side
RC	Reactor Compartment
RHF	Radiation-Hazardous Facility
RV	Reactor Vessel
RW	Radioactive Waste
RWDF	Radioactive Waste Disposal Facility
RWLTS	Radioactive Waste Long-Term Storage Point
SB	Starboard
SCO	Facility With Surface Contamination
SG	Steam Generator
SNF	Spent Nuclear Fuel
SRW	Solid Radioactive Waste
SSG	Specific Safety Guide
SSR	Specific Safety Requirements
SSS	Steam Supply System
TC	Training Center
VLLW	Very Low-Level Waste
VSLW	Very Short Lived Waste

INTRODUCTION

This work was executed under terms of the research Contract No.33 / EKS0101-09 as of 17 September 2014 between AS A.L.A.R.A. and UAB EKSORTUS «Preliminary studies for the decommissioning of the reactor compartments of the former Paldiski military nuclear site and for the establishment of a radioactive waste repository».

The aim of work performance is to:

- review and analyze the available data concerning the reactor compartments of the former Paldiski military nuclear site and the establishment of a radioactive waste repository;
- review IAEA, the European Union, the Estonian Republic and the Russian Federation regulations, relating to the area of decommissioning of the NS reactor compartments, which shall be observed upon making decisions on decommissioning of the reactor compartments of the former Paldiski military nuclear site;
- review the documents of the IAEA, European Union, Republic of Estonia and Russian Federation, regulating radioactive waste disposal, eliciting requirements to the radioactive waste disposal, which shall be observed under making decisions on the permanent radioactive waste disposal generated under decommissioning of the reactor blocks of the former Paldiski military facility.

CHAPTER 1

COLLECTION AND ANALYSIS OF THE AVAILABLE DATA CONCERNING THE REACTOR COMPARTMENTS AND OTHER RELATED ASPECTS

1.1 ORIGIN, OPERATION AND DECOMMISSIONING OF REACTOR STAND UNITS OF THE FORMER TRAINING CENTER OF NAVAL FORCE OF THE RUSSIAN FEDERATION IN THE PAKRI PENINSULA

In the late 1960s a training center of Naval Force of Russia was built at the territory of the Pakri Peninsula near the city of Paldiski (Estonia) for nuclear powered submarine crews training under the conditions maximally close to the real life. The main facility of the training center was a functional ground stand, simulating the nuclear power unit (NPU) of the first generation nuclear powered submarine (installation 346A). Except the nuclear compartment the stand included all necessary control, command and logistic equipment assembled in the compartments of the section by form and sizes fit the casing of actual nuclear-powered submarine. The stand was situated in the main technological section, surrounded by the buildings and constructions securing the safety of the stand in case of probable emergencies, as well as by the buildings and constructions used for formed radioactive waste management. The nuclear reactor and all logistic infrastructure were put into operation in 1968 and functioned trouble-free. In 1980 installation 346A was reconstructed: steam generators were replaced with more perfect ones and nuclear fuel was replaced by the fresh one. Unloaded nuclear fuel after relevant cooling was transported to the Russian Federation for processing.

Later, in 1983 main technological section was extended by means of attaching to it of an additional surface prototype of nuclear power unit of the second generation nuclear powered submarine (installation 346B). The stand was located in the compartments complying by shape and sizes with the actual compartments of a nuclear powered submarine of the second generation. Both stands functioned trouble-free till 1989, when they were stopped finally due to the political situation in the Soviet Union and a question of their decommissioning came up. No accidents related to the emergency aggravation of radiation situation in the main technological section were revealed during the entire period of operation of both installations. No technogeneus pollution of environmental objects such as soil, vegetation, groundwater, and etc., as well as of surrounding areas was observed for the period of long-term observations. The data of radiation independent studies carried out by the US experts in summer of 1995 confirmed satisfactory radiation environment at the site itself and at the surrounding area [1].

1.2 PRINCIPAL TECHNICAL SPECIFICATION OF ENERGY STANDS

Reactor stands were the analogs of nuclear power facilities of nuclear-powered submarine situated in the ground conditions and serving to train specialists on control of the reactor facilities.

Technical specification of stands and stages of operation are given in Table 1.

Table 1: Technical specification of stands and stages of operation

Stand	346A	346B
Reactor type	PWR/BM-A	PWR/BM-4
Heat power, MW	70	90
Outside sizes of a stand, m: Length Diameter	 50 7.5	 50 9.5
Operational stages of a stand: commissioning final shutdown total operating time of a stand, hr fuel recharging	 10/04/1968 January 1989 20281 1980	 10/02/1983 December 1989 5333 -
Final unloading	July – September 1994	

Both installations were situated inside the main technological section in the general stand hall with the length of 180, width of 18 and height of 22 m, which was equipped with two bridge cranes with the lifting capacity of 50 t each. In the last years the lifting capacity was limited to 30 tons by the Technical supervision authority of the Republic of Estonia.

1.3 ARRANGEMENT OF WORKS ON DECOMMISSIONING OF ENERGY STANDS OF THE FORMER TRAINING CENTER OF THE RUSSIAN FEDERATION IN PALDISKI CITY IN THE REPUBLIC OF ESTONIA

In July 1994 an intergovernmental agreement was concluded between the Russian Federation and the Republic of Estonia under which the territory of the training center together with all the constructions were transferred into ownership of the Republic of Estonia. Whereas all facilities should be put to the stable safety condition, i.e. a question of decommissioning of radiation hazardous facility came up.

Arrangement and works performance on safe long-term storage of the former training center of Naval Force of the Russian Federation was entrusted to GI VNIPIET (Lead Institute of the All-Russia Science Research and Design Institute of Power Engineering Technology).

At the first stage the spent nuclear fuel of both reactors was unloaded in September 1994 and transported to Russia for processing under the documentation of GI VNIPIET and in accordance with the Agreement. After this operation the former training center stopped being a nuclear hazardous facility but the radiation danger was remaining because of equipment and waste presence having high radioactive pollution. At the same time for development of the documentation on decommissioning of the facility in Paldiski the Russian party formed a working group consisting of the specialist of the following enterprises:

- Research and development institute GI VNIPIET;
- Design and engineering bureau CDB ME “Rubin” (Central Design Bureau for Marine Engineering);
- Research and development institute NIKIET;
- Experimental design bureau for mechanical engineering OKBM.

The specialists from PO «Sevmash» were involved at the stage of dismounting works of compartments adjacent with the reactor compartment and dismounting of non-radioactive equipment of the reactor compartments.

GI VNIPIET developed a preliminary concept of the reactor stands decommissioning. In the Concept three options for reactor compartments decommissioning were proposed and studied with evaluation of complexity, durability and cost of practical works performance:

1 Disposal of reactor compartments at the place of their installation. Duration of works was evaluated as 4 – 6 years;
2 Disposal of reactor compartments in a new constructed near-surface repository of radioactive waste in the territory of the Pakri peninsula. Duration of works was evaluated as 5 – 8 years;
3 Preparation and placement of reactor compartments for long-term controlled storage with the term up to 50 years. Duration of works was evaluated as 1 - 1.5 year.

The concept was studied by the Estonian party with involvement of the IAEA experts. The 3rd option was chosen as the most acceptable for the owners of constructions because of the least cost and term of execution with consideration of compliance of all safety measures [1].

1.4 EQUIPMENT CONFIGURATION AND RADIOLOGICAL CHARACTERISTICS OF REACTOR STANDS 346A AND 346B

A certain amount of radioactive waste was placed in the reactor compartments and fixed with concrete during 1995. Lists of these wastes were compiled in September 1995 and given to the Estonian authorities when transferring ownership of the site. It is understood that most of the radioactive wastes stored in reactor compartment 1 are low level (rags, metallic wastes, tools etc.), with surface contamination. These wastes are located principally on the third floor of the reactor compartment. The total weight of such wastes in RC1 (346A) is thought to be around 15 tons.

However, about 100 radioactive sources (used for calibrating radiological measurement equipment) were also entombed in concrete poured into the compartment within five or so containers (at the present moment it is not possible to indicate the exact location of sources), and comprise:

- neutron sources: Pu-238, Be-7, Cf-252
- γ-radiation sources: Co-60
- β-radiation sources: Na-22, Cl-36, Sr-90/Y-90, Cs-137, Tl-204
- α-radiation sources: Pu-239

Plutonium and cesium sources ranged from a few kBq to a few MBq. The total activity of the radioactive sources that were on site and might have been placed into RC1 was about 4.4 TBq in 1995 (mainly Co-60). All these sources are located inside shielding containers (Tables 2-4). For neutron sources and some γ-radiation sources, the container is constructed of special paraffin and/or lead. For β-radiation and α-radiation sources, the container is of plastic or wood. Most sources were placed into the U-shaped first-floor room where the main equipment of the first loop is located, and in the second floor area containing the motors and pumps, before these spaces were grouted with concrete. However, some sources could also have been placed in concrete poured onto the reactor vessel lid [1].

Table 2: List of ionizing radiation sources

№	Denomination of isotope, material, source	Activity (by passport)	Date of a passport issue (certificate) by manufacturer**
1	Fast neutron source Pt-Be ИБН-87 based on Pu-238	$5.0x10^7$ neutron/sec	March 1980
2	Co-60 gamma-source of the 2nd grade ГИК-2-14	$1.02x10^{10}$ Bq	January 1987
3	Co-60 gamma-source of the 2nd grade ГИК-2-14	$1.02x10^{10}$ Bq	January 1987
4	Pu-239, 9 $1/100cm^2$	3.62 Bq	February 1991
5	Pu-239, 9 $1/100cm^2$	16.2 Bq	February 1991
6	Pu-239, 9 $1/100cm^2$	44.3 Bq	February 1991
7	Pu-239, 9 $1/100cm^2$	158 Bq	February 1991
8	Pu-239, 9 $1/100cm^2$	447 Bq	February 1991
9	Pu-239, 9 $1/100cm^2$	1580 Bq	February 1991
10	Pu-239, 9 $1/100cm^2$	4380 Bq	February 1991
11	Pu-239, 9 $1/100cm^2$	17100 Bq	February 1991
12	Pu-239, 9 $1/100cm^2$	40000 Bq	February 1991
13	Pu-239, 9 $1/100cm^2$	412 Bq	February 1991
14	Pu-239, 9 $1/100cm^2$	1490 Bq	February 1991
15	Pu-239, 9 $1/100cm^2$	4300 Bq	February 1991
16	Pu-239, 9 $1/100cm^2$	16500 Bq	February 1991
17	Pu-239, 9 $1/100cm^2$	40000 Bq	February 1991
18	Pu-239, 9 $1/100cm^2$	176000 Bq	February 1991
19	Pu-239, 9 $1/100cm^2$	424000 Bq	February 1991
20	Pu-239, 9 $1/100cm^2$	1470000 Bq	February 1991
21	Pu-239, 9 $1/100cm^2$	416 Bq	April 1991
22	Pu-239, 9 $1/100cm^2$	40.6 Bq	April 1991
23	Pu-239, 9 $1/100cm^2$	3.61 Bq	April 1991
24	Pu-239, 9 $1/100cm^2$	450 Bq	April 1991
25	Pu-239, 9 $1/100cm^2$	1040 Bq	April 1991
26	Pu-239, 9 $1/100cm^2$	2670 Bq	April 1991
27	Pu-239, 9 $1/100cm^2$	2590 Bq	April 1991
28	Pu-239, 9 $1/100cm^2$	2890 Bq	April 1991
29	Pu-239, 9 $1/100cm^2$	4280 Bq	April 1991
30	Pu-239, 9 $1/100cm^2$	4370 Bq	April 1991
31	Pu-239, 9 $1/100cm^2$	4390 Bq	April 1991
32	Pu-239, 9 $1/100cm^2$	11200 Bq	April 1991
33	Pu-239, 9 $1/100cm^2$	43500 Bq	April 1991
34	Pu-239, 9 $1/100cm^2$	247 Bq	April 1991
35	Pu-239, 9 $1/100cm^2$	253 Bq	April 1991
36	Pu-239, 9 $1/100cm^2$	235 Bq	April 1991
37	Pu-239, 9 $1/100cm^2$	110 Bq	April 1991

№	Denomination of isotope, material, source	Activity (by passport)	Date of a passport issue (certificate) by manufacturer**
38	Pu-239, 9 1/100cm^2	706 Bq	April 1991
39	Pu-239, 9 1/100cm^2	1760 Bq	April 1991
40	Pu-239, 9 1/100cm^2	1760 Bq	April 1991
41	Pu-239, 9 1/100cm^2	1740 Bq	February 1991
42	Pu-239, 9 1/100cm^2	1770 Bq	February 1991
43	Pu-239, 9 1/100cm^2	87 Bq	March 1990
44	Pu-239, 9 1/100cm^2	137 Bq	March 1990
45	Pu-239, 9 1/100cm^2	395 Bq	March 1990
46	Pu-239, 9 1/100cm^2	929 Bq	March 1990
47	Sr-90 chlorous	0.6x10^{-3} Bq	November 1991
48	Sr-90+Y-90 alloy 1; 40; 160 cm^2	7460000 Bq	April 1991
49	Sr-90+Y-90 alloy 1; 40; 160 cm^2	744000 Bq	April 1991
50	Sr-90+Y-90 alloy 1; 40; 160 cm^2	73500 Bq	April 1991
51	Sr-90+Y-90 alloy 1; 40; 160 cm^2	7410 Bq	April 1991
52	Sr-90+Y-90 alloy 1; 40; 160 cm^2	739 Bq	April 1991
53	Sr-90+Y-90 alloy 1; 40; 160 cm^2	3020002 Bq	April 1991
54	Sr-90+Y-90 alloy 1; 40; 160 cm^2	505000 Bq	April 1991
55	Sr-90+Y-90 alloy 1; 40; 160 cm^2	270000 Bq	April 1991
56	Sr-90+Y-90 alloy 1; 40; 160 cm^2	68 Bq	April 1991
57	Sr-90+Y-90 alloy 1; 40; 160 cm^2	207 Bq	April 1991
58	Sr-90+Y-90 alloy 1; 40; 160 cm^2	290 Bq	April 1991
59	Sr-90+Y-90 alloy 1; 40; 160 cm^2	302 Bq	April 1991
60	Sr-90+Y-90 alloy 1; 40; 160 cm^2	528 Bq	April 1991
61	Sr-90+Y-90 alloy 1; 40; 160 cm^2	553 Bq	April 1991
62	Sr-90+Y-90 alloy 1; 40; 160 cm^2	727 Bq	April 1991
63	Sr-90+Y-90 alloy 1; 40; 160 cm^2	1910 Bq	April 1991
64	Sr-90+Y-90 alloy 1; 40; 160 cm^2	3250 Bq	April 1991
65	Sr-90+Y-90 alloy 1; 40; 160 cm^2	5660 Bq	April 1991
66	Sr-90+Y-90 alloy 1; 40; 160 cm^2	5590 Bq	April 1991
67	Sr-90+Y-90 alloy 1; 40; 160 cm^2	20600 Bq	April 1991
68	Sr-90+Y-90 alloy 1; 40; 160 cm^2	26000 Bq	April 1991
69	Sr-90+Y-90 alloy 1; 40; 160 cm^2	1960000 Bq	April 1991
70	Sr-90+Y-90 alloy 1; 40; 160 cm^2	53800 Bq	April 1991
71	Sr-90+Y-90 alloy 1; 40; 160 cm^2	27900 Bq	April 1991
72	Sr-90+Y-90 alloy 1; 40; 160 cm^2	6680 Bq	April 1991
73	Sr-90+Y-90 alloy 1; 40; 160 cm^2	5290 Bq	April 1991
74	Sr-90+Y-90 alloy 1; 40; 160 cm^2	4770000 Bq	April 1991
75	Standard spectrometric source «ОСГИ» beta-activity type	10^5 decay per second	
76	Standard spectrometric source «ОСГИ» beta-activity type from II sources	10^5 Bq	November 1991
77	Cf-252	1.7x10^7 neutron/sec	March 1980
78	Na-22 chlorous	600000 Bq	
79	Tl-204	0.5x10^{-3} Bq	November 1991
80	Co-60 ГИК-2-18	5.11x10^{11}Bq	January 1987
81	Co-60 ГИК-2-18	5.11x10^{11}Bq	April 1980

№	Denomination of isotope, material, source	Activity (by passport)	Date of a passport issue (certificate) by manufacturer**
82	Co-60 ГИК-5-2	$3.16x10^{12}$Bq	March 1987
83	Pu-Be source of ИБН-87 type	$4.85x10^{7}$neutron/sec	July 1987
84	Standard spectrometric source alpha emission (ОСИАИ)	38400 Bq	November 1989
85	Standard spectrometric source alpha emission (ОСИАИ)	4180 Bq	November 1989
86	Standard spectrometric source alpha emission (ОСИАИ)	35000 Bq	November 1989
87	Standard spectrometric source alpha emission (ОСИАИ)	39400 Bq	November 1989
88	Standard spectrometric source alpha emission (ОСИАИ)	44200 Bq	July 1991
89	Standard spectrometric source alpha emission (ОСИАИ)	3940 Bq	July 1991
90	Standard spectrometric source alpha emission (ОСИАИ)	38400 Bq	July 1991
91	Standard spectrometric source alpha emission (ОСИАИ)	37400 Bq	July 1991
92	Pu-239	1060 Bq	March 1990
93	Pu-239	4020 Bq	March 1990
94	Pu-239	10700 Bq	March 1990
95	Pu-239	41000 Bq	March 1990
96	Pu-239	3.59 Bq	March 1990
97	Pu-239	40.3 Bq	March 1990
98	Pu-239	403 Bq	March 1990
99	Pu-239	660 Bq	March 1990
100	Pu-239	4 Bq	February 1988
101	Pu-239	39 Bq	February 1988
102	Pu-239	445 Bq	February 1988
103	Pu-239	700 Bq	February 1988
104	Pu-239	117 Bq	February 1988
105	Co-60 ГИК-2-7	$3.4x10^{8}$Bq	January 1987
106	Cs-137 nitrate	$0.5x10^{-3}$ Bq	November 1991
107	Co-60 type ЗК-0 (solution)	$0.5x10^{-3}$ Bq	November 1991

** “alloy 1” – ionizing radiation sources material which incorporates the radionuclides (in Russian – «Сплав 1»)*

*** the passport issue date corresponds to the production date. Some of the sources were delivered to the Paldiski site after the reactor shutdown (1989). The dates of the passports issue are based on the sources passports list provided by ALARA AS (the copies of the sources passports are unavailable).*

Table 3: List of solid radioactive waste placed into reactor compartment of Unit 1 (346A)

No.	Description	Weight [kg]	Quantity [item]	Surface dose rate γ [μSv/h], 1995	Contamination β [Bq/cm^2], 1995
1	Container for transportation of spent fuel sleeves	6000		1.7	8
2	Bag with industrial trash and rags	40		0.3	1.7
3	Bag with boots and PVC film	50		0.3	1.7
4	Bag with boots, plastic, protective clothes, etc.	30		0.3	3.4
5	Bag with industrial trash.	15		0.3	25
6	Stand for transport rod's sleeves	110		1.7	5
7	Companion ladder	130		1.7	5
8	Support for transport container (item No. 1)	260		1.7	5
9	Device for turning off reactor lid nuts.	60		1.7	2.5
10	Pipes of the 2nd,3^{d} loops and draining systems		5	2.8	15
11	Mooring rings		5	2.3	5
12	Compensating grids driving gears		170	2.3	3.3
13	Driving gears (small)		12	2.3	1.7
14	Air filter	200		0.3	16.7
15	Leading gears	1500		0.6	50
16	Cross-arm	500		2.3	66.7
17	Saucer	500		0.3	2
18	Saucer with ropes	150		0.9	2.7
19	Lodgement with pipes, valves armature.	300		0.3	16.7
20	Valves	100		0.3	5
21	Steel and lead container (for overload) in the transport cask (waterproof) with 5 Co-60 sources	1200		5700	
22	Paraffin container with 5 neutron sources	400		$5.0x10^7$n/sec	**-**
23	Laboratory container with 1 Co-60 source	350		0.3	
24	Wooden box with flat Pu-239 and Sr-90 control sources	60		0.4	
25	Box (wooden) with 50 smoke detectors	25		0.3	**-**

Table 4: Characteristics of radioactive sources that were on site and had or might have been placed into reactor compartment of Unit 1 (346A)

№	Type of wastes	Type of container	№ of container	Isotopic composition	Radiation type	Specific Activity	Number of wastes	Total Activity of containers with sources (as calculated by the Site Radiation Safety Unit in 1994-1995)
1	Solid	Paraffin container	10	Fast neutrons source plutonium-beryllium, IBN-87, with Plutonium 238	neutrons	$5.0x10^7$n/s	01	$8.8x10^{10}$ Bq (estimate)
2	Solid	Steel and lead container (for overload) in the transport cask (waterproof).	04	Cobalt-60 γ-sources category 2, GIK-2-14	gamma	$1.02x10^{10}$Bq	02	$1.04x10^{10}$Bq
3	Solid	Wooden box	-	Pu-239 91/100cm^2	alpha		43	$2,554x10^6$Bq
4	Solid	Metallic box	-	Cl Sr-90 act.5mk	beta	$6x10^5$ Bq	01	$6x10^5$ Bq
5	Solid	Wooden box	—	Strontium-90+Ittrium-90 1; 40 ; 160cm^2	beta		27	$1,9x10^7$ Bq
6	Solid	Plastic box		Spectrometric control sources γ-radiation (SSERG) type B	gamma	10^5 desint/s	01	10^5 desint/s
7	Solid	Plastic box	-	SSERG type B	gamma	10^3 Bq	11	$1.1x10^6$ Bq
8	Solid	Paraffin container	10	Californium-252	neutrons	$1.7x10^7$n/s	01	$1.5x10^8$ Bq (estimate)
9	Solid	Metallic box	-	NaCl-22	beta gamma	$6x10^5$ Bq	01	$6x10^5$ Bq
10	Solid	Metallic box	-	Tallium-204	beta gamma	$5x10^5$ Bq	01	$5x10^5$ Bq
11	Solid	Steel and lead container / Paraffin container	04, 10	Cobalt-60 GIK-2-18	gamma	$5.1x10^{11}$ Bq	01	$5.1x10^{11}$ Bq
12	Solid	Steel and lead container / Paraffin container	04, 10	Cobalt-60 GIK-2-18	gamma	$5.1x10^{11}$Bq	01	$5.1x10^{11}$ Bq
13	Solid	Steel and lead container / Paraffin container	04, 10	Cobalt-60 GIK-2-18	gamma	$3.16xl0^{12}$ Bq	01	$3.16xl0^{12}$ Bq
14	Solid	Paraffin container	10	Source PuBe	neutrons	$4.86x10^7$ n/s	01	$8.5x10^{10}$ Bq

				type IBN-87				(estimate)
15	Solid	Plastic box	-	SSEAR	alpha			2,409x10^5 Bq
16	Solid	Wooden box	-	Pu-239	alpha		13	5,92x10^4 Bq
17	Solid	Steel and lead container (for overload) in the transport cask (waterproof).	04	Cobalt-60 GDC-2-7	gamma	3.4x10^8 Bq	01	3.4x10^8 Bq
18	Solid	Metallic box		Cesium-137 nitrate	beta, gamma	5x10^5 Bq	01	5x10^5 Bq
19	Solid	Metallic box		Cobalt-60 Type ZK-0 (solution)	gamma	5x10^5 Bq	01	5x10^5 Bq

1.4.1 Key Process Equipment In Reactor Compartment Of Stand 346A

Stand 346A was fitted with a VM-A nuclear power unit complete with all necessary equipment to ensure long-term, fail-free and safe operation of the energy stand. List of key equipment components and their weight and size characteristics are summarised in Table 5.

In addition to equipment components listed in the Table there are also equipment components belonging to circuits 3 and 4, in particular circulating pumps CP-21 and CP-23 (two in each), which only have minimum radioactive contamination and are installed on the second floor of the pump well. In terms of their weight and size, they are close to heat exchanger VP2-1-0, only somewhat shorter.

Table 5: Key circuit equipment of stand 346A

Equipment	Number	Overall dimensions, mm	Weight, t
1 Reactor vessel VM-A	1	2100x2100x4295	30
2 Steam generator chamber	8	800x940x2300	21.6
3 Main Circulation Pump GCEN-146	1	L—2150; H-2150	4.6
4 Aux. Circulation Pump VCEN-147	1	L – 850 H -1870	1.8
5 Pressuriser	6 bottles	L – 620 H- 3550	1.185x6 (7.2)
6 Activity filter	2	350x550x1800	0.565x2 (1.13)
7 Refrigerator HGCEN-601	1	405x700	0.3
8 Refrigerator HGCEN-146M	1	400x1200	0.115
9 Refrigerator XVCEN-147M	1	300x1200	0.052
11 Heat exchanger VP2-1-0	1	500x1510	0.45
12 Iron-water protection tank	1	2300x2300x3200	52
13. Piping (primary circuit)	3	180x17	0.2
	34.2	140x15	1.6
	9.4	108x11	0.25
	42	83x9	0.706
	7.0	89x9	0.13
	44.0	28x4	0.105
	20.0	15x2,5	0.015
14. Piping (secondary circuit)	29	83x4	0.226
	18.5	36x3	0.045

	30	22x2.5	0.037
	8.0	219x7	0.293
	12	108x6	0.181
	26	108x5	0.330
15. Piping (circuit 3)		63x6.5 34x4.5 22x3.5 16x3	
16. Piping for storage and SG rinsing		32x3.5 16x3	
17. Steam connections piping		194x10 127x14	

Materials used for key circuit equipment:

Reactor vessel and pressuriser - alloyed steel with internal surfacing of stainless steel;

Steam generator - body of steel grade 20, internal tubing of titanium alloys;

Main and auxiliary pumps in the primary circuit - body of alloyed steel with internal surfacing, scroll of stainless steel;

Refrigerator of activity filter - internal tubing of cupro-nickel;

Refrigerator of main and auxiliary pumps in primary circuit - body of alloy MNZH5-1;

Activity filter - stainless steel.

Pump well according to the design is fitted with various pipelines with diameters ranging from 180 to 15 mm which interconnect all available equipment. Considering the amount of installed equipment, piping and cabling, in pump rooms on the 1st and 2nd floors there is very little space left, making the rooms difficult to visit. Further difficulties are created by concrete poured into those rooms.

REACTOR

The reactor (or its metal) is considered as SRW intended for unconditional disposal. The reactor may be leaky in the seams for welding the reactor head to the reactor vessel and for welding the plugs in the reactor head because of inspection being performed through "external examination" only.

STEAM GENERATOR

The steam generator of the PG-14T type consists of 8 cylindrical chambers connected in pairs into 4 sections (Figure 1). The overall dimensions of one chamber are 786 mm diameter and 2300 mm height. All pipelines connected to the chamber are made of 1Cr18Ni9Ti stainless steel.

Three legs welded to each chamber are attached to the ship bases using M24 studs.

The primary water goes above from the reactor to the SG chamber via an 83x9 mm tube and inside the chamber via coils of 18x2.5 mm titanium alloy tubes. The primary water is discharged from the chamber below over an 83x9 mm tube.

The secondary water is supplied to the SG chamber below over a 36x3 mm tube and discharged as steam via an 83x4 mm tube.

A primary water sample has shown the volumetric activity of 1443 Bq/l.

A secondary water sample has shown the volumetric activity of 4.07 Bq/l.

Samples were taken for analysis in September 1994 (the reactor was shut down in January 1989).

The non-discharged secondary water amount is ~ 1000 L.

All the samples were taken from the circuits directly before the removal of water (excluding removal of trapped water). Circuit water measurements were made by the Paldiski Facility Radiation Safety Unit in approximately 1993.

The gamma radiation dose rate (on the above date of measurement, 1994) on the SG cylindrical chamber surface was <0.3 mSv/h.

The steam generator may be decontaminated when a part of the primary circuit tubes are cut for the reactor disconnection and connection of the system with a special pump, a tank for injection of chemical agents, a heater for solutions, etc.

The potential SG decontamination does not have sense because of the low activity of corrosion depositions that have been accumulated on the primary circuit tube inside during 7107 hours.

The radioactivity values are as follows (major radionuclides Co-60, Fe-55, Ni-59, Ni-63):

- after reactor shutdown (in 6 months) - 2.9×10^{11} Bq (over the entire SG surface),
- In 2001 – 1.95×10^{11} Bq,
- In 2015 – 1.36×10^{11} Bq,
- In 2039 – 8.3×10^{10} Bq.

The SG is accessible via a manhole at the fore end of the RC left board (portside) corridor. The steam generator at the RC preservation moment was leak tight.

The weight of the SG-14T with pipelines is 21600 kg.

REACTOR COOLANT PUMP

The GTsEN-146 pump (Figure 2) was intended for the circulation of the primary water. The overall dimensions are 1250 mm diameter and 2150 mm height. All parts contacting the primary circuit are made of 1Cr18Ni9Ti stainless steel. The pump stator is separated from the primary circuit by a Nichrome alloy jacket. The pump body and the scroll (lower portion) are made of 08Cr19Ni12V stainless steel. The scroll flange is made of steel 20.

The pump is attached to the story 2 floor using 12 studs M28.

The pump weight is 4600 kg.

AUXILIARY REACTOR COOLANT PUMP

The VTsEN-147P pump (Figure 3) is auxiliary and its location in the pumping enclosure is similar to that of the GTsEN pump. Its differences from the GTsEN are smaller capacity and dimensions. The overall dimensions are 850 mm diameter and 1870 mm height. All parts contacting the primary circuit are made of 1Cr18Ni9Ti stainless steel.

The pump stator is separated from the primary circuit by a Nichrome alloy jacket. The pump body is made of CrNiTiV steel and the scroll (pump lower portion) is made of 0Cr18Ni10Ti stainless steel.

The pump is attached to the story 2 floor using 11 studs M24.

The pump weight is 1800 kg.

PRESSURIZER

A pressurizer is installed only in the special fore enclosure in the RC of stand 346A. It is intended for compensating the primary circuit volume increase during heating-up.

The pressurizer (Figure 4) consists of 6 steel cylinders with the capacity of 340 liters each. The overall dimensions (assembly 13) are 620 mm diameter and 3190 mm height. The Inside of the cylinders is clad with a thin-wall jacket (the thickness of 3 mm) of stainless steel.

One of the cylinders (assembly 14) (Figure 5) has a special tube with a flange for installation of a level gage and the level gage upper portion is capped with a lead plug protruding over the height from the fore SCS enclosure floor. The gap between the cylinders is filled with carboryte bricks (contain boron carbide,B_4C , protection from neutrons). The overall dimensions (assembly 14) are 620 mm diameter and 3550 mm height.

The cylinders are installed with the support (plate) on the foundation and fastened with 4 studs M20. From the top the cylinders are pressed against the enclosure wall with yokes.

The weight of one cylinder is 1185 kg.

RADIOACTIVITY FILTER

The radioactivity filter (Figure 6) is intended for purifying the primary water of fission product activity and corrosion products through their absorption by sorbents. The primary water delivered to the radioactivity filter is cooled in the KhGTsEN-601 chiller to prevent the sorbents from caking. To protect the radioactivity filter from external heat sources, it has a jacket cooled by the tertiary water.

The overall dimensions are 346 mm diameter and 1790 mm height.

The RC of stand 346A has two filters installed in the rear reactor enclosure. Each filter is attached via a support flange using 10 studs M28.

The material of the filter body, jacket and connected tubes is 1Cr18Ni9Ti steel. The radioactivity filter weight is 565 kg.

KHGTSEN-601 CHILLER

This chiller (Figure 7) is intended for cooling the primary water delivered to the radioactivity filter for purification. The primary water was cooled by circuit 4 with its characteristics on stand 346A are similar to those of the tertiary circuit. The overall dimensions are 405 mm diameter and 1100 mm height.

The chiller is installed on a special support on the pumping enclosure story 1 using 7 studs M20. The KhGTsEN weight is 300 kg.

KHGTSEN-146 M AND KHVTSEN-147 M CHILLERS

These chillers (Figures 8 and 9) are intended for cooling the primary water delivered for cooling the pump rotor bearing. The primary water was cooled by circuit 4 with its characteristics on stand 346A similar to those of the tertiary circuit. Structurally, the chillers are U-shaped, and differ in dimensions only. The overall dimensions are 346 mm diameter and 1200 mm height (for KHGTSEN-146 M) and 240 mm diameter and 1200 mm height (for KHGTSEN-147 M). The chillers are located on the pumping enclosure story 1 and are attached via brackets each using 4 studs M16.

The weight of the KhGTsEN-146M is 114 kg and the weight of the KhVTsEN-147M is 52kg.

HEAT EXCHANGER VP 2-1-0

The VP 2-1-0 heat exchanger (Figure 10) is intended for the tertiary water cooling with the circuit 4 water. The overall dimensions are 450 mm diameter and 1510 mm height.

Two heat exchangers are installed on the story 1 of the pumping enclosure near its fore partition.

The heat exchanger is attached to the base using 6 bolts M16 and to the partition using yokes.

The weight of one heat exchanger is 450 kg.

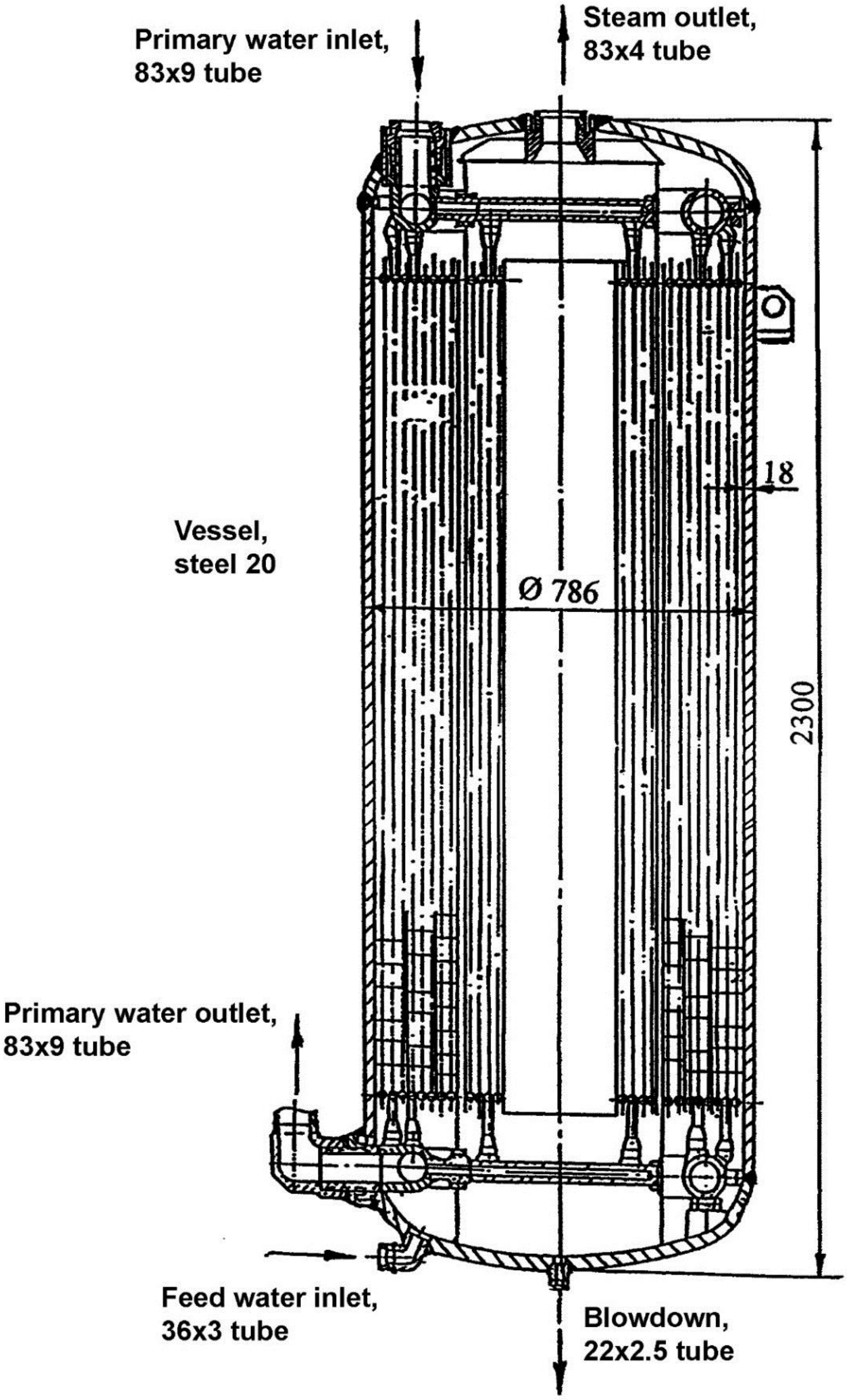


Figure 1. PG-14T steam generator chamber

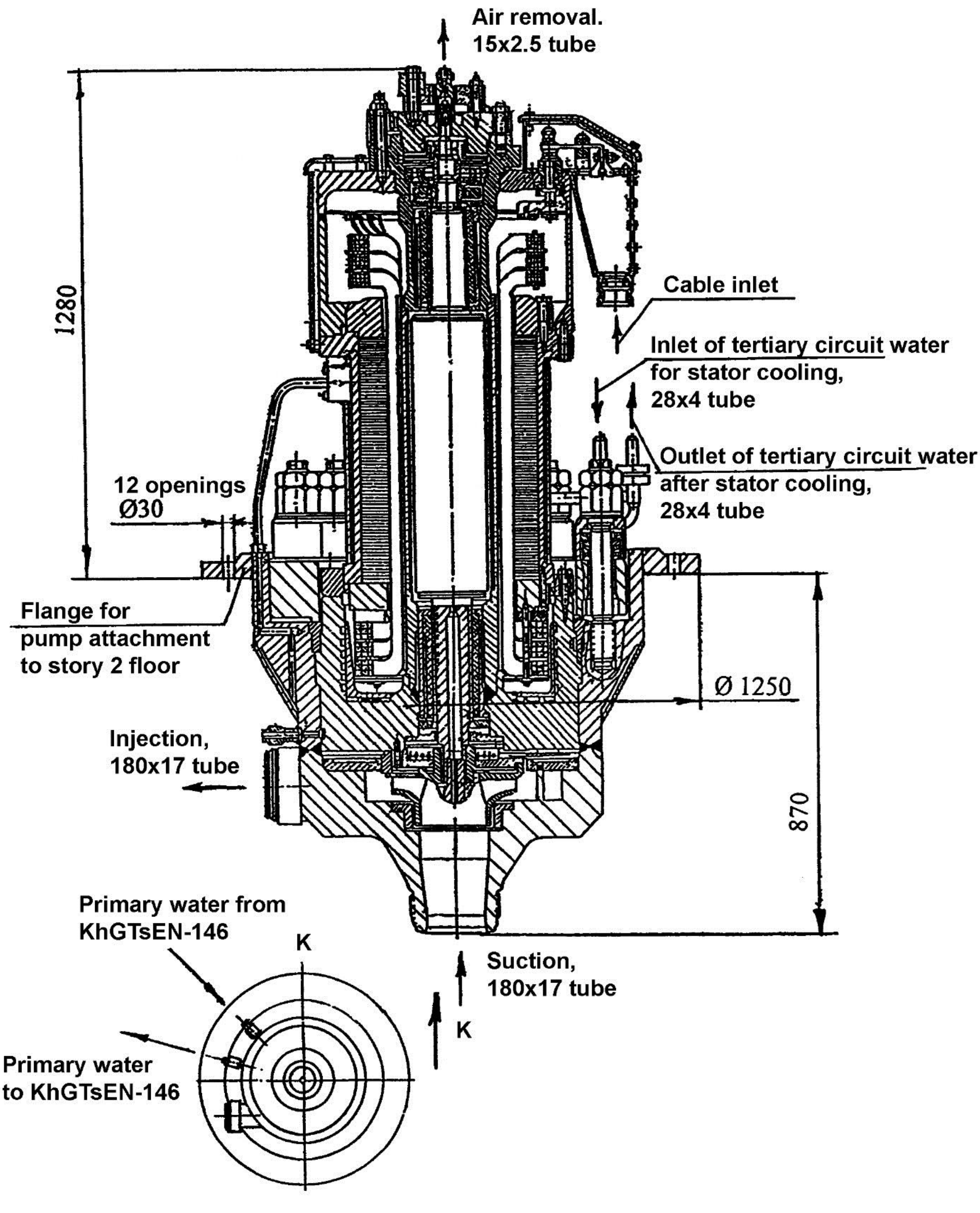


Figure 2. Reactor coolant GTsEN-146 pump

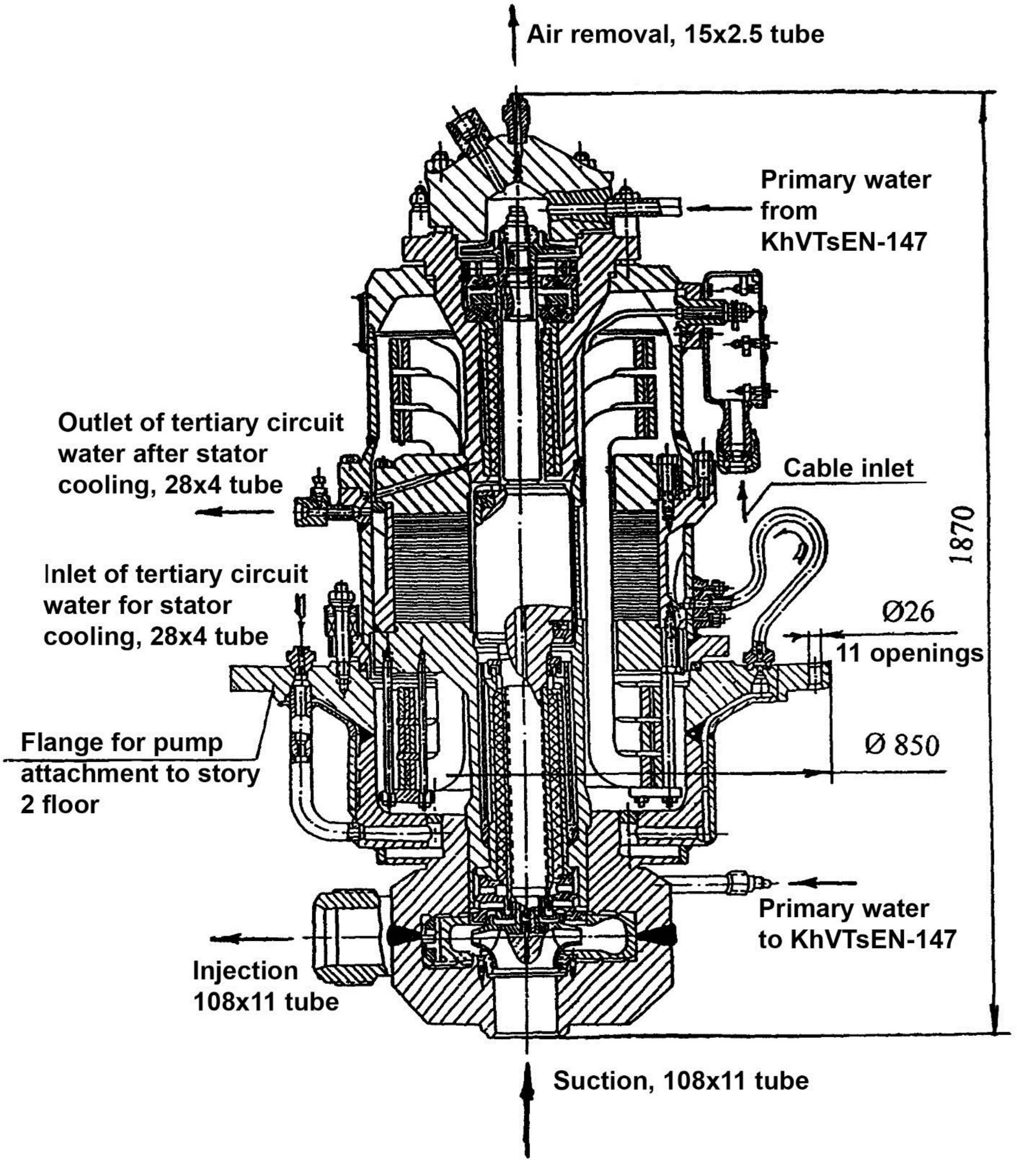


Figure 3. Auxiliary reactor coolant VTsEN-147P pump

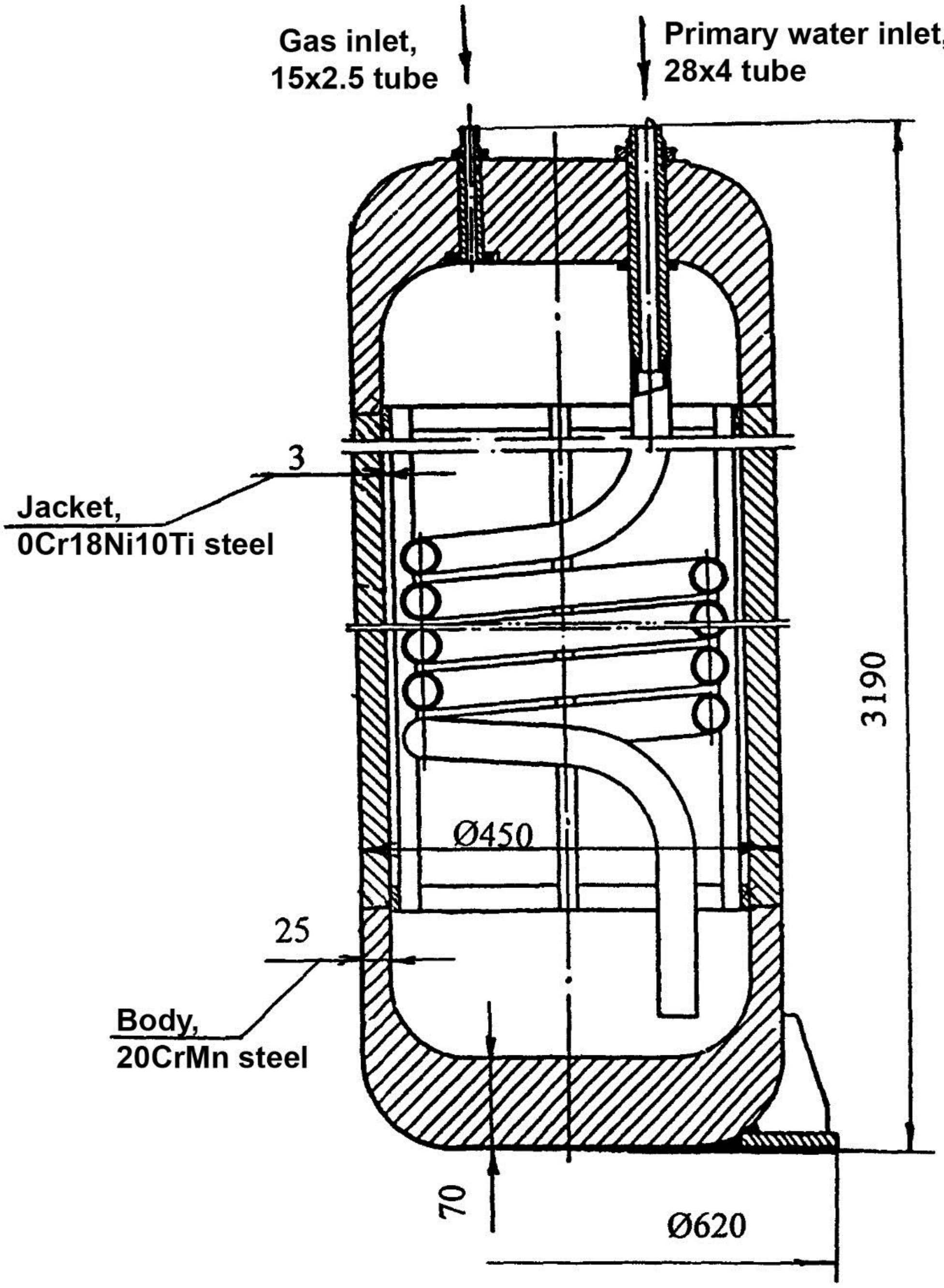


Figure 4. Pressurizer (cylinder), assembly 13

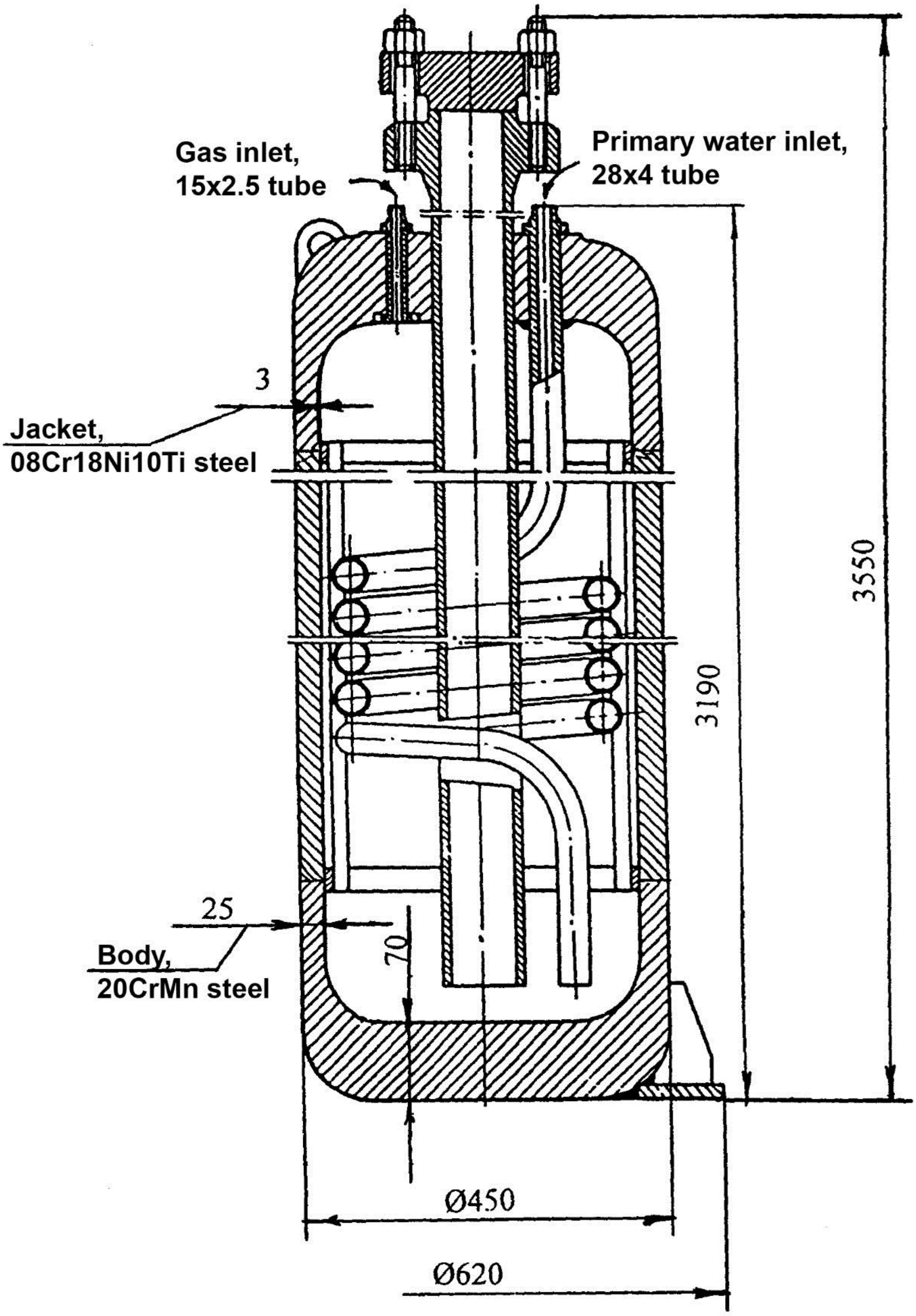


Figure 5. Pressurizer (cylinder), assembly 14

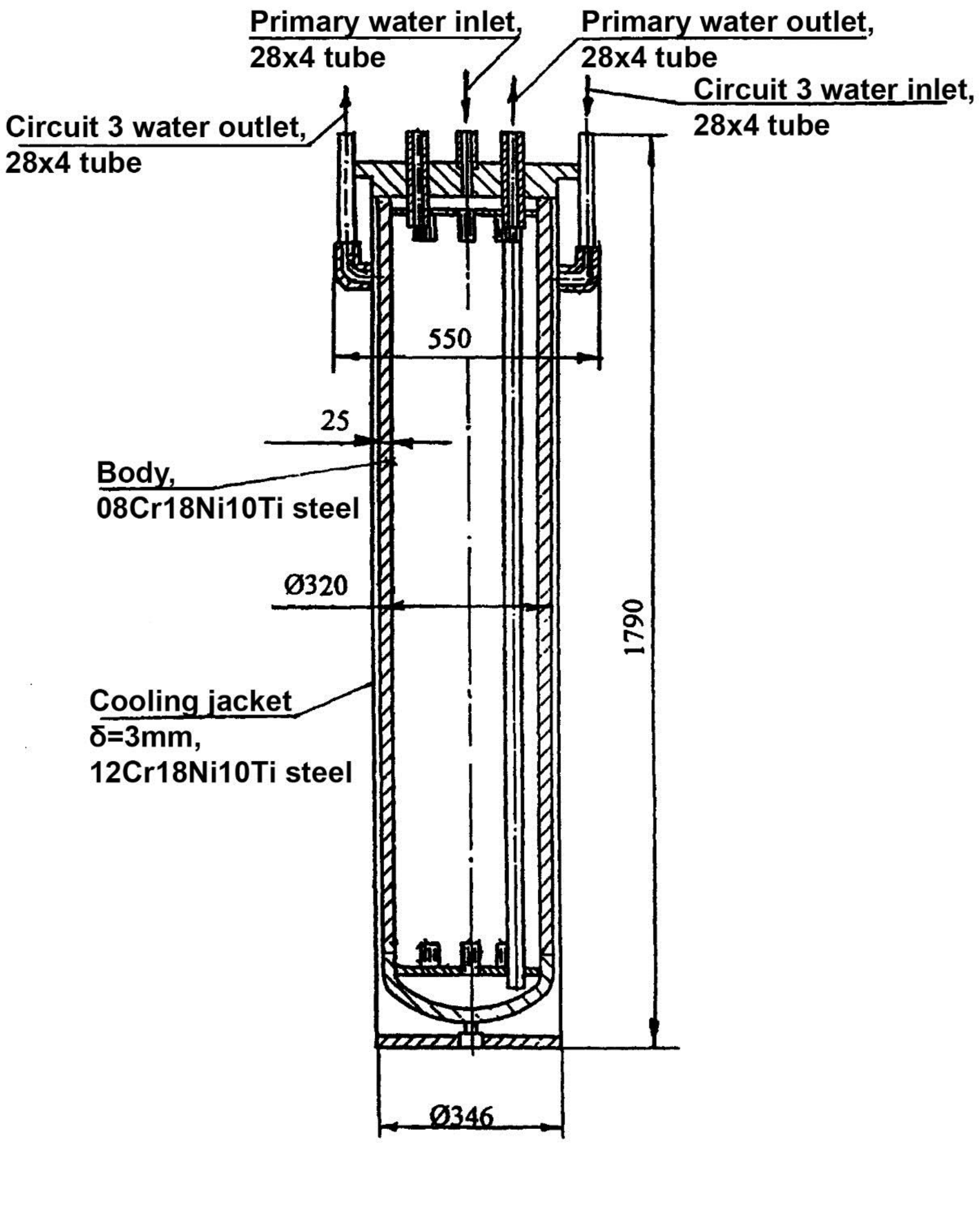


Figure 6. Radioactivity filter

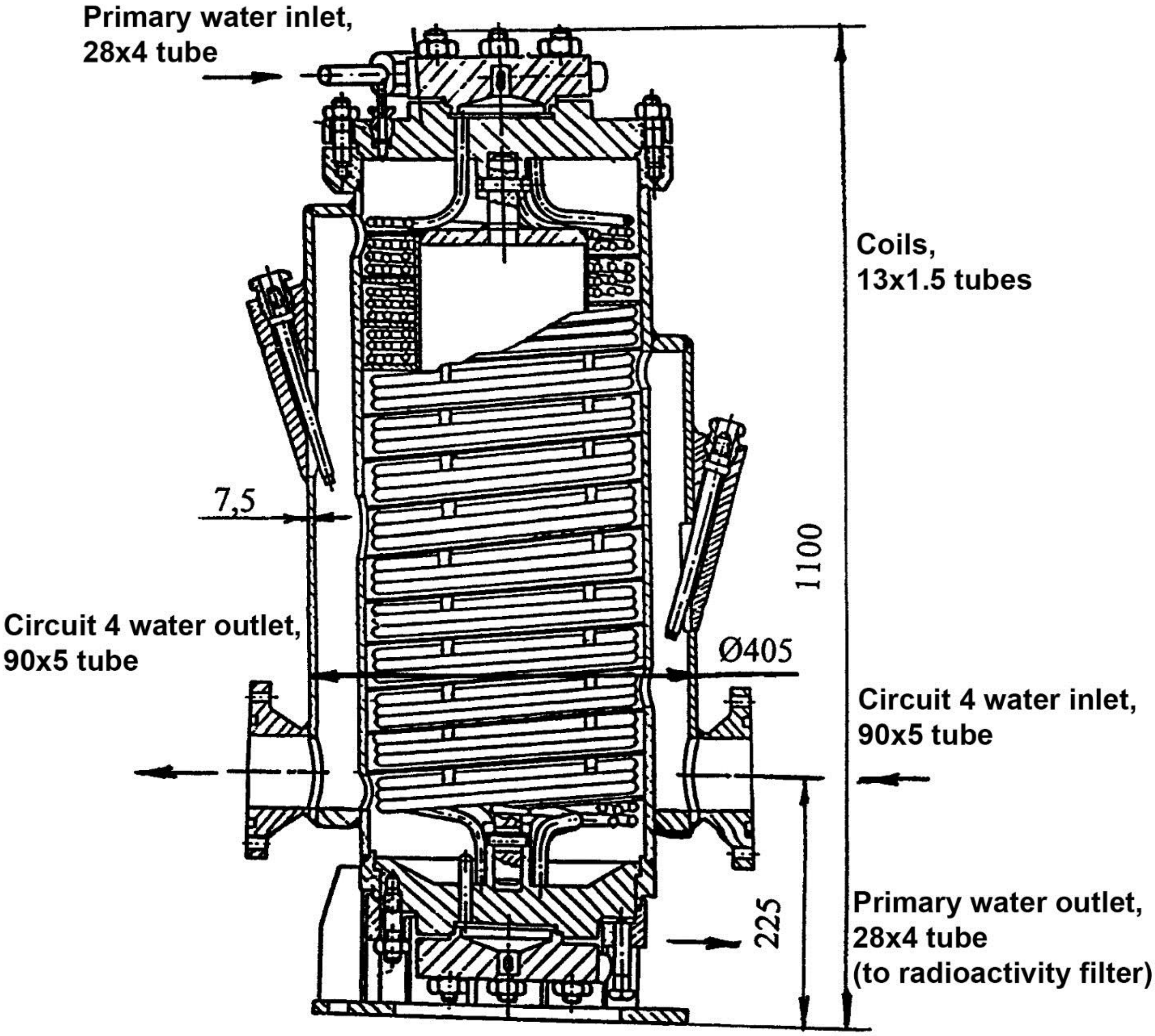


Figure 7. KhGTsEN-601 chiller

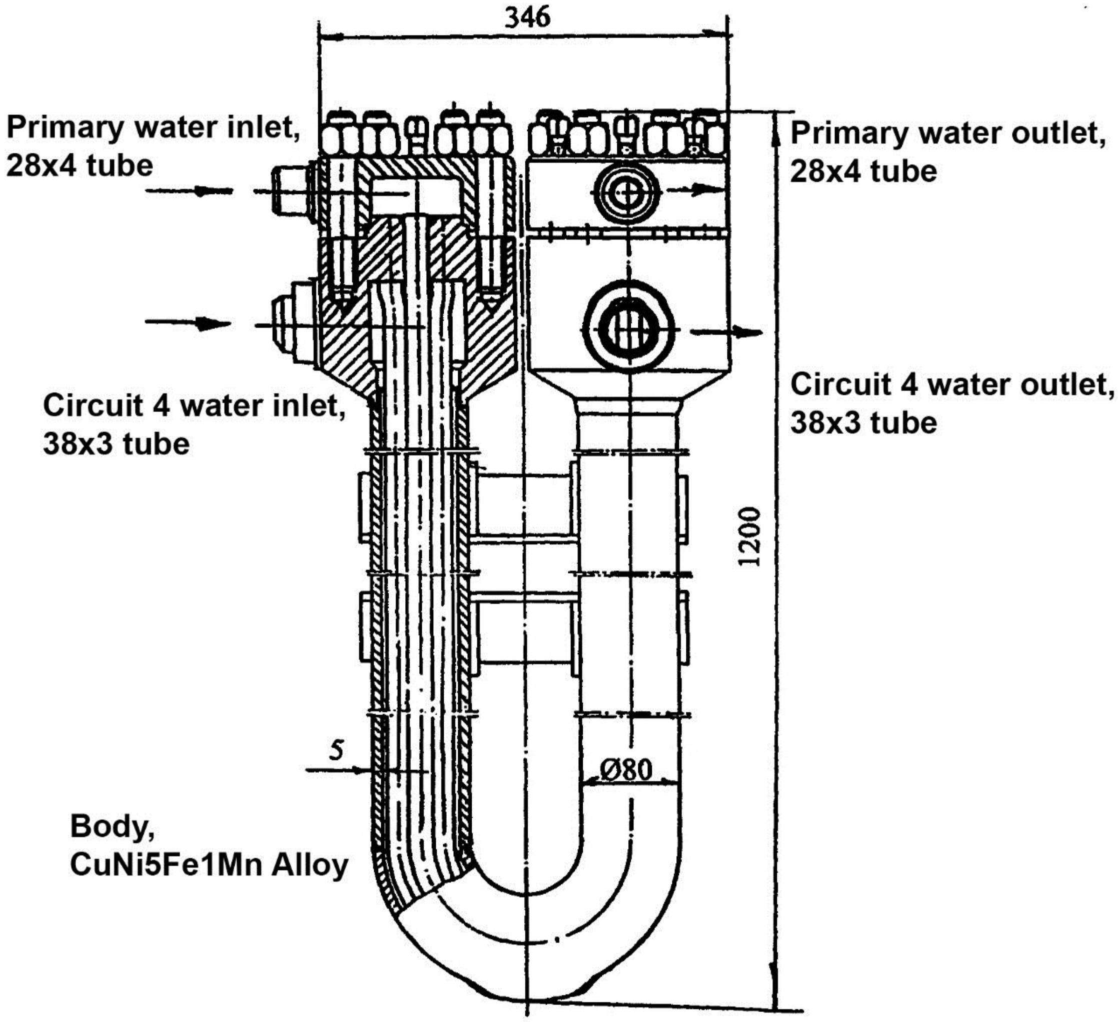


Figure 8. KhGTsEN-146M chiller

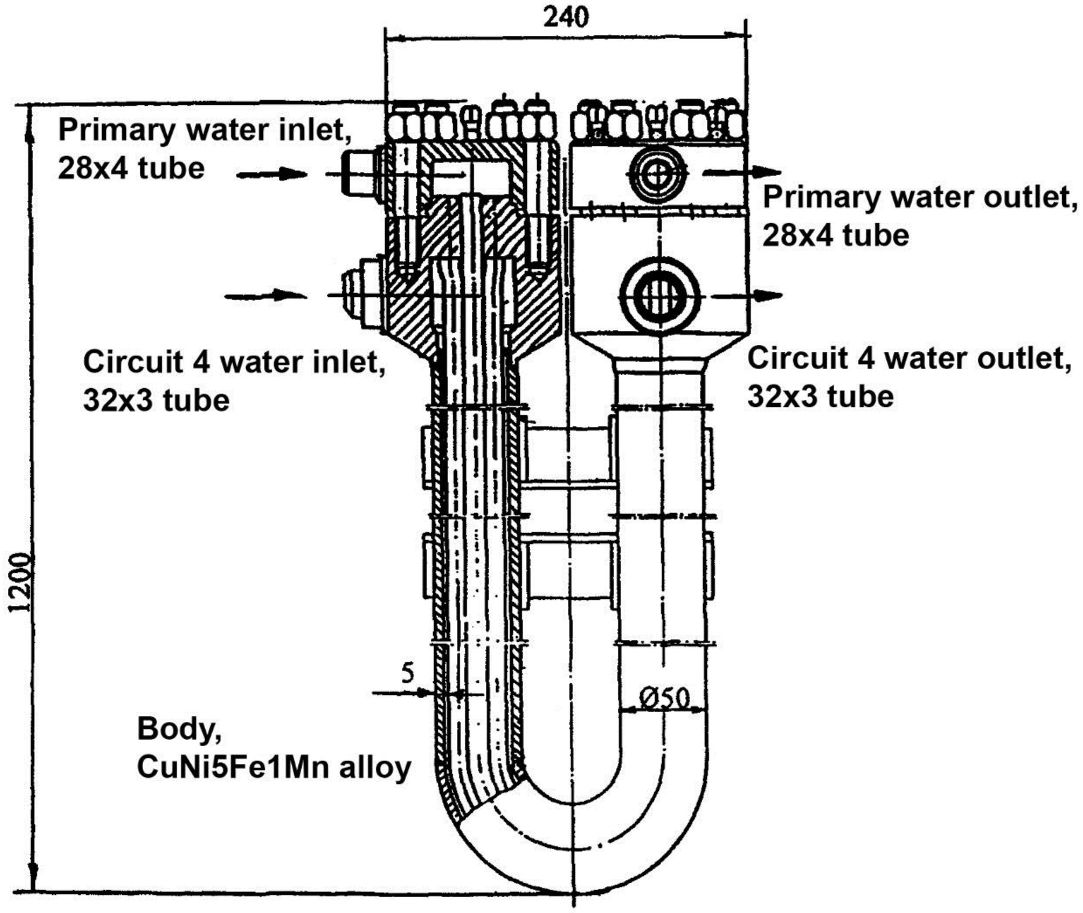


Figure 9. KhVTsEN-147M chiller

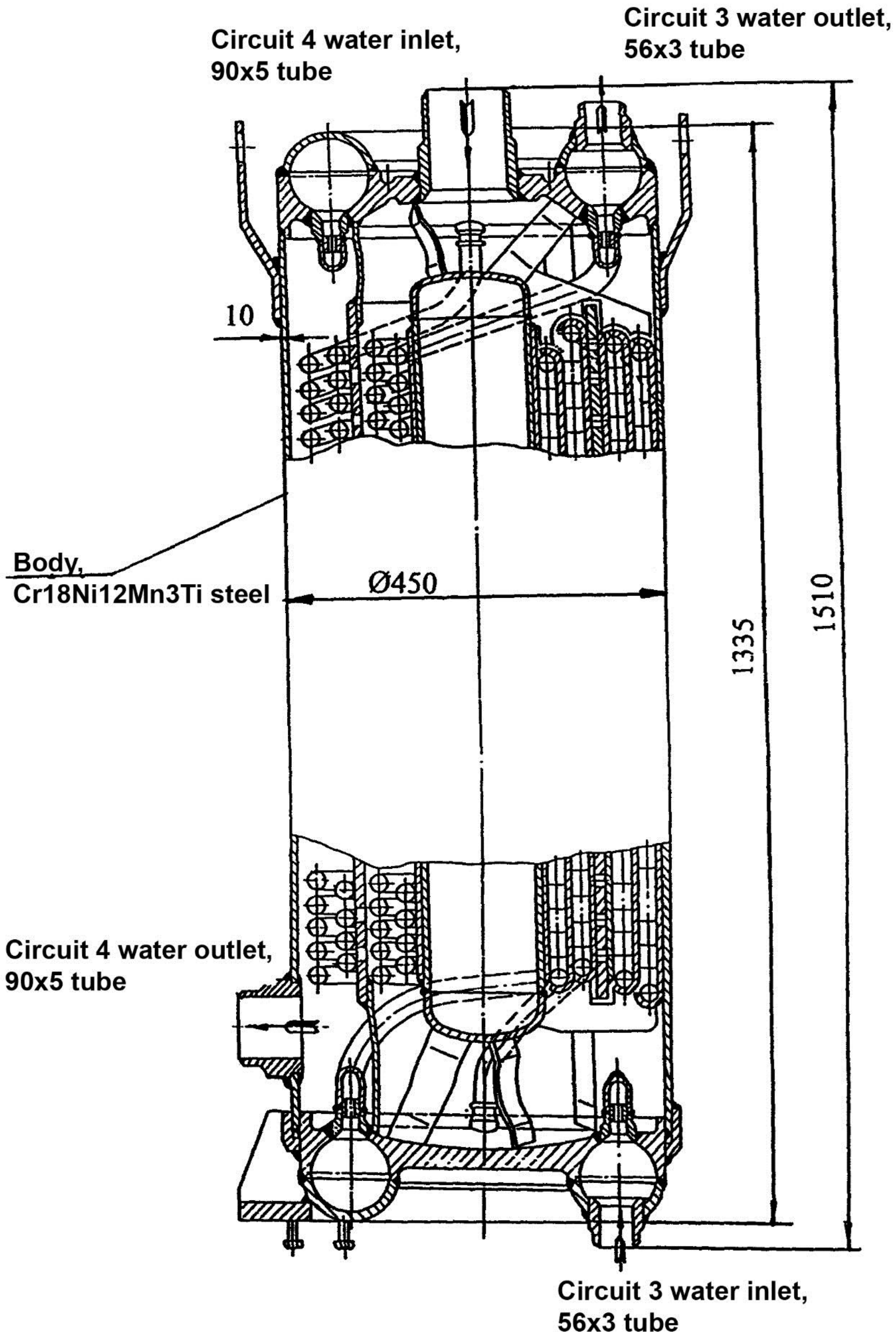


Figure 10. Circuits 3-4 VP 2-1-0 heat exchanger

PIPELINES OF THE MAIN SSS CIRCUITS

Primary circuit

The components of the primary circuit (reactor, steam generator, pumps with chillers, radioactivity filters with a chiller, pressurizer, valves) (Figure 11) are connected by 180x17, 140x15, 108x11, 89x9, 28x4 and 15x2.5 tubes. The length of the tubes and the weights are presented in Table 6.

Table 6: The length of the tubes and the weights (primary circuit)

Tube dimension (outer diameter x wall thickness), mm	Length (m)	Weight (kg)
180x17	3	200
140x15	34.2	1600
108x11	9.4	250
83x9	42	706
89x9	7.0	130
28x4	44.0	105
15x2.5	20.0	15

All tubes are made of 1Cr18Ni9Ti stainless steel.

Secondary circuit

The components of the secondary circuit (steam generator of 8 chambers, feed water header, steam collector, valves) are connected by 83x4, 36x3, 22x2.5, 108x6 and 108x5 tubes. The length of the tubes and the weights are presented in Table 7.

Table 7: The length of the tubes and the weights (secondary circuit)

Tube dimension, mm	Length (m)	Weight (kg)
83x4	29	226
36x3	18.5	45
22x2.5	30	37
219x7	8.0	293
108x6	12	181
108x5	26	330

All tubes are made of 1Cr18Ni9Ti stainless steel except the 219x7 tube made of steel 20. This tube runs from the steam collector to the rear partition over the fore enclosure story 2.

Practically all the tubes of the secondary circuit are located within SG partition-off at the portside.

The steam collector and the feed water header are located at story 2 of the pumping enclosure that is grouted together with equipment and different SRW placed in the compartment before grouting.

The steam generators are accessible through a manhole in the portside corridor.

Tertiary circuit

The tertiary circuit cools the reactor coolant pump stators, radioactivity filter and IWS tank. A TsN-21 pump is responsible for water circulation. The TsN-21 pumps (the second pump is standby) are installed on the pumping enclosure story 2. The tertiary water is delivered to the IWS tank and goes back to the heat exchanger of circuits 3 and 4 (VP 2-1-0) via 56x3 tubes running along the portside in the very bottom between the reactor and the SG. The rest of the tubes are rather small; their dimensions are 28x4, 25x2.5, 20x2.5,16x3.

The last tertiary water sample (prior to drying) has volumetric activity of 4.07 Bq/l. In accordance with the experts opinion of JSC “Atomproekt” these tubes are extremely hard to dismantle because of their location - along the portside at the very bottom between the reactor and the SG (both reactor and SG are radioactive).

Fourth circuit

The circuit 3 and 4 water quality on stand 346A was similar - twice distilled water.

The circuit 4 water was not active. The circuit 4 water cooled chillers KhGTsEN-601, KhGTsEN-146 M, KhGTsEN-147 M and heat exchanger VP ВП 2-1-0. A TsN-23 pump is responsible for water circulation. The TsN-23 pumps (the second pump is standby) are installed on the pumping enclosure story 2. The rest of the tubes (90x5, 38x3 and 32x3) are located on the pumping enclosure story 1. The rest of the tubes are 55x3 and 14x2.5.

The pumps of circuits 3 and 4 were grouted.

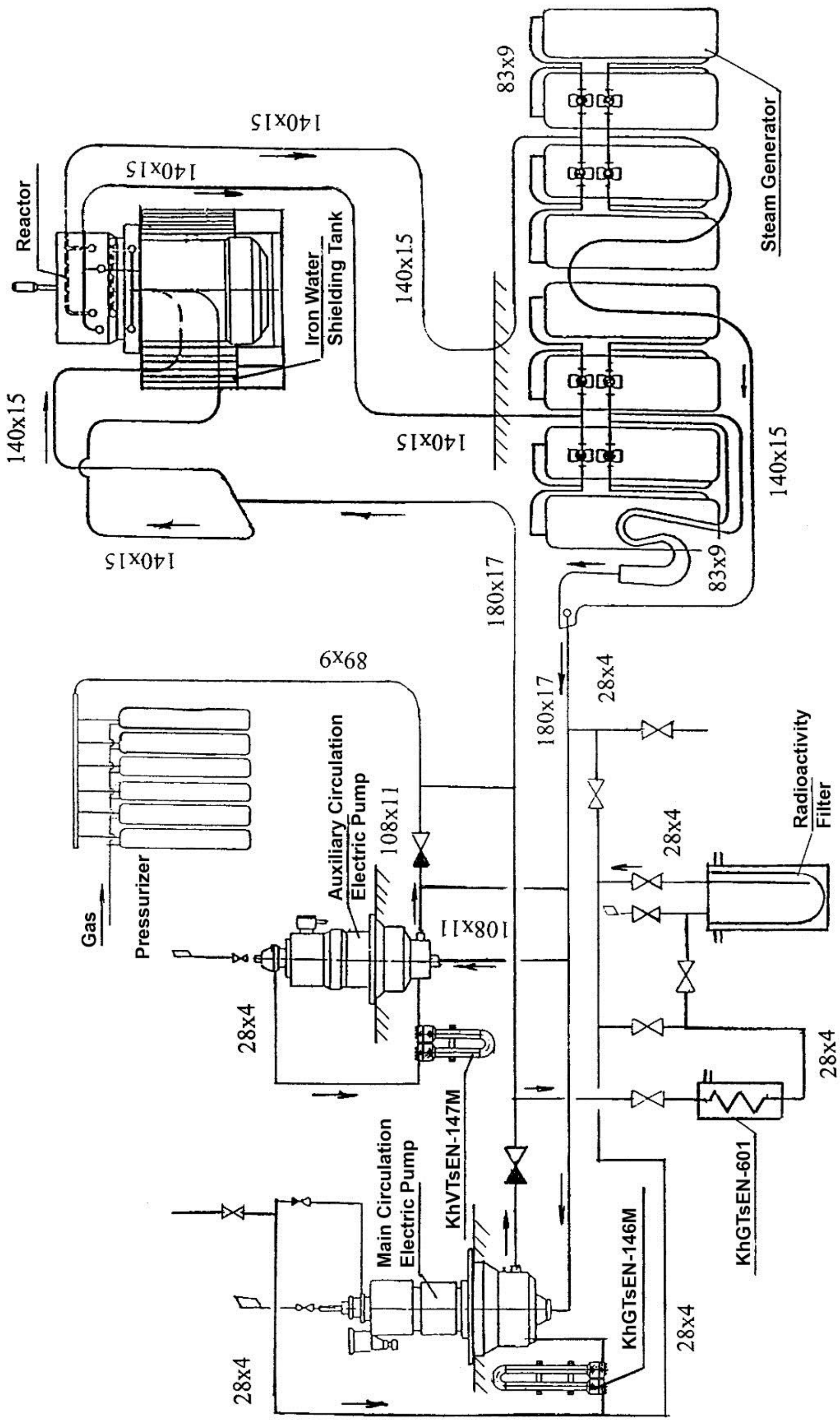


Figure 11. Layout of primary circuit pipelines

1.4.2 Radiological conditions at the energy stand 346A after reactor final shut-down

The stand nuclear units were operated in accordance with a training programme, and their operating conditions only envisaged running at 20 ÷ 40% of nominal reactor power, with rather frequent complete shut-downs. No considerable abnormalities or accident situations have been recorded. No cases of fuel element breach were registered either. As consequence, coolant radioactivity in the primary circuits of both units was kept low, as well as contamination of internal surfaces in the primary circuit equipment. Coolant samples collected from the primary circuit of 346A stand prior to draining registered volumetric activity of 1.4 kBq/l. Radiological conditions during stands operation were normal. After the final shut-down of the reactors in 1994, a radiological survey of internal reactor rooms was undertaken, with the survey results in attended rooms on 346A stand registering the following ambient dose equivalent rate values, in μSv/h:

- in 3rd floor through hallway – up to 0.12;
- in the reactor well – 1.1;
- on reactor lid – 1.9;
- on hatch lid of steam generator well – 8.

Background exposure dose rate values lay within 0.11 to 0.14 μSv/h.

Calculated dose rates for 2015 (μSv/h, peak values, based on Co-60, Ni-59, Ni-63, Fe-55):

- 3rd floor hallway ≈0.024;
- central area ≈ 0.13
- near open hatch to steam generator well ≈ 1.72;
- on reactor lid along axis ≈ 0.78;
- reactor control rods well ≈ 0.0007;
- steam generator well ≈ 64;
- pumping room, 2nd floor, near auxiliary pump VCEN-147 ≈ 0.74;
- near the pumps – ≈ 0.16 (Note: during reactor compartment preparation for long-term storage, the pump room was poured with concrete);
- pump room 1st floor, near primary circuit pipeline ≈ 65;
- on pressure hull above the reactor – ≈ 0.0015;
- on pressure hull below (room 140): beneath reactor along centre line plane – ≈ 185; near front wall ≈1.1; along PS (port side) ≈51.7; along SB (starboard) ≈169.5;
- beneath stern - along centre line plane ≈8.3; along PS ≈0.6; along SB ≈17.8; peak near stern ≈ 0.8; peak near stern reactor control rods well ≈5.9; beneath pump room ≈0.1 (room poured with concrete).

Said exposure dose rates are computational as of 2015, and by the end of the design storage life they will drop naturally down to natural background (0.1 – 0.15 μSv/h), expect rooms where exposure dose rate may actually increase. Such rooms include:

- steam generator well ≤ 20 μSv/h;
- pump room (1st floor) ≤ 20 μSv/h;

– pressure hull in room 140 (beneath reactor) ~ 3.2 μSv/h.

On 346A stand, the space in front of the iron-water protection tank was provided with concrete blocks during stand construction to improve radiation shielding. Calculations have determined that the concrete will become activated as a consequence of being hit by neutrons emitted from the reactor to the depth of ~ 0.5 m from the wall of the iron-water protection tank. Its specific activity build-up over the period of operation and computed as of 2015 may be as high as ≈ 5 kBq/kg. Radionuclide composition by activity, (%): Fe-55 – 20.9; Co-60 – 3.5; Eu-152 – 72.0; Eu-154 – 3.6. Materials used for the control rods absorbers at 346A power plant – special alloy with Europium (Eu) which was used as the neutron resonance absorber (n, γ - absorber).Those materials are with the big neutron absorption cross section and do not produce new neutrons during the neutrons trapping.

According to the Technicatome report TA-247836 Ind. A [1] concrete samples collected from beneath the reactor compartment in 1994 were analysed in 2001 and demonstrated that specific activity of samples (peak values) does not exceed 0.29 Bq/g. Radionuclide composition by activity, (%): Eu-152 – 62; Co-60 – 12; Cs-137 – 5; K-40 – 18. Co-60 and Eu-152 formed as a result of neutrons emanating from the reactor hitting the trace impurities present in concrete, and Cs-137 as a result of surface contamination or leaks, while K-40 represents radioactivity naturally present in construction materials.

In accordance with the general approach used in the Russian Federation based on the statistic data of operational experience of water-pressured reactor units, the majority of induced radioactivity (up to 99 %), disregarding nuclear fuel, tends to concentrate in the reactor vessel because reactor pressure vessel is under neutron flux [22]. Second most radioactive piece of equipment is iron-water protection tank (protects other equipment from neutron flux), which accumulates about 1 %, with the balance of equipment in the primary circuit accountable for fractions of a percent of total radioactivity of nuclear power unit.

1.4.3 Activity of primary circuit equipment of stand 346A [1]

The assessment of the equipment radionuclides activity for the years 2015 and 2039 rests on the data of the previous measurements and calculations which is assumed as basic. In 1994 JSK NIKIET specialists performed experimental and computational studies to determine the accumulated activity in the RC structures. Stand 346A was examined and samples of concrete and metal were collected from the structures of the sarcophagus and RC for the immediate measurement of their activity. The sampling was done only for the physically accessible structures and components, the measurements of the samples were made by the means of the local laboratory of the facility Radiation Safety Unit. For the rest of the components of the RC structures and especially those operated in high neutron fields, the accumulated radioactivity was determined by calculations. The radioactivity of corrosion products on the surface of the components flowed over by the primary coolant, was also determined by calculations. Calculation procedures were confirmed on the basis of the experimental data of operating facilities of the similar characteristics. To determine the accumulated activity in the SSS equipment and materials, the following calculations were conducted:

- calculation of neutron fields in materials of structures, equipment and shielding;
- calculation of the induced activity of materials of the main structures;
- calculation of the corrosion products accumulated in the primary circuit equipment.

Calculations were performed on the basis of 346A stand actual operation mode:

- work beginning: 1968;
- work completion: 29.01.1989;
- the stand operated for two lifetime periods:
  - lifetime period 1- 1968 - 1977, power generation of 280 000 MWh;
  - lifetime period II - June 1981 - January 1989, power generation of 190 540 MWh;
- the average reactor power for the operation period: 20 - 40% of the nominal value (the calculations took into account the number of startups during each year of operation and the average power level during the startup time).

To obtain the distribution patterns for neutron fluxes, ANISN and DOT-III codes were used that implemented the solution of the transport equation by discrete ordinates method with regard for dispersion anisotropy for single- and two-dimensional geometries respectively. The energy spectrum of neutrons was divided into 12 groups.

Based on the actual operation mode and calculated neutron fields, there were performed calculations of the induced activity of materials using SAM code that used the constant library for activation reactions of chemical target elements in the neutron energy range of 14.7 MeV to thermal energy.

To calculate the activity of corrosion products, RAPK-6 code was used that implemented the solution by Runge-Kutta method of the differential equations system describing the process of generation, transport and accumulation of corrosion products and their activity in the nuclear power facility circuit. The reactor operation during the second lifetime period only was considered in calculating the accumulation of active corrosion products in the 346A stand SSS primary circuit. It is explained by the fact that most of the active corrosion products accumulated during the first lifetime period operation was removed during primary circuit decontamination between lifetime periods, during unloading of spent reactor cores and replacement of the SG chambers.

Results of induced activity calculations (extrapolation basing on the IAEA nuclear data for half-lives and decay branching fractions for activation products) for structural materials of key circuit equipment, are summarised in Table 8, based on the initial data for the calculations of radionuclides activity made by NIKIET in 2001 [1]

Table 8: Induced activity of radionuclides in key equipment for different cooling periods (T) after reactor shut-down. Bq

Radionuclide	T-12 years (2001)			T – 26 years (2015)			T – 50 years (2039)		
	Reactor	Iron-water protection tank	Nuclear power unit as a whole	Reactor	Iron-water protection tank	Nuclear power unit as a whole	Reactor	Iron-water protection tank	Nuclear power unit as a whole
Fe-55	9,21E+13	9,92E+11	9,32E+13	8.4 E+10	4.7E+09	8.5E+10	1.96 E+08	11 E+6	1.99 E+08
Co-60	1,21E+14	1,34E+12	1,22E+14	4.5E+12	5.0E+10	4.6E+12	1.93 E+11	2.12 E+09	1.95 E+11
Ni-59	1,17E+12	1,37E+10	1,19E+12	1.2E+12	1.4E+10	1.2E+12	1.17 E+12	1.37 E+10	1.19 E+12
Ni-63	9,33E+14	1,10E+12	9,47E+13	7.8E+13	9.2E+11	7.9E+13	6.66 E+13	7.81 E+11	6.73 E+13
Total	3,08E+14	3,44E+12	3,12E+14	8.4E+13	9.9E+11	8.5E+13	6.81 E+13	7.99 E+11	6.88 E+13

In other equipment components of the nuclear power unit, induced activity is within $1x10^3 \div 10^6$ Bq.

Activity of corrosion products on internal surfaces in the primary circuit of 346A stand is summarised in Table 9.

Table 9: Corrosion products activity in the primary circuit, Bq

Equipment title	T – 12 years (2001)	T – 26 years (2015)	T – 50 years (2039)
1 Reactor and primary circuit	2,77 E+11	1.7 E+11	6.79 E+10
2 SG	2,44 E+10	1.5 E+10	5.98 E+09
3 PR	1,26 E+09	7.5 E+09	3.09 E+08
4 GCEN-146	3,90 E+08	2.3 E+08	9.58 E+07
5 VCEN- 147	3,12 E+08	1.9 E+08	7.66 E+07
6 HGCEN-601	7,22 E+08	4.3 E+08	1.77 E+08
7 HGCEN-146M	4,17 E+08	2.5 E+08	1.02 E+08
8 XVCEN-147M	1,56 E+08	9.3 E+07	3.83 E+07

Average specific surface activity of corrosion products on internal surfaces of the primary circuit equipment and pipelines is $3.9x10^4$ and $9.6x10^3$ Bq/cm^2 after 12 and 50 years of cooling, respectively.

For example, although steam generators primarily have surface contamination on primary circuit side of their tubing, this causes outer surfaces of steam generator cylinder to register exposure dose rates up to 300 μSv/h.

In order to identify whether non-fixed contamination is present on outer surfaces of equipment and pipelines, smear samples were collected in 1994 from such surfaces in the reactor compartment. The samples were taken using the acidic smear method, with gauze tampons soaked in a weak solution of nitric acid. A total of 17 smears were collected from outer surfaces, including equipment and pipelines in the primary circuit (primary and auxiliary circulation pumps and their connection piping). Control measurements of collected smear samples demonstrated that their β – activity levels were within background. This essentially demonstrates that there is no non-fixed contamination present on the surfaces of examined equipment.

According to calculations, build-up of long-lived radionuclides activity in the materials of stand 346A, disregarding nuclear fuel, measured ~ 312 TBq. Radionuclide composition as of 2001 was as follows (%): Co-60 – 39.2; Fe-55 – 30.0; Ni-59 – 0.3; Ni-63 – 30.3.

As cooling time increases before the start of dismantling operations in the reactor compartment, exposure of involved personnel will decrease approximately in proportion to the drop in Co-60 activity, which is the main dose-contributing radionuclide in this composition. The contribution of Cs-137, which is present in corrosion products on internal surfaces in the primary circuit, is insignificant.

Technicatome & BNFL (2000) report [1] that about 360 liters of water remains in the primary cooling circuit of reactor 346A, with a total inventory of 2.2 MBq l^{-1} at the time of shutdown in 1989. The main radionuclides were Cs-137, Co-60, Sr-90 and tritium. The presence of Cs and Sr radionuclides in the cooling water (only) is explained by the operating features of PWR type reactors. The steam generators were replaced in 1980, apparently in order to test a new type of steam generator made of titanium alloy. According to information supplied by VNIPIET and reported in Technicatome & BNFL (2000), the reason for changing the steam generators was not a leakage from the primary part to the secondary part of the steam generators, which would have resulted in contamination diffusing into the secondary circuits. After drainage of all the circuits it was estimated that about 1000 liters remain in the secondary circuit (within the steam generators), with very low levels of contamination (approx. 4 Bq l^{-1}). The third and fourth coolant circuits were used for auxiliary equipment and are believed to contain no contamination. About 6 liters of water remains in the fourth circuit. According to the previous data there is no information about water remains in third circuit. The third circuit is believed to have no water remains. In the above paragraph shows activity prior to drying.

Table 10: Radioactive inventory of residual cooling water for 2005, 2015 and 2039 (346A)

Radionuclide	Total activity, Bq		
	Reactor Compartment 1		
	2005 *	2015	2039
H-3	4.28E+06	2.44E+06	6.32E+05
Co-60	2.73E+06	7.33E+05	3.12E+04
Sr-90	5.19E+06	4.08E+06	2.29E+06
Cs-137	5.23E+06	4.15E+06	2.39E+06

** Input data*

Overview of stand 346A reactor compartment (cross and lengthwise sections) prepared for long-term storage (shield cover built, concrete poured inside) is illustrated by Figure 18.

Detailed description related to the measurements, sampling, techniques, instrumentation etc. is presented within Technicatome report «Collection and Analysis of Information Regarding the Design and Content of the Reactor Compartments of Russian Nuclear Submarines that are being stored in Estonia» [1] and assumed as sufficient and reliable data to some extent for the tasks of the current preliminary studies for the decommissioning of the RCs.

1.4.4 Key process equipment of stand 346B [1]

The second-generation nuclear power units (346B) were designed in consideration of the first-generation unit's weaknesses. In view of this, the nuclear power unit design layout was changed. Its scheme remained loop but configuration and size of the primary circuit were significantly reduced. There was taken an approach of "pipe-in-pipe" configuration and primary circuit pumps "hanging" on the steam generators. The quantity of the big-diameter piping of the main equipment (primary circuit filter, pressurizers, etc.) was reduced. The majority of the primary circuit piping (big and small diameter) were positioned within the premises under the biological shielding. The plant automation and instrumentation systems and remote-controlled fittings (valves, shutters, stoppers etc.) were significantly changed.

Stand 346B is fitted with power unit VM-4 complete with all necessary equipment to ensure long-term, fail-free and safe operation of the power unit in all design-basis conditions of operation and in case of operational abnormalities.

List of key equipment components and their weight and size characteristics are summarised in Table 11.

Table 11: Key equipment components of stand 346B nuclear power unit

Equipment	Number	Unit weight, t	Overall dimensions, mm
1 Reactor	1	50.4	2550x2550x4660
2 Steam generator - primary circuit pump	5	14.2	1440x1550x4485
3 Pressuriser	3 bottles	2.0	795x795x2826
4 Primary circuit filter	1	1.98	800x800x2075
5 Primary circuit filter refrigerator	1	2.78	800x800x2130
6 Shield tank	1	66.18	2565x4860x6140
7 Electric cool-down pump	1	0.75	545x566x1135
8 Shielding blocks (concrete, lead, thermal insulation), lining of carbon steel	30	up to 1.27	475x1450x1850
9. Pining of circuit 3			63x6.5 34x4.5 22x3.5 16x3
10. Piping for storage and SG rinsing			32x3.5 16x3
11. Steam connections piping			194x10 127x14

Main equipment components of the reactor unit, such as reactor vessel, steam generator shell, pressuriser, filter and refrigerator case are made of alloyed carbon steel with internal stainless steel surfacing in contact with the primary circuit coolant. Protective tank shell and caissons are made of alloyed steel, except reactor caisson, which is made of stainless steel. All pipelines and valves in the primary circuit are made of stainless steel.

Concrete blocks placed during rig construction with the objective of improving radiation shielding also tend to develop induced radioactivity as a consequence of being hit by neutron flux, especially those blocks closest to the reactor vessel. Total averaged accumulated radioactivity of concrete blocks was computed in 2015 to be ~ 2 MBq, with the following radionuclide composition (%): Fe-55 – 50.0; Co-60 – 36.6; Ni-63 – 14.0.

<u>The filter cooler</u> (Figures 12 and 13) is a vertical house-tube heat exchange assembly with an integrated recuperator, two-sectional coil tube system of the cooler on cooling fluid.

The filter cooler consists of the following key units:
- casing 1
- cover 2 with connecting pipes for inlet-outlet of heat exchange fluids
- cooler 3
- recuperator 4
- support 5

Casing 1 is made of heat-resistant chrome-molybdenum steel with anti-corrosion surfacing on the internal surface, with ultimate strength of 568 MPa.

Cover 2 is made of stainless steel of 18-8 type with ultimate strength of 490 MPa.

Tube systems of cooler-recuperator are made of corrosion stainless steel of 18-8 type with ultimate strength of 549 MPa.

Support 5 is made of carbon steel with ultimate strength of 441 MPa.

The overall dimensions of the filter cooler are 750 mm diameter 2130 mm height.

<u>The filter</u> (Figures 14 and 15) is a welded vessel consisting of the following key units:
- casing 1
- cover 2 with connecting pipes for fluids supply and removal
- support 3
- housing 4

All elements are made of corrosion-resistant stainless steel of 18-8 type with ultimate strength of 490 MPa.

Overall dimensions of the filter are 748 mm diameter 2075 mm height.

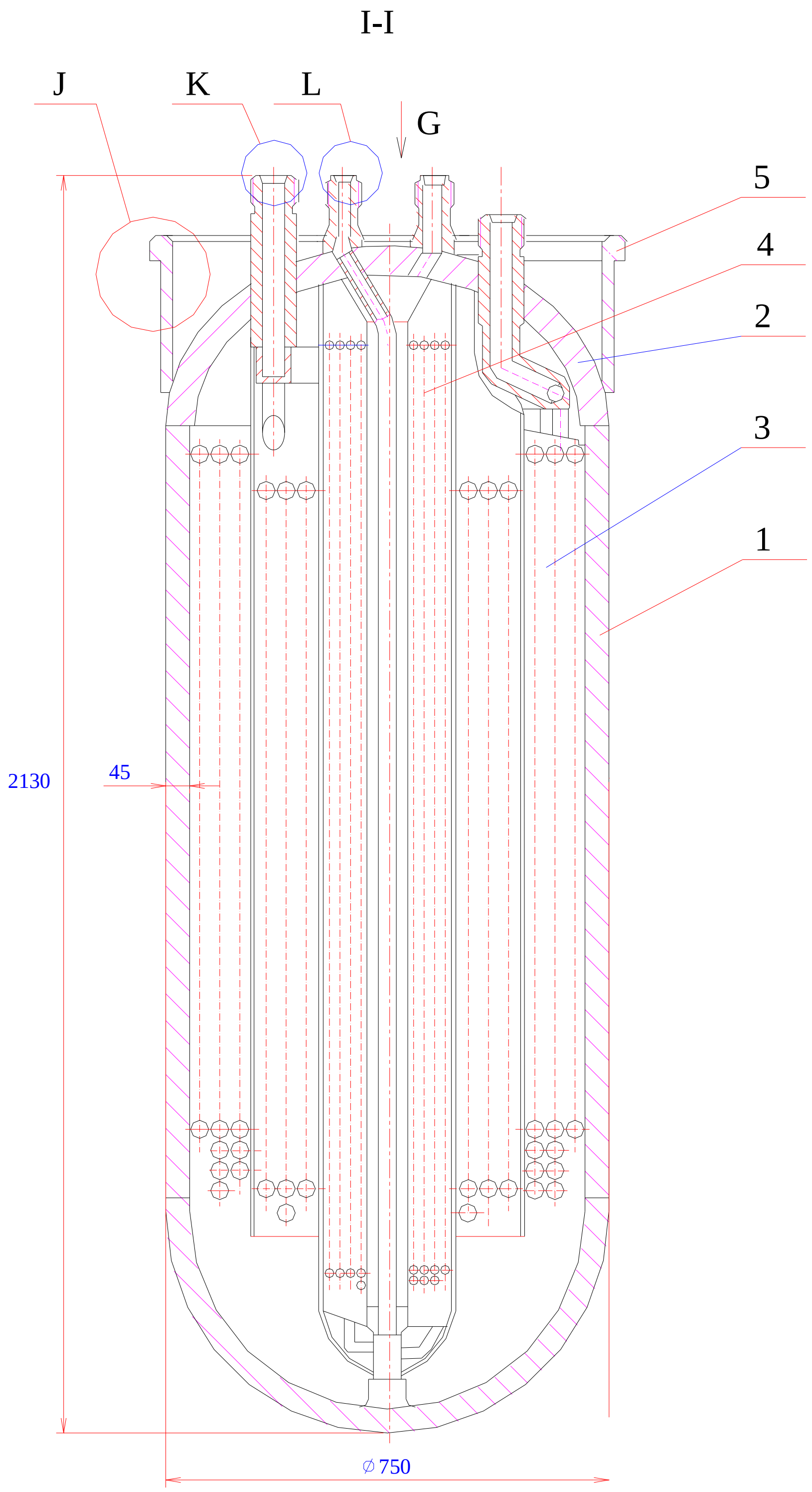
<u>The pressurizer</u> (Figures 16 and 17) is a welded vessel consisting of the following key units:
- casing 1

- cover 2 with connecting pipes for fluids supply and removal
- neck 3
- support 4

Casing 1 and cover 2 are made of heat-resistant chrome-molybdenum steel with anti-corrosion surfacing on the internal surface, with ultimate strength of 569 MPa.

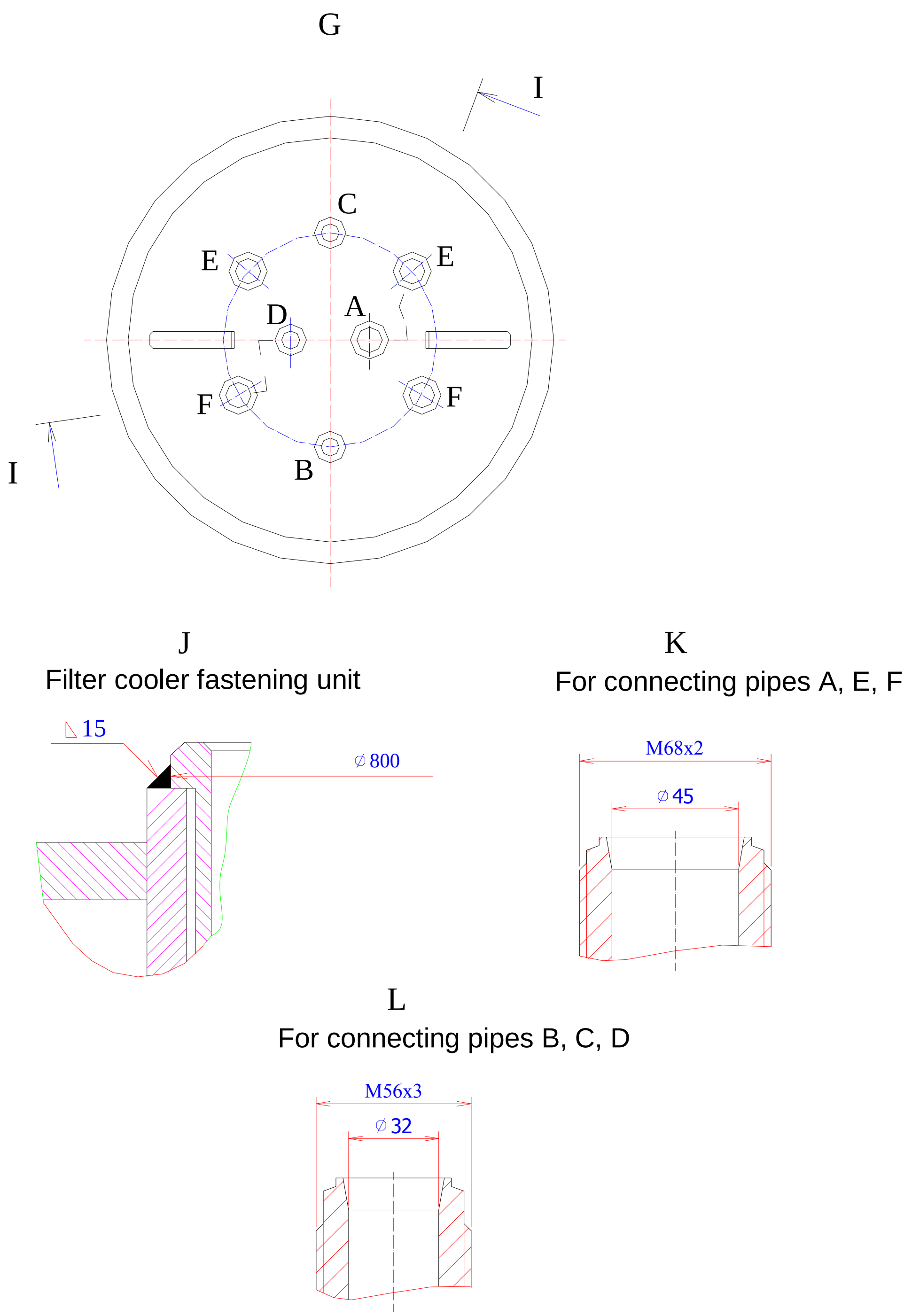
Other units are made of corrosion-resistant stainless steel of 18-8 type with ultimate strength of 490 MPa.

Overall dimensions of the pressurizer are 750 mm diameter 2826 mm height.



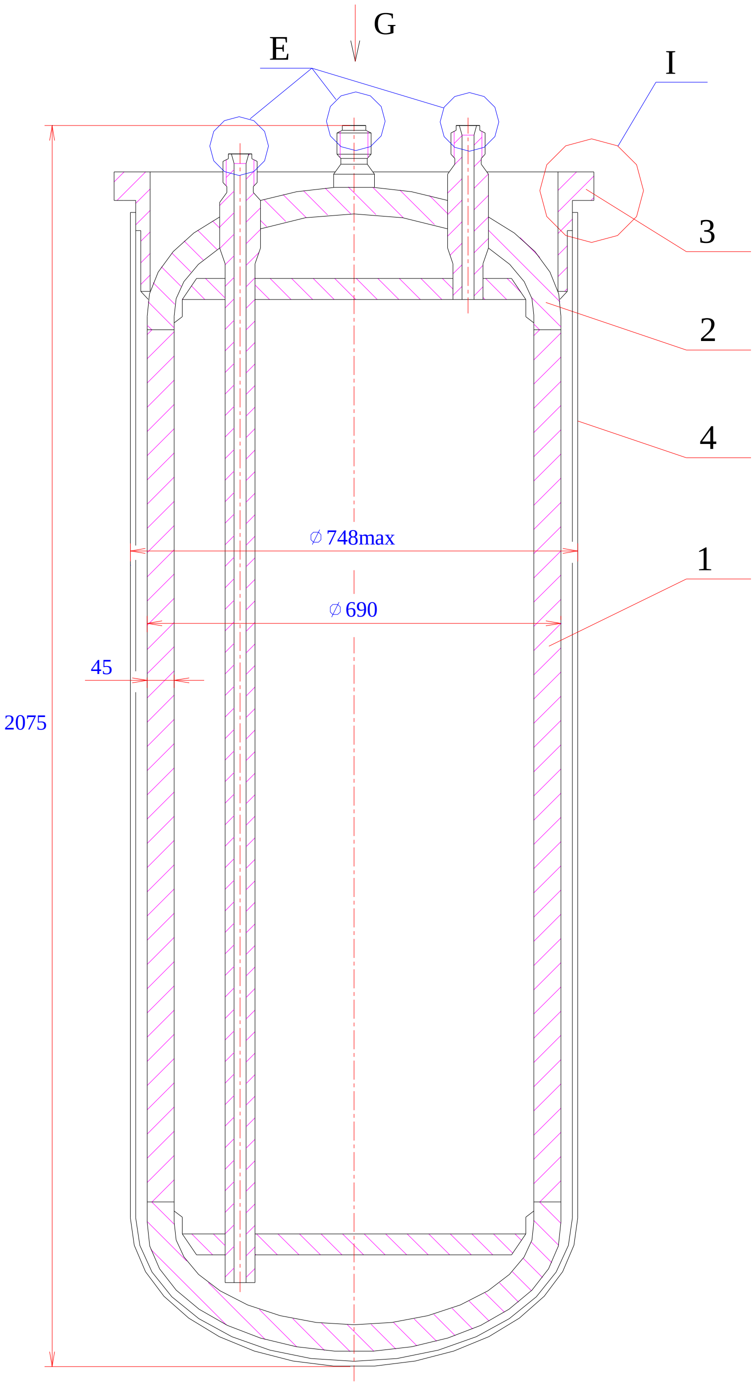
1 - casing; 2 - cover; 3 - cooler; 4 - recuperator; 5 - support.

Figure 12.Filter cooler.



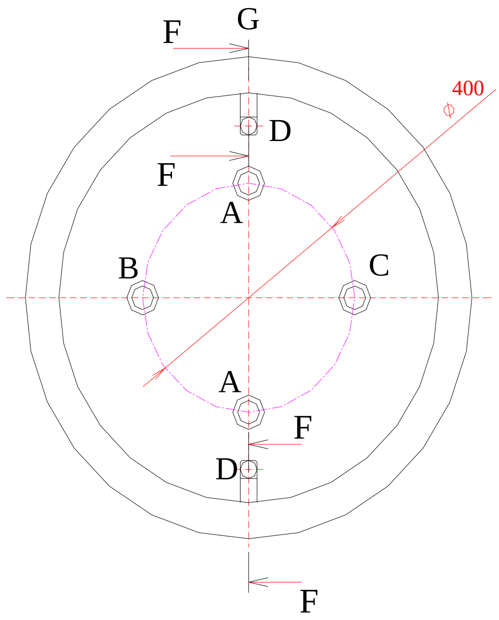
A - recuperator inlet; B - cooler outlet; C - recuperator inlet after filter;
D - recuperator outlet; E - III circuit inlet; F - III circuit outlet.

Figure 13. Arrangement of filter cooler connecting pipes.



1 - casing; 2 - cover; 3 - support; 4 - housing.

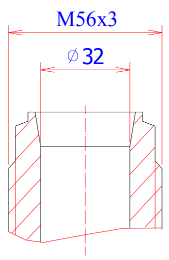
Figure 14. Filter

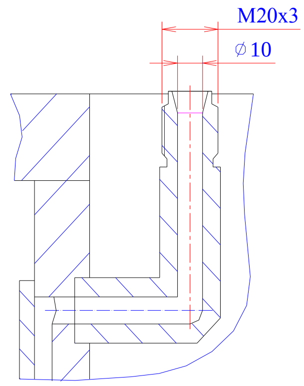


E

F – F

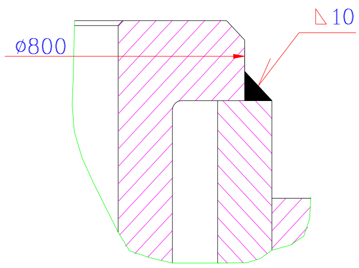
For connecting pipes A, B, C





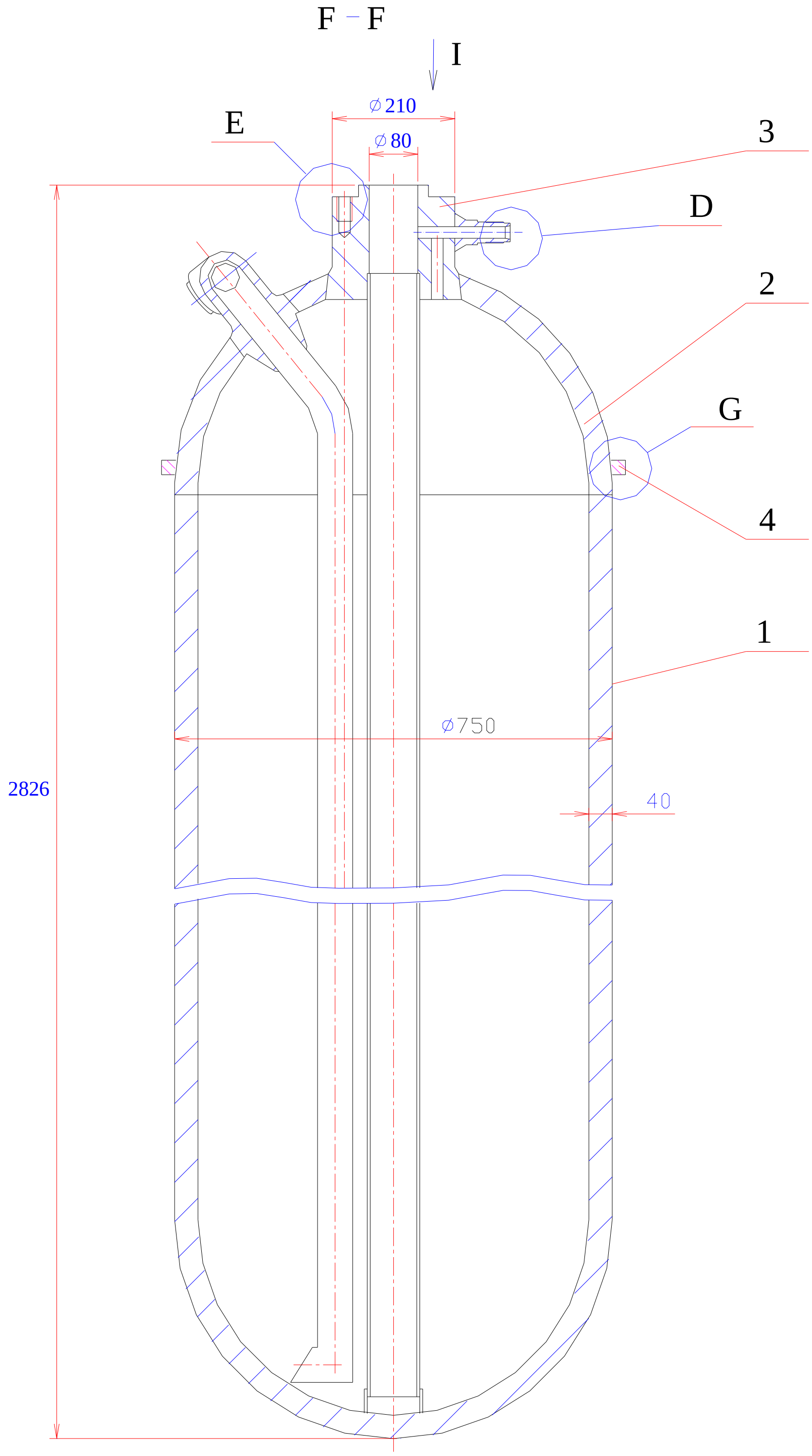
I

Filter fastening unit



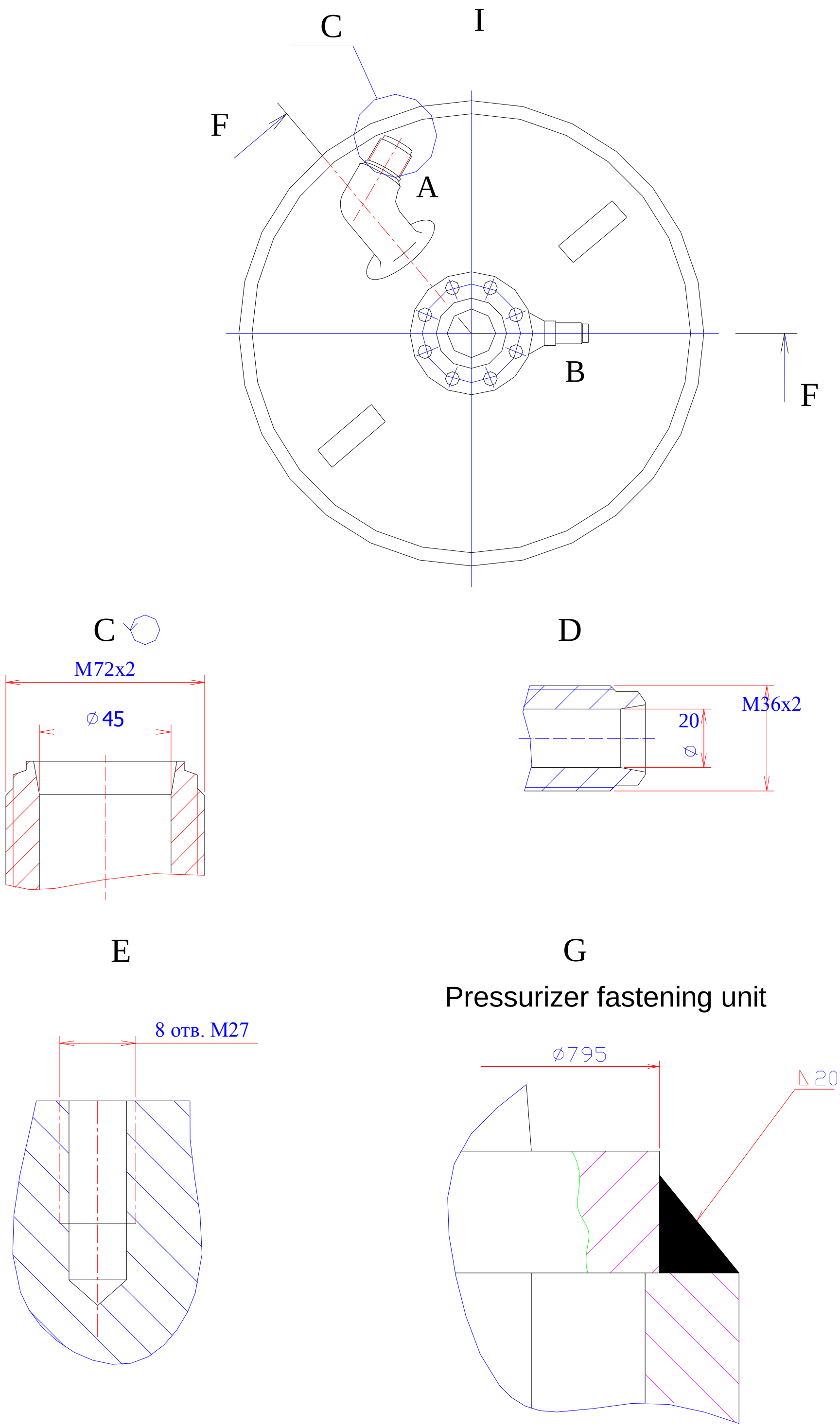
A - water inlet; B - water outlet; C - loading-unloading; D - III circuit inlet-outlet.

Figure 15. Arrangement of filter connecting pipes.



1 - casing; 2 - cover; 3 - neck; 4 - support.

Figure 16. Pressurizer.



A - water inlet-outlet; B - gas inlet-outlet.

Figure 17. Arrangement of pressurizer connecting pipes.

1.4.5 Radiological conditions and radioactivity of equipment of reactor stand 346B [1]

The second reactor stand (346B) was only in operation for a relatively short period of time (1983 to 1989). During this period, the reactor unit actually ran for only 5,333 hours at 20 – 40% of nominal power. No noticeable deviations in stand operation were recorded. Radiological conditions in work rooms of the stand were normal and stable. Coolant activity in the primary circuit remained at a minimum. There has been no noticeable build-up of activated corrosion products on internal surfaces in the primary circuit. Hence, radiological conditions in attended rooms of the stand were only slightly different from natural background levels. A radiological survey conducted in 1994 returned the following ambient dose equivalent rate values (μSv/h): instrument well - 0.2; reactor lid – 0.23; second floor near pump motors – 0.9. Background exposure dose rate values lay within 0.11 to 0.14 μSv/h.

Induced activity levels in equipment exposed to neutron flux emanating from the reactor are low compared to similar equipment of stand 346A.

In 1995 JSK NIKIET specialists performed collection of samples of concrete and metal from the structures of the sarcophagus and RC of the stand 346B for experimental and computational studies of the accumulated activity determination. The sampling was done only for the physically accessible structures and components, the measurements of the samples were made by the means of the local laboratory of the facility Radiation Safety Unit. For the most of the components of the RC structures the accumulated radioactivity was determined by calculations. The specialists from JSC «Afrikantov OKBM» performed calculations of induced activity in the primary circuit equipment accumulated over the operational time of the reactor taking into account the natural decay of radionuclides basing on the same methods and techniques as for 346A stand. The extrapolation calculations for 26 and 50 years of cooling after the final shut-down are summarized within Table 12 and based on the aforementioned measurements and results which are assumed as the basic data.

Table 12: Activity and radionuclide composition for stand 346B equipment, for 26 and 50 years of cooling

Equipment	Radionuclide	Activity, Bq		
		Cooling time, years		
		T-10 (1999)	T-26 (2015)	T-50 (2039)
Reactor	Fe-55	7,03 E+13	3.6E+11	8.37E+08
	Co-60	4,4 E+13	5.4E+12	2.3 E+11
	Ni-59	1,5 E+13	1.5 E+11	1.5 E +11
	Ni-63	1.7 E+13	1.4 E+13	1.2 E+13
	Nb-94	1.4 E+10	1.4 E+10	1.4 E+10
	Eu-152	1.2 E+13	5.1 E+12	1.5 E+12
	Eu-154	1.1 E+13	3.3 E+12	4.8 E+11
	Total	**1.6 E+14**	**2.9 E+13**	**1.5 E+13**
Steam generator	Fe-55	5,2 E+9	8.1 E+7	1.9 E+5
	Co-60	2.8 E+9	3.3 E+8	1.4 E+7
	Ni-59	1,5 E+7	1.5 E+7	1.5 E+7
	Ni-63	1,8 E+9	1.3 E+9	1.1 E+9
	Total	**9.7 E+9**	**1.7 E+9**	**1.2 E+9**
	Fe-55	3.7 E+9	4.7 E+7	1.1E+5
	Co-60	1.6 E+9	1.9 E+8	8.1 E+6

Equipment	Radionuclide	Activity, Bq		
		Cooling time, years		
		T-10 (1999)	T-26 (2015)	T-50 (2039)
Filter refrigerator	Ni-59	8.6 E+6	8.5 E+6	8.5 E+6
	Ni-63	1.0 E+9	9.2 E+8	7.8 E+8
	Total	**6.2 E+9**	**1.2 E+9**	**7.8 E+8**
Pressuriser	Fe-55	7.0 E+8	9.4 E+6	2.2 E+4
	Co-60	3.7 E+6	3.5 E+6	1.5 E+5
	Ni-59	2.3 E+5	2.3 E+5	2.3 E+5
	Ni-63	2.6 E+7	2.2 E+7	1.9 E+7
	Total	**7.0 E+8**	**3.6 E+7**	**1,9 E+7**
Ion-exchange filter	Fe-55	3.1 E+8	4.0 E+6	9,3 E+3
	Co-60	1.7 E+8	1.8 E+7	7,8 E+5
	Ni-59	8.1 E+5	8.1 E+5	8,1 E+5
	Ni-63	1.1 E+8	9.2 E+7	7,8 E+7
	Total	**6.0 E+8**	**1.2 E+8**	**7,8 E+7**
Primary circuit pump	Fe-55	2.1 E+8	3.2 E+6	7,4 E+3
	Co-60	1.0 E+8	1.2 E+7	5,2 E+5
	Ni-59	5.6 E+5	5.5 E+5	5,5 E+5
	Ni-63	6.7 E+7	6.1 E+7	5,2 E+7
	Total	**3.7 E+9**	**7.7 E+7**	**5,2 E+7**
Cool-down pump	Fe-55	3.7 E+7	1.8 E+6	2,5 E+3
	Co-60	1.5 E+7	1.7 E+6	7,4 E+4
	Ni-59	9.3 E+4	9.3 E+4	9,3 E+4
	Ni-63	1,1 E+7	9.6 E+6	8,1 E+6
	Total	**6.3 E+7**	**1.2 E+7**	**8,1 E+6**
Shield tank	Fe-55	1.4 E+12	4.1 E+10	9,5 E+7
	Co-60	1.0 E+11	1.2 E+10	5,2 E+8
	Ni-59	4.1 E+9	4.1 E+9	4,1 E+9
	Ni-63	4.1 E+11	3.5 E+11	3,0 E+11
	Nb-94	3.3 E+8	3.3 E+8	3,3 E+8
	Total	**2.8 E+12**	**4.1 E+11**	**3,1 E+11**
Concrete shield blocks (closest to reactor)	Fe-55	5.6 E+6	1.6 E+5	3,7 E+2
	Co-60	4.1 E+6	4.9 E+5	2,1 E+4
	Ni-59	1.6 E+4	1.5 E+4	1,5 E+4
	Ni-63	1.6 E+6	1.4 E+6	1,2 E+6
	Total	**1.1 E+7**	**2.1 E+6**	**1,2 E+6**
Reactor unit as a whole		**1.1 E+14**	**2.9 E+13**	**1.5 E+13**

Activity of radionuclides accumulated in structural materials as a consequence of exposure to neutrons and internal surface contamination of the primary circuit equipment creates elevated levels of exposure dose rate. Exposure dose rate levels on stand 346B equipment as computed by OKBM are summarised in Table 13.

Niobium (Nb) was used as the alloying agent within the cover of the reactor fuel elements (1-2.5%) to prevent the fuel-element cladding inconsistent deformation in gamma-neutron field. Due to the neutron activation of the Nb-93 natural isotope the small presence of Nb-94 was traced within the equipment of the reactor stands (not in the water).

As the Table 12 indicates, there is no C-14 radionuclide (β – source with Eβ - 0.156 MeV, T1/2 5730 years) in the list of radionuclides produced as a result of neutron radiation of NPP construction materials. Indeed, in that time, the generation of radionuclides was not considered in the reactor vessel metal due to its low content and absence of tendency to its dissemination in the environment. According to IAEA – TECDOC – 938, the content of the radiocarbon produced in the general balance of induced activity in constructive materials of Russian nuclear submarine NPPs is no more than 0.01% ÷ 0.001% of the total induced activity. If we convert this data into the average specific activity, we will obtain C-14 content in the reactor vessel metal: $3.7 \cdot 10^4 \div 9.3 \cdot 10^5$ Bq/kg (data is averaged for 10 nuclear submarine reactor vessels). In our case, power generation of vessels was relatively small, so the accumulation of C-14 was even smaller. Furthermore, the same IAEA materials show that the C-14 content in the balance of induced activity is somewhat 10 times less than that of Ni-59 produced, that has a significantly longer half-life (75,000 years) and that defines radioactive waste storage to be maintained until full decay of radionuclide.

The radionuclide content has no fission fragments and actinides, which is explained by their almost full absence. Operation of these NPPs was not accompanied by emergency destruction of fuel assemblies, so there was no contact of heat carrier with fuel composition. Specific activity of stand 346 A 1st circuit heat carrier before its discharge was 1.4 kBq/kg, and was generally defined by radionuclides of activation origin. Stand 346 B 1st circuit heat carrier had even smaller activity. This data differs from TECDOC-938 data, as the given publication describes reactor units, which active zone contained emergency fuel assemblies with damaged fuel-element cladding, so the activity of fission products was two times more than the activity of activated corrosion products.

Table 13: Estimated peak exposure dose rate for stand 346B equipment for various cooling times after reactor shut-down, in µSv/h.

Equipment title	Cooling time, years		
	T-10 (1999)	T-26 (2015)	T-50 (2039)
1 Reactor	$4{,}0 \times 10^5$	2.4×10^3	200.0
2 Steam generator	$4{,}0 \times 10^2$	5.7	0.2
3 Filter refrigerator	$9{,}0 \times 10^2$	13.0	0.5
4 Pressuriser	$2{,}0 \times 10^2$	2.8	0.1
5 Ion-exchange filter	$5{,}0 \times 10^2$	7.2	0.26
6 Primary circuit pump	$3{,}0 \times 10^3$	44.0	1.6
7 Cool-down pump	$2{,}0 \times 10^2$	2.8	0.1
8 Shield tank (reactor caisson)*	$3{,}6 \times 10^6$	52.1×10^3	1.9×10^3
9 Concrete shield blocks (closest to reactor)	$\leq 1{,}0 \times 10^2$	4.3	1

** Expose dose rate from shielding tank is higher because of its dimensions (as a radiation source)*

Considering the short time of stand 346B reactor operation, exposure dose rate levels on the reactor vessel and its surrounding structure are relatively low. At the end of the design-basis cooling period (50 years), reactor vessel exposure dose rate will decrease by a further two orders of magnitude, meaning that the residual γ- activity will no longer be a major obstacle to the performance of dismantling operations on reactor compartment equipment, i.e. they will not require the use of complex robotics, and may be performed by already available hardware with the use of relatively light shields and specialised ventilation equipment to clean airborne radioactivity out of work zone air.

The materials with the big neutron absorption cross section and which do not produce new neutrons during the neutrons trapping are used as absorbers. Europium (Eu) is the neutron resonance absorber (n, γ - absorber) and this material was used within the control rods of the 346B nuclear power plant. During the period of the 346B power plant operation its control rods never lost sealing or showed leakages so the remained water is free of Eu radionuclide.

VNIPIET surveyed the accessible area inside RC of 346B in 1994. Information summarized by Technicatome & BNFL (2000) [1] indicate dose rates in the range 0.14 to 2.5 µSv h^{-1} prevailed generally, although around the reactor and IWS shield the dose rate reached tens of Sv h^{-1}. Technicatome & BNFL (2000) also report that about 600 l of water remains in the primary cooling circuit of reactor 2, with a total inventory of 1 MBq l^{-1} at the time of shutdown in 1989. The main radionuclides were Cs-137, Co-60 and Sr-90. The presence of Cs and Sr radionuclides in the cooling water of the primary circuit is explained by the operating features of PWR type reactors, so, after the removal of the water from the reactor and circuit only the traces of Cs-137 and Sr-90 could be detected on the internal surfaces of the reactor and primary circuit tubes. There was no known leakage from the primary part to the secondary part of the steam generators during the operation of reactor 2 and there is no recorded contamination in the secondary circuit. The third and fourth coolant circuits were used for auxiliary equipment and are believed to contain no contamination. Volumes of water remaining in the second, third and fourth circuits are not recorded.

Table 14: Radioactive inventory of residual cooling water for 2005, 2015 and 2039 (346B)

Radionuclide	Total activity, Bq		
	Reactor Compartment 2		
	2005*	2015	2039
H-3	-	-	-
Co-60	1.59E+05	4.27E+04	1.82E+03
Sr-90	3.03E+05	2.38E+05	1.34E+05
Cs-137	3.05E+05	2.42E+05	1.39E+05

** Input data*

In any case, it would be sensible to begin complete dismantling of the reactor compartment with stand 346B, where key equipment components have at least an order of magnitude lower values of radionuclide contamination as compared to those on stand 346A and accordingly, their exposure dose rates are correspondingly lower by about the same rate.

1.5 OPERATIONS CARRIED OUT TO PREPARE STANDS 346A AND 346B FOR LONG-TERM STORAGE

The engineers of CDB ME “Rubin” prepared and implemented a project aimed at fully dismantling adjacent compartments which do not contain radioactively contaminated equipment, after which there remained two reactor compartments, one from each stand, which were subject to de-commissioning as radioactively hazardous facilities [1].

The hull structures and the equipment of the auxiliary compartments of both stands, uncontaminated with radiation, were dismantled and transferred to the Estonian side.

Subsequently, the engineers of CDB ME “Rubin” created a design aimed at preparing reactor compartments for long term storage for a period of no less than 50 years given seismic impacts maximally possible for this particular region.

Concurrently, GI VNIPIET developed a project for protection shelters for the reactor compartments, which were capable of withstanding natural and man-made disasters, including earthquakes up to 7 points according to MSK-64, the dropping of heavy objects on them and other unfavorable factors.

Projects solutions in respect of preparation of the reactor compartments for long term storage and erection of protection shelters were reviewed by experts at a special meeting with IAEA in May 1995 and were approved.

The nuclear power units, installed in the reactor compartment shells were prepared pursuant to the project and placed for long term, controlled storage for a period of 50 years.

Prior to this, all the accumulated radioactive solid wastes were removed from the building which, after they had been appropriately processed, were deposited in concrete containers and put in temporary storage for radioactive wastes. All the reactor compartment systems were emptied in respect of circuits 1, 2, 3 and 4, compressed gases and process liquids were removed from the equipment, sorbents were unloaded from coolant purification filters. All the tanks, reservoirs and the hold were dried out, however, in view of special design features of the equipment and pipelines in circuits 1, 2, 3, 4, there remained an irremovable amount of water (reactor vessel, steam generators, circuits 1, 2 and 3) in the quantity of ~ 1370 liters in the nuclear power unit of Stand 346A (include 360 liters of borated water in the primary circuit) and in the quantity of ~ 2280 liters in the nuclear power unit of Stand 346B (include 600 liters of borated water in the primary circuit).

Both for 346A [26] and 346B [27]: operating mechanisms (OM) and instrumentation of control and protection system (CPS) were dismantled in 1994 and could have low level surface contamination (control rods are still within the reactor pressure vessels but control rods which had been removed from 346A reactor during fuel change had been placed into solid waste storage facility and were later retrieved by AS ALARA, packed within shielded containers and stored in interim storage), all of the sorbents were removed from the filters of the circuits 1 and 2, the part of equipment and components over the biological protection were dismantled and removed from RC; stream generation plant’s equipment and piping located below standard and supplementary biological protection within the RC are braced in accordance with the operational state.

As calculations made by the engineers showed, multiple cycles of water freezing and thawing in the pipe-work and the equipment during the period of long term storage (50 years) are not expected to result in causing the systems to leak.

The reactor units were prepared for long term storage:

- the reactor was dried out and is currently under atmospheric pressure;
- the reactor was closed with the cover welded to the shell;
- actuators of the control and protection system were removed;
- all the holes in the reactor in the systems of the 1st circuit were plugged with welded plugs;
- some of the equipment and structures located above the biological shield were unloaded from the reactor compartment;
- in the reactor compartment shells, all the holes were tightly sealed with welds, air-tightness of the compartments was tested by blowing pressurized air;
- the atmosphere of the reactor compartment was dried up and a stock of moisture desiccants was left inside;
- duration of safe storage for the math-balled reactor compartments is no less than 50 years without subsequent re-activation of the nuclear power plant;
- the reactor compartments placed for long term storage do not require any service, control or supply of utilities throughout the entire period of storage;
- visits to the reactor compartments during the storage period are not foreseen;
- radiation safety of the reactor compartments during the period of storage is ensured by design measures and for that purpose three security barriers were created: air tightness of the equipment and the 1st circuit systems; tightly sealed reactor compartment shell; erection of reinforced concrete shelter around the reactor compartment designed for natural and man-made disasters.

Due to existence of solid radioactive wastes, left after doing repair work and re-loading the solid radioactive wastes on Stand 346A, it was decided to deposit these wastes in the reactor compartments before concreting. The above mentioned wastes comprised cut off pipe sections, fittings, tools, small size parts, re-loading equipment, containers, jackets for spent nuclear fuel assemblies, as well as spent sealed sources (control and calibration ones) together with protection containers and other radioactive wastes, referred, mainly, to the category of low radioactive wastes and some sources classified as the category of medium radioactive wastes.

Extraction of those waste from concrete is complicated by the presence of the sealed sources of ionized irradiation in standard containers, including:

- Drum-type transfer container in package with gamma radiation sources, Co-60 (05 pcs.) weighing 1,200 kg;
- Paraffin container with neutron radiation sources (5·107 n/s), 5 pcs., weighting 400 kg;
- Container with cobalt gamma radiation source 60 (01 pcs.), weighing 350 kg;
- Box with control and reference sources of beta and alpha radiation weighing 60 kg;
- Fire detectors with integrated alpha radiation sources ADI, each 2.1x10^{7} Bq (50 pcs.) weighing – 25 kg.

The majority of the shielding containers with sources of ionized irradiation were placed within U-shape room at the first level which contained the main equipment of the primary circuit, and within the room at the second level which contained pumps and motors. Then, the rooms were grouted with the concrete. Supposedly, some of the shielding containers with sources of ionized irradiation were placed within the concrete which was poured on the reactor vessel lid [24].

Furthermore, the wastes poured with concrete also include organic wastes in bags: rags, overshoes, film, brushes, etc., with total weight of about 140 kg.

RC 346B includes metallic wastes (tools, loading equipment, electrical equipment, etc.) There are no sealed sources in loaded wastes and only one air filter weighing about 200 kg represents organic wastes.

Radioactive wastes, with a mass of ~ 15 tons, were put on the 1st and 2nd floors of the non-pass-through premises of the reactor compartment, Stand 346A, and approximately 10 tons on the premises of Stand 346B. Subsequently, the deposited radioactive wastes were grouted in with concrete laid inside the compartments.

The RC wastes placed for long term storage have the following mass and dimension characteristics set out in Table 15.

Table 15: Mass and Dimension Characteristics of RCs

Reactor Compartment Shell:	346A	346B
Diameter of Transverse Sections, m	7.5	9.5
Length, m	15.3	12.3
Width, m	8.08	10.8
Height, m	8.8	11.1
Shell Thickness, mm	27	20
Thickness of End Bulkheads, mm	10	12
Mass, tons	855	950
Protection Shelter:	346A	346B
Length, m	16.9	13.5
Width, m	10.4	12.3
Height, m	12.4	13.0
Wall Thickness, m	0.4	0.4
Weight of radioactive wastes with reinforced concrete shelter, t	~1,570	~1,650

To ensure additional protection for the equipment of the nuclear power unit, concrete was laid inside the reactor compartment:

- on Stand 346A [26]: onto the reactor lid at forward apparatus partition-off – 4.7 m^3, into U-shaped partition-off 17.65 m^3, onto the lid of the U-shaped partition-off – 7.5 m^3, onto the hatch of the portside steam-generator partition-off – 0.9 m^3, total ~ 30.75 m^3 (weight 67,650 kg);
- on Stand 346B [27]: onto the lid of iron-water protection tank – 9.0 m^3, onto the floorings of the upper premises of the apparatus partition-off – 31.0 m^3, onto the

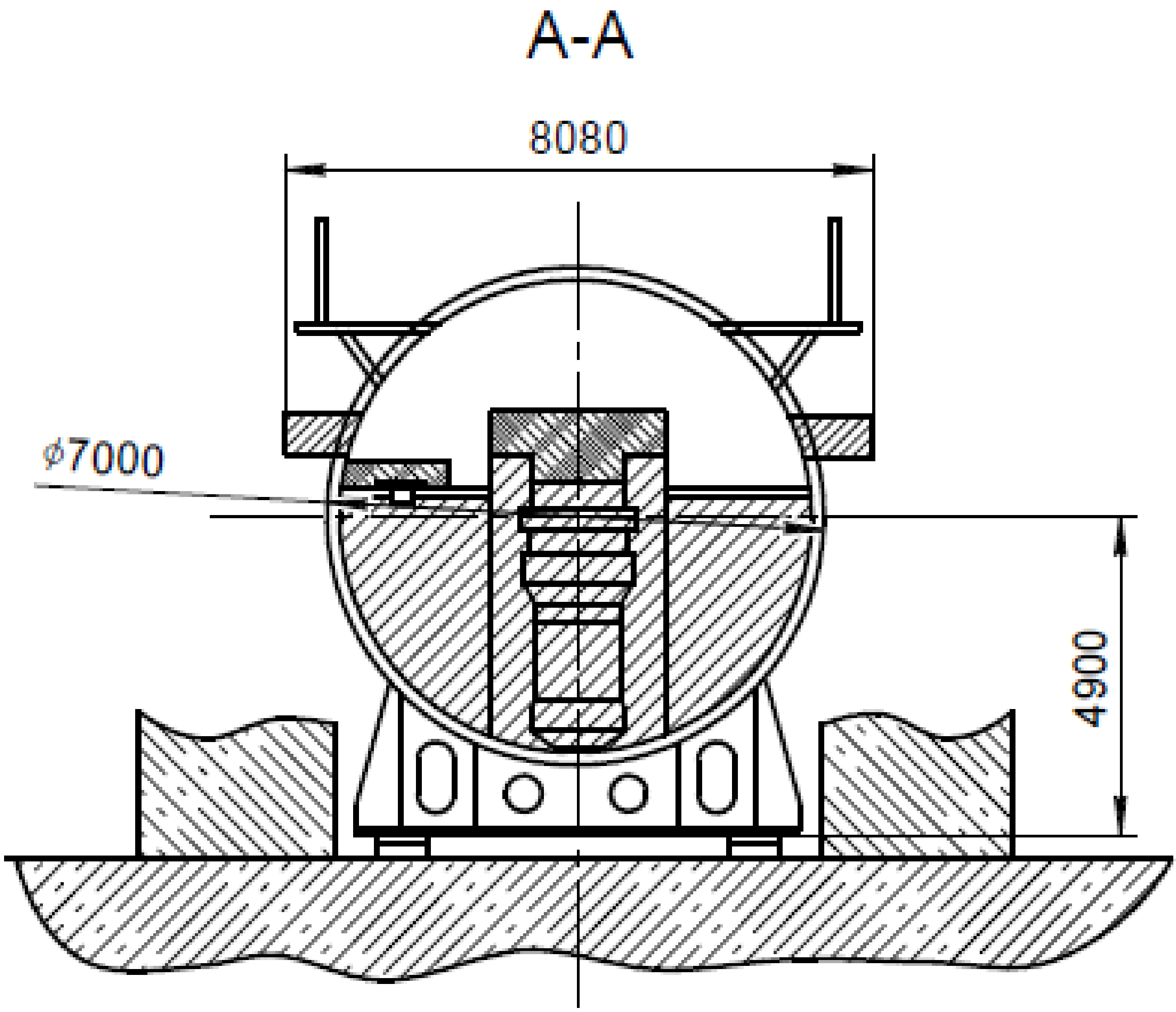
hatches of the starboard and portside pump partition-off – 1.2 m^3, total ~ 41.25 m^3 (weight – 90,700 kg).

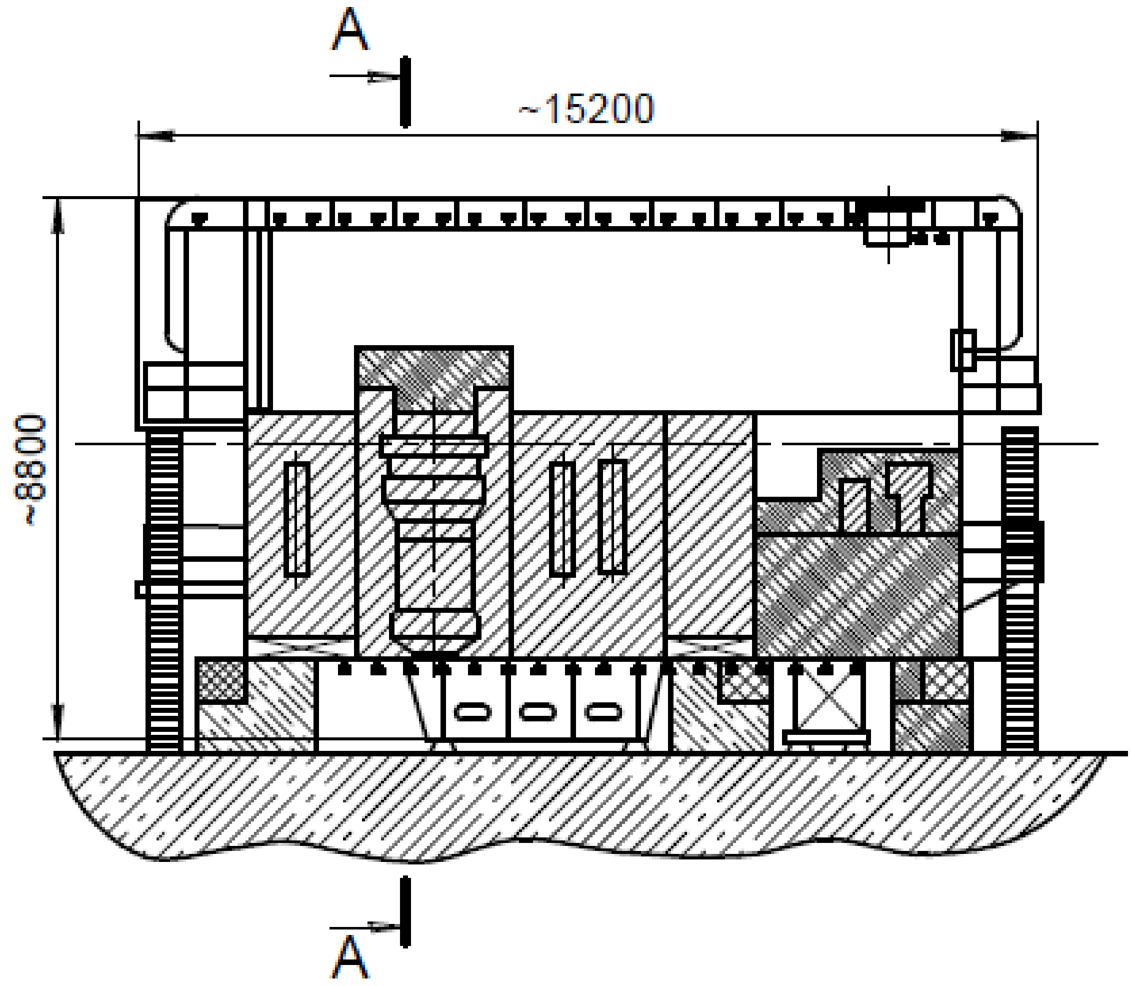
At the same time, radiation monitoring was made of the external surfaces of the building structures of the process hall of the main technological section with a view to identifying contaminated areas and eliminating them. Local contaminated areas of outside surfaces were decontaminated to allowable levels in the locations where such contamination had been detected.

Figures 18-20 show longitudinal and transverse sections of the reactor compartments of Stand 346A and Stand 346B, in accordance with the project for the reactor compartments installed in the shelters and prepared for long term storage.

The implemented project for placement of the reactor compartments of Stand 346A and Stand 346B for long term storage, including the safety precautions undertaken, was considered by a special meeting with the IAEA in May 1995 and was approved.

Figure 18 (a, b, c). Reactor Stand 346A

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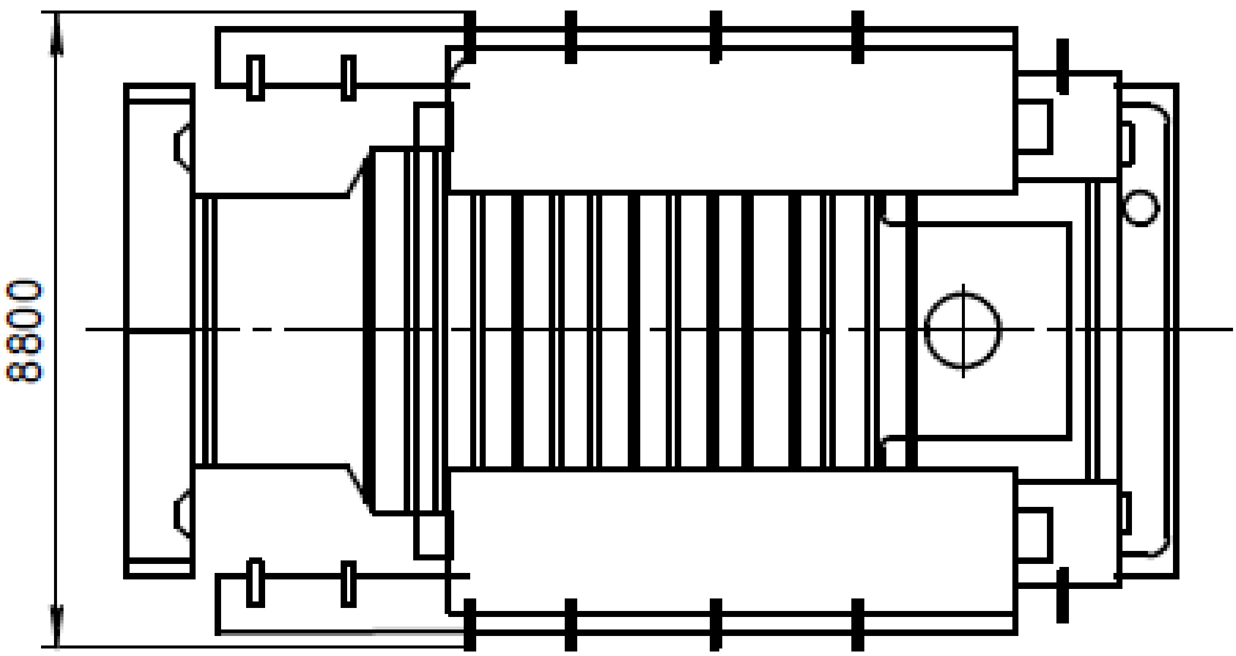
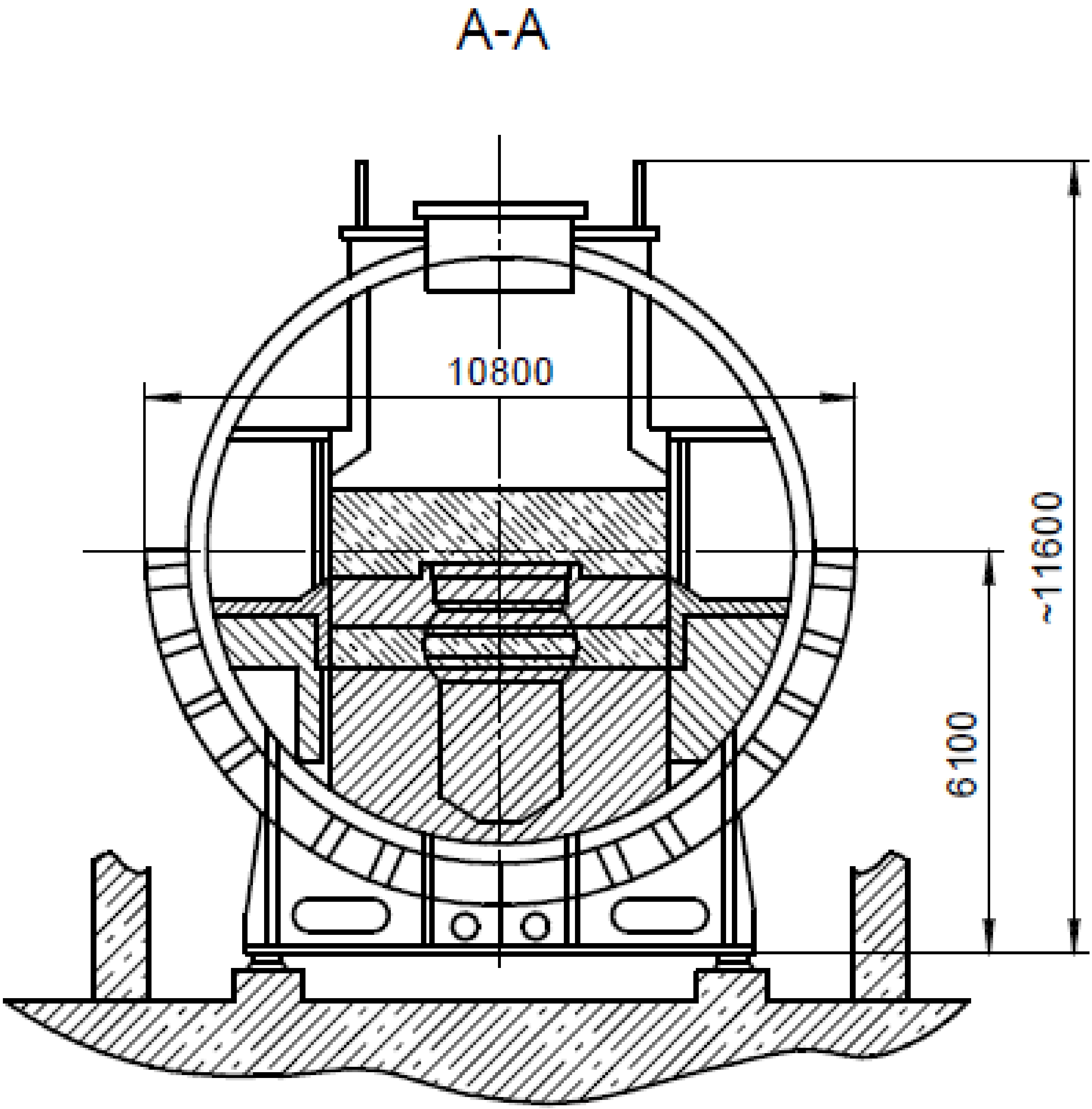
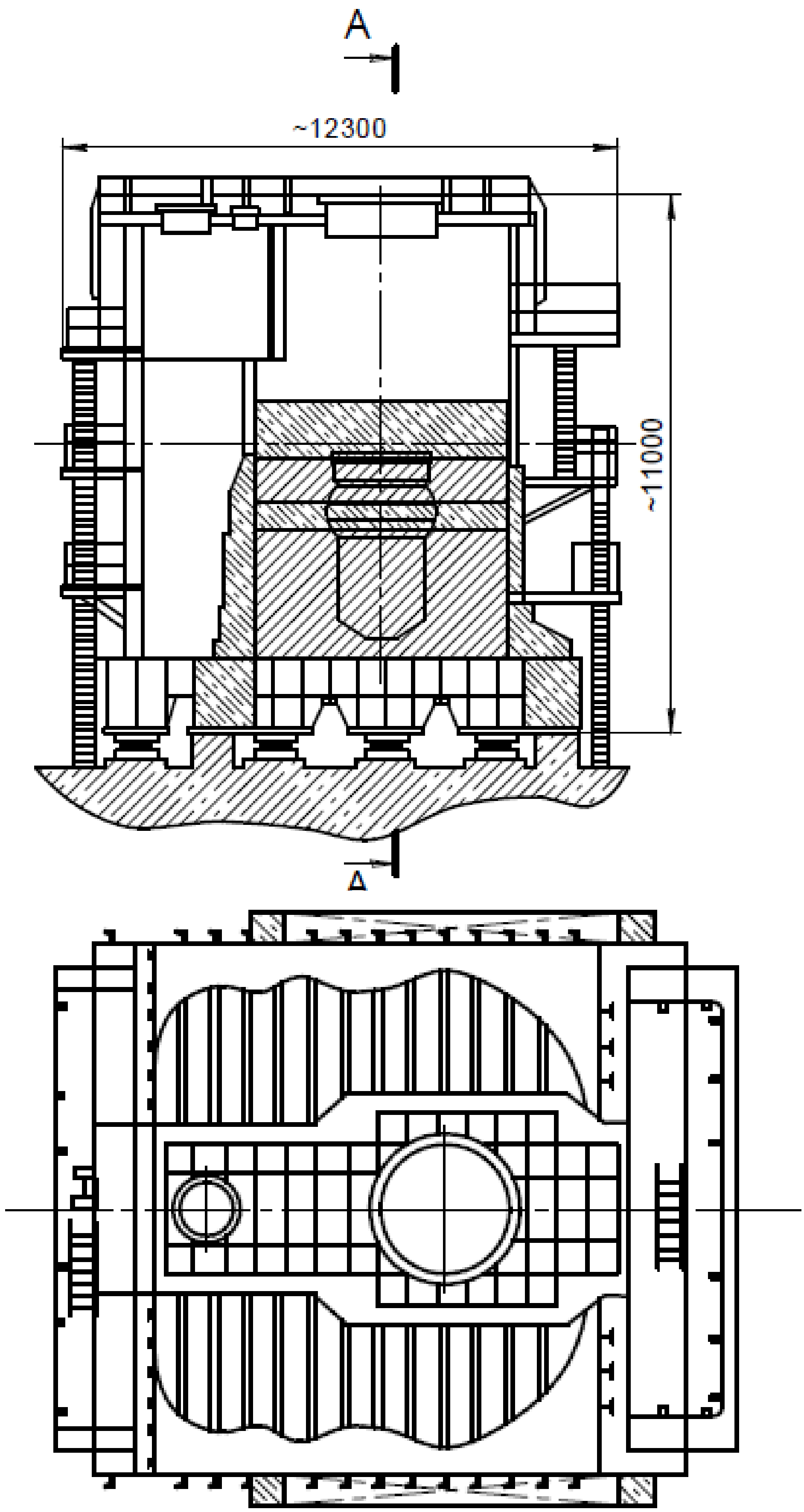

8800

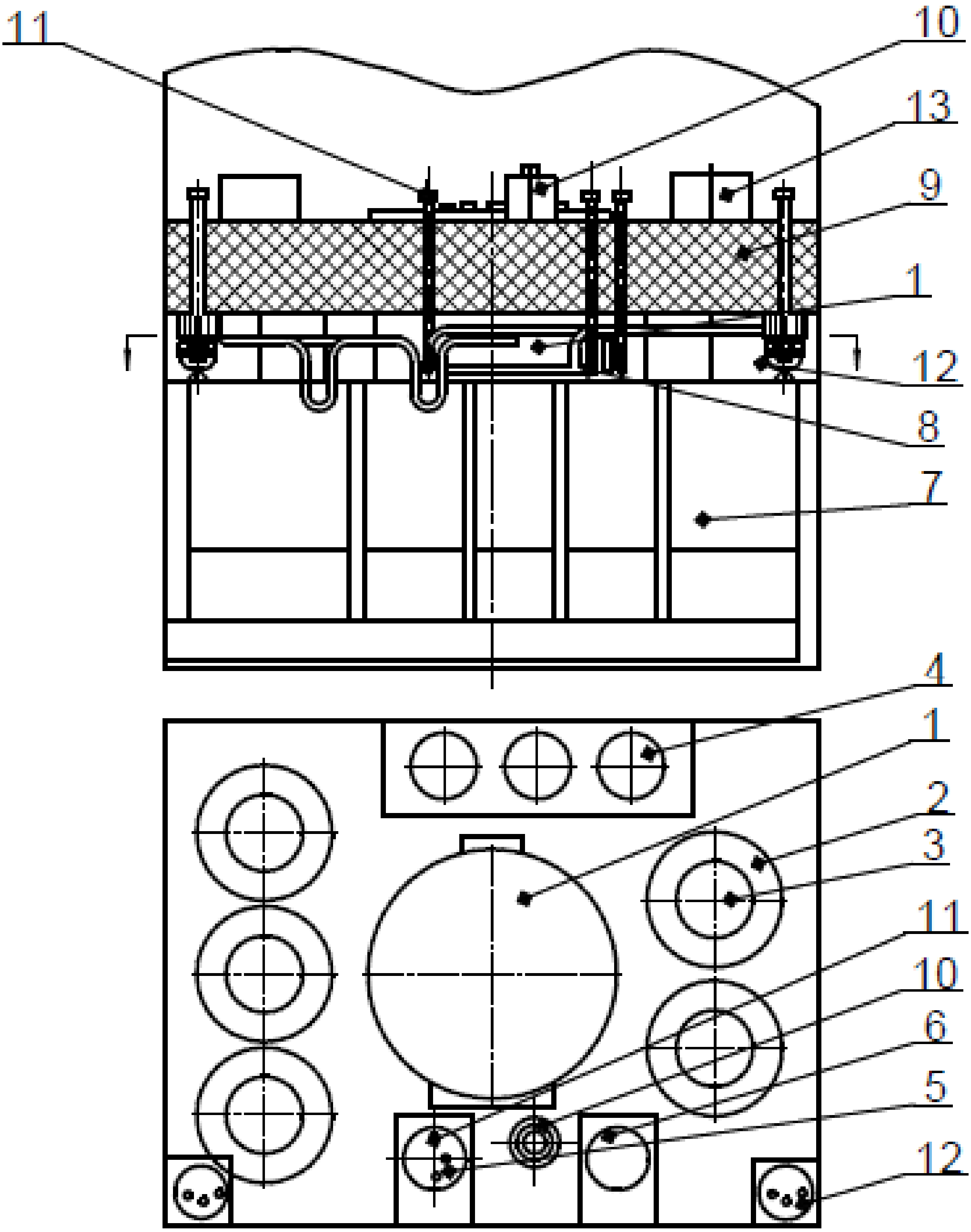
Figure 19 (a, b, c). Reactor Stand 346B





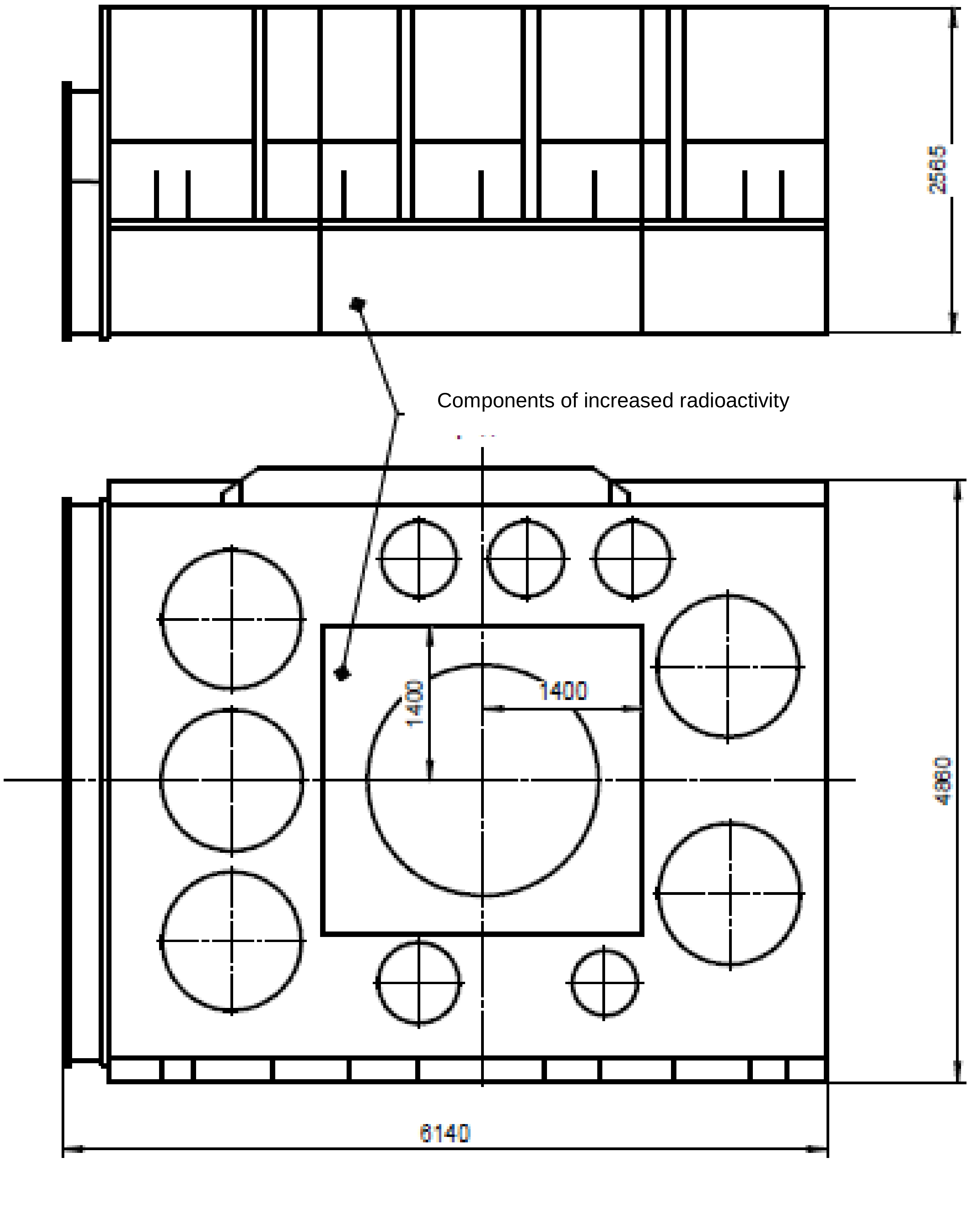
A
~12300
~11000
A

Figure 20 (a, b). Scheme of components and equipment



1 reactor; 2 steam generator; 3 primary circuit pump; 4 primary circuit pressurizer filter refrigerator; 5 valve unit; 6 primary fluid filter; 7 shield tank; 8 primary pipings; 9 bioshield; 10 cool-down pump;

11 primary circuit valves; 12 valve unit; 13 - primary circuit pump



1.6 RADIOLOGICAL SITUATION IN THE REACTOR COMPARTMENT AREA BEFORE PLACEMENT FOR LONG TERM STORAGE

Before erecting reinforced concrete shelters around the reactor compartments, during 1995, a radiological check-out was made of the external surfaces of the reactor compartments. Only calibrated, validated instruments were used for the inspection [1]. The test results yielded the following readings of ionization exposure rate in :

Power Stand 346A

- external surfaces of transverse bulkheads of the reactor compartment (bow and stern) 0.11 - 0.14 µSv/h, which corresponds to the level of natural environment;
- on top of the reactor compartment over the bow partition-off 0.11 - 0.14 µSv/h;
- on top of the reactor compartment on the removable sheet (over the reactor partition-off) 0.12 - 0.17 µSv/h;
- on the bottom of the reactor compartment on the surface of the shell, directly underneath the reactor (along the vertical axis) 4800 µSv/h;
- on the bottom of the reactor compartment, ~ 1.5 m from the reactor centerline towards port and starboard 440 - 1340 µSv/h;
- on the bottom of the reactor compartment, ~ 1.5 m from the reactor centerline towards bow and stern 21 - 28 µSv/h;
- on the bottom of the reactor compartment, ~ 2.0 m from the reactor centerline towards stern 3.0 - 11.0 µSv/h;
- on the bottom of the reactor compartment, ~ 1.5 m from the reactor centerline towards bow up to 22.0 µSv/h.

Power Stand 346B

- external surfaces of the transverse bulkheads of the reactor compartment (bow and stern) 0.11 - 0.14 µSv/h, which corresponds to the level of natural environment;
- on top of the reactor compartment, on the surface of the shell, throughout its entirety 0.12 - 0.14 µSv/h;
- on the bottom of the reactor compartment, on the surface of the shell, directly underneath the reactor (along the vertical axis) 2.2 µSv/h;
- on the bottom of the reactor compartment, ~ 1.5 m from the reactor centerline towards port and starboard 2.2 µSv/h;
- on the bottom of the reactor compartment, ~ 2.0 m from the reactor axis towards bow 0.1 µSv/h;
- on the bottom of the reactor compartment, ~ 1.0 m from the reactor axis towards stern 0.76 µSv/h.

Thus, it can be seen that the highest radioactivity on the reactor compartment shells is typical of the spot directly under the reactor, 1.5 - 2.0m in diameter, on the remaining surface of the shell, ionization radiation rate approaches environmental levels. Ionization radiation rate under the reactor of Stand 346B has a much smaller value due to design reinforcement of the biological shield and shortened energy yield.

A more detailed description of the design and the makeup of the compartments, is given in the input data document Report "Collection and analysis of information regarding the design and content of the reactor compartments of Russian Nuclear Submarines that are being stored in Estonia" Technicatome [1].

1.7 WORK CARRIED OUT BY AS ALARA ON THE SHELTERS OF THE REACTOR COMPARTMENTS AFTER 1995

The main hall of the main technological section (MTS) where the reactor compartments are located for storage in reinforced concrete shelters was left unheated after preparation the compartments for long term storage.,. The shells of the reactor compartments, during the winter, are cooled down to sub-zero temperatures and with the onset of the warm season of the year, moisture begins to condense on them, which leads to their sweating. This results in forming a condensate on the surface of the reactor compartment and this causes damage to the lacquer and paint coats on the shells and speeds up corrosion of the shell external surfaces.

For the purpose of eliminating undesirable processes, the engineers of AS ALARA, in the early 2000s, decided to install ventilation with heated air into the shelters of the reactor compartments. For this purpose, they made door openings in the reinforced concrete walls of the shelters, installed ventilation equipment and air heaters, necessary control and measuring instrumentation as well as automation, which allows automatic actuation of the system during such periods when air moisture reaches dew point. Availability of the above system allows pre-determined air moisture level to be maintained inside the shelters and moisture condensation on the reactor compartment shells with following corrosion will be avoided [1]. For improving of storage conditions of RCs were installed a monitoring system on the reactor compartments for the purpose of detecting possible spills and the main building surrounding the reactors was renovated, thereby making it more weather-proof. Those works were done 2005-2008. As the coating of the shells of RCs were damaged AS A.L.A.R.A. re-painted shells 2014.

1.8 DATA COLLECTION PROCEDURE AND ASSESSMENT OF THE NEED FOR FURTHER INFORMATION AND ADDITIONAL SURVEYS

Initial data from reports, operating documents data, reports of Technicatome Company, etc. [1, 17-20] were used in the work. Data on design and weight as well as dimensional characteristics of basic equipment of power stands, data on the arrangement of equipment inside reactor compartments (RC), data on the design accumulated activity in the equipment, were taken from reports of reactor stands developers – ATOMPROJECT AO, NIKIET AO, OKBM AO and Rubin CKB MT. The credibility of this data is apparent, and no additional confirmation is required. This data is enough to develop options for reactor compartment decommissioning and assess the volume and radioactivity of wastes produced.

From the point of view of obtaining additional data, the information on the design and location of the radioactive waste disposal facility to be erected is of great importance, as this information defines design peculiarities of containers for radioactive waste disposal after the reactor compartment decommissioning and the distance of transportation from the loading place to