ENGINEERING SERVICES ASSOCIATED WITH DISMANTLING OF IGNALINA NUCLEAR POWER PLANT REACTOR CORES

ANNEX F2

Waste inventory and

interactions with radioactive waste management facilities

1. Introduction

This Annex to the Terms of Refference provides preliminary information on the primary waste quantities in the R3 zones. The links between management of these wastes and the INPP's existing and planned radioactive waste management facilities are described and key items and requirements to be taken into consideration are pointed out. However, this Annex does not provide all the technical information that will be required for the implementation of the contract. SE Ignalina NPP (the Client) will provide further information at the Client's disposal to the Consultant during the contract implementation according to the requests made as described in the contract.

2. Solid Radioactive Waste Classification

Classification of solid radioactive waste is defined by VATESI in nuclear safety requirements BSR 3.1.2-2017 “Pre-disposal Management of Radioactive Waste at Nuclear Facilities” [1].

Summary information regarding waste classification is provided in Table 1 below.

Table 1. Solid Radioactive Waste Classification

Radioactive waste class	Definition	Abbreviation	Surface dose rate, mSv/h	Final conditioning	Disposal method*
0	Exempt waste	EW	-	Not required	Treatment and disposal pursuant to the requirements laid down in the legal act under sub clause 3.11 of the Requirements
Short-Lived Very low, Low and Intermediate Level Waste **					
A	Very low level waste	VLLV	<0.2	Not required	Very Low Level Waste Repository
B	Low level waste	LLW-SL	0.2–2	Required	Near Surface Repository
C	Intermediate level waste	ILW-SL	>2	Required	Near Surface Repository
Long-Lived Low and Intermediate Level Waste ***					
D	Low level waste	LLW-LL	<10	Required	Near Surface Repository (cavities at the intermediate depth)
E	Intermediate level waste	ILW-LL	>10	Required	Deep Geological Repository
High Level Waste					
G	High level waste	HLW	-	Required	Deep Geological Repository
Spent Sealed Sources					
F	Spent sealed sources	SSS	-	Required	Near Surface or Deep Geological Repository ****

** Disposal method is determined considering the radioactive waste package conformity to the acceptance criteria set for a specific radioactive waste disposal facility.*

*** Containing alpha emitters with half-life longer than the half-life of ^{137}Cs and the specific activity, measured and (or) calculated by using approved methods, is less than 4000 Bq/g in an individual waste package on the condition that the calculated average specific activity of these alpha emitters is less than 400 Bq/g after averaging of all waste packages. Activity of alpha, beta and (or) gamma emitters shall not exceed the values set for the waste acceptance criteria for the Near Surface Repository.*

**** Containing alpha emitters with half-life longer than the half-life of ^{137}Cs and the specific activity, measured and/or calculated by using approved methods, is more than 4000 Bq/g in an individual waste package, also if after averaging of* *all waste packages the average calculated specific activity of these alpha emitters exceeds 400 Bq/g and (or) activity of alpha, beta and (or) gamma emitters exceeds the values set for the waste acceptance criteria for the Near Surface Repository.*

***** Depending on the acceptance criteria applied to spent sealed sources.*

3. Waste inventory

The primary inventory of materials of which Zone R3 of both Units is composed is shown in Figure 1 [2; 16]. In terms of inventory mass Unit 1 and 2 reactors are very similar - the masses of the materials are the same except for the mass of apertural filling (Unit 2 has a higher mass). The estimated masses of materials in Zones R3 to be removed and processed will be about 30 515 tonnes.

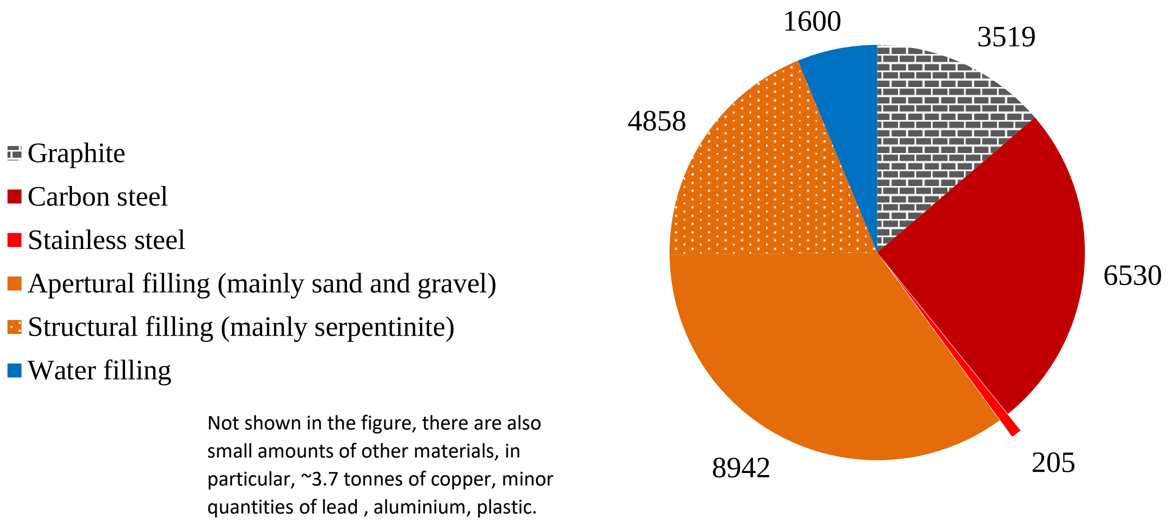


Figure 1. Material inventory in Zone R3 (tonnes, both Units together)

In Zone R3 there are no other chemically hazardous or toxic materials; however, it shall be noted that serpentinite, which is a byproduct of asbestos mining, contains inclusions of asbestos. As per manufacturer specification, there might be up to 0.5÷2% of unbound asbestos by mass of serpentinite.

Distribution of waste by classes depends on a number of factors (decay time, availability and interpretation of radiological data, waste acceptance criteria, etc.). Radiological characterisation of Unit 1 started in 2014, in Unit 2 in 2018 and information about radiological characteristics of materials is available at INPP; however, distribution of waste by classes still is subject to uncertainties. In order to successfully implement the dismantling project for Zones R3, it is important to perform verification / re-estimation of waste distribution by class (this shall be done by the Consultant).

The current estimation regarding Zone R3 waste inventory distribution by class and its changes over time due to decay is shown in Figure 2[1]. It must be noted:

- this and other diagrams represent only a preliminary forecast and shall be verified / re-estimated in the course of this contract implementation;
- possible re-classification of the waste due to decontamination and cross-contamination is not considered (it represents just initial quantities, before processing and without packaging).

[1]Primary mass of water filling not included (instead mass of waste arising from its processing is included (just 3.2 tons of class B+C waste)).

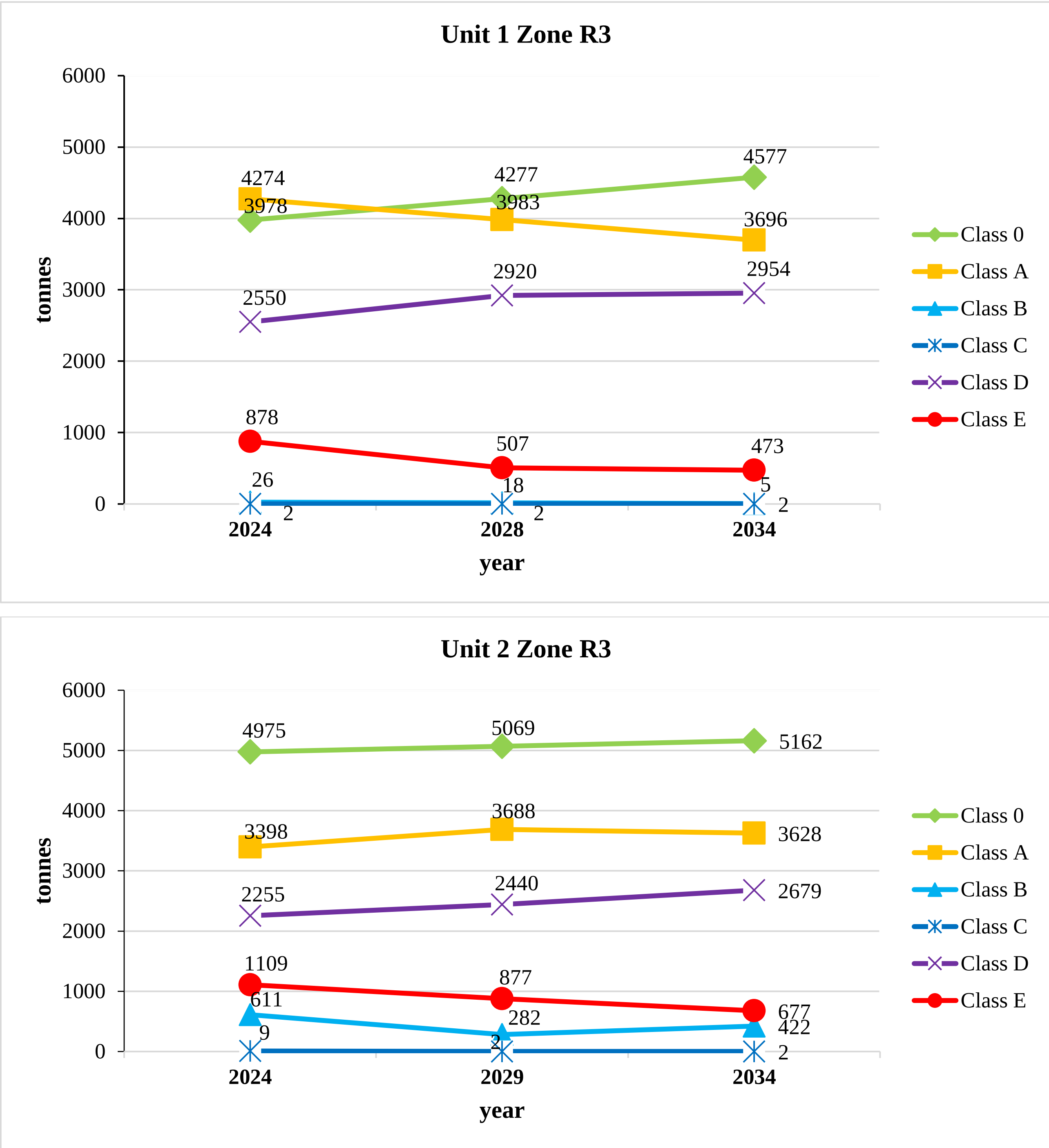


Figure 2. Waste inventory distribution according waste class (forecast)

3.1 Irradiated graphite

The irradiated graphite to be considered under this project can be divided into the following three categories:

(a) Blocks and rods from graphite stacks

The blocks and rods that make up the graphite stack are shown in Figure 11 of Annex F1. Based on the dimensions of the stack (14 m diameter × 8 m height), total volume of graphite (including voids) in both units is approx. 2 463 m^3. The mass of graphite blocks and rods from graphite stacks to be dismantled from both Units is approx. 3 519 tonnes (design data, may slightly differ in reality). The technology for removal of graphite and its interim storage solution shall be developed in the scope of this project (this shall be done by the Consultant).

(b) Graphite rings and sleeves from technological channels

The graphite rings and sleeves of technological channels, which will be removed in the frame of Zones R1/R2 dismantling, amounts to about 247 tonnes. It is planned to put crushed rings / sleeves into 200 litre steel drums. The drums will be placed into F-ANP concrete containers (8 drums per container). It is estimated that 200÷230 F-ANP containers will be sent for temporary storage in Bld.158/2 (Cemented Waste Storage Facility) [3].

(c) Graphite from instrumentation channels

During the prior dismantling in Zones R1/R2, 2 gas sampling channels (1 item per Unit) and 30 temperature channels (14 from Unit 1 + 16 from Unit 2) will be removed from the reactors and transferred to the respective in-unit storage pools awaiting suitable processing and packaging. Because INPP has no established technology for removing the graphite rings / sleeves from these components, they will remain attached. From both Units combined, this category will add approx. 500 kg of graphite waste. Technology for its removal and handling shall be developed by the Consultant.

The estimated mass of graphite waste from both Units is shown below[2].

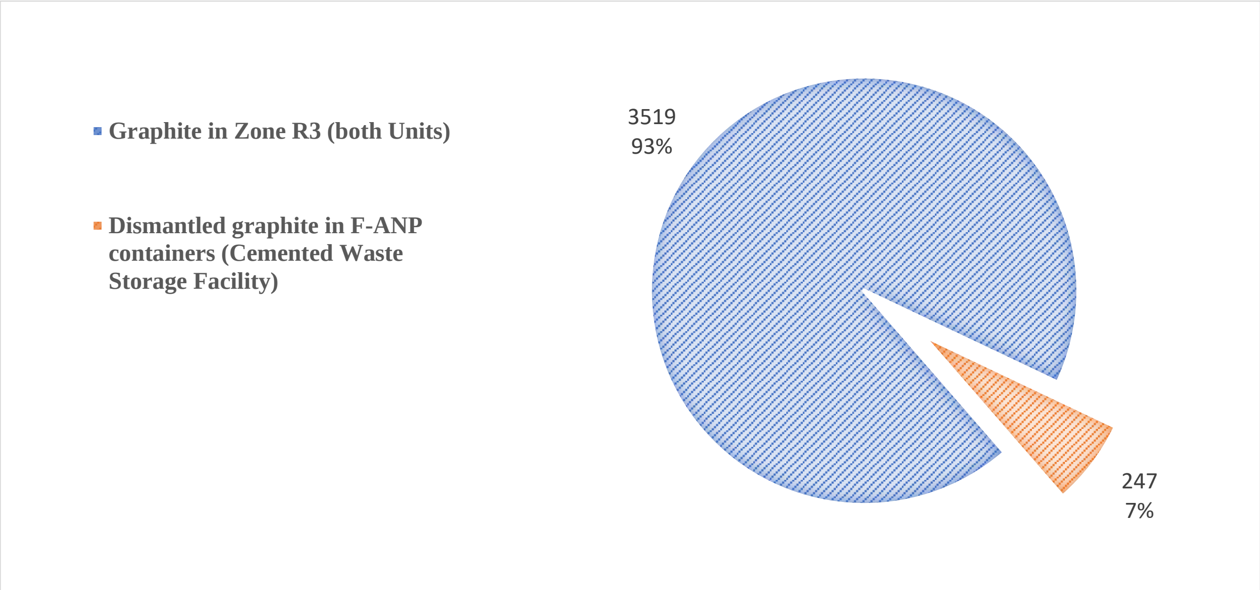
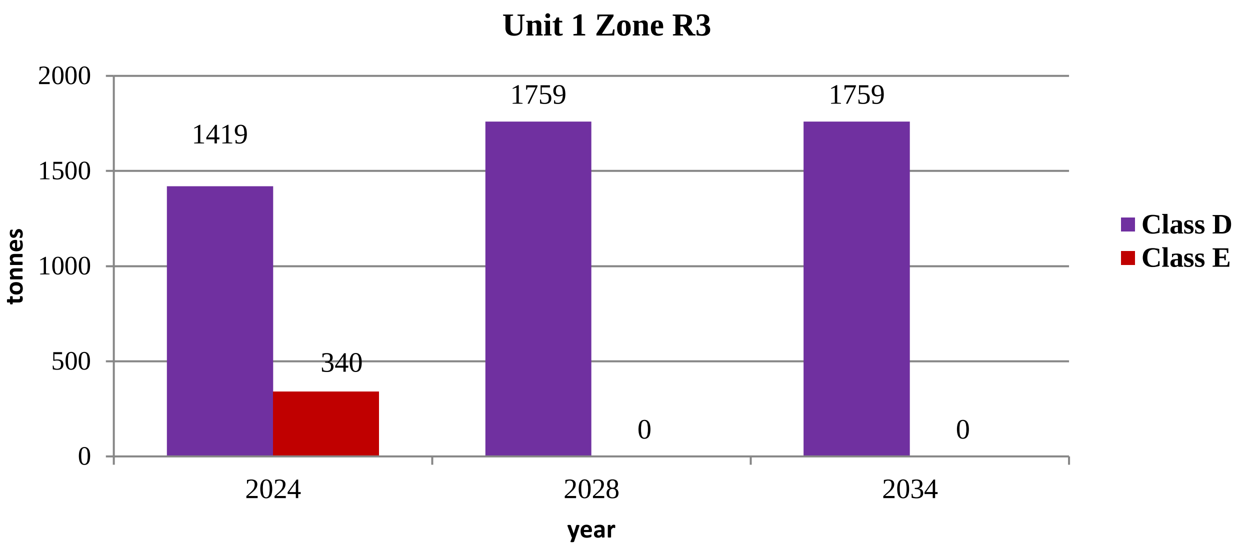


Figure 3. Graphite waste inventory of both Units (tonnes)

Forecast of graphite distribution by class and its evolution during the time is shown in Figure 4.

[2] Including 0.5 tonnes of graphite associated with instrument channels dismantled in R1/R2 but not yet separated from these components



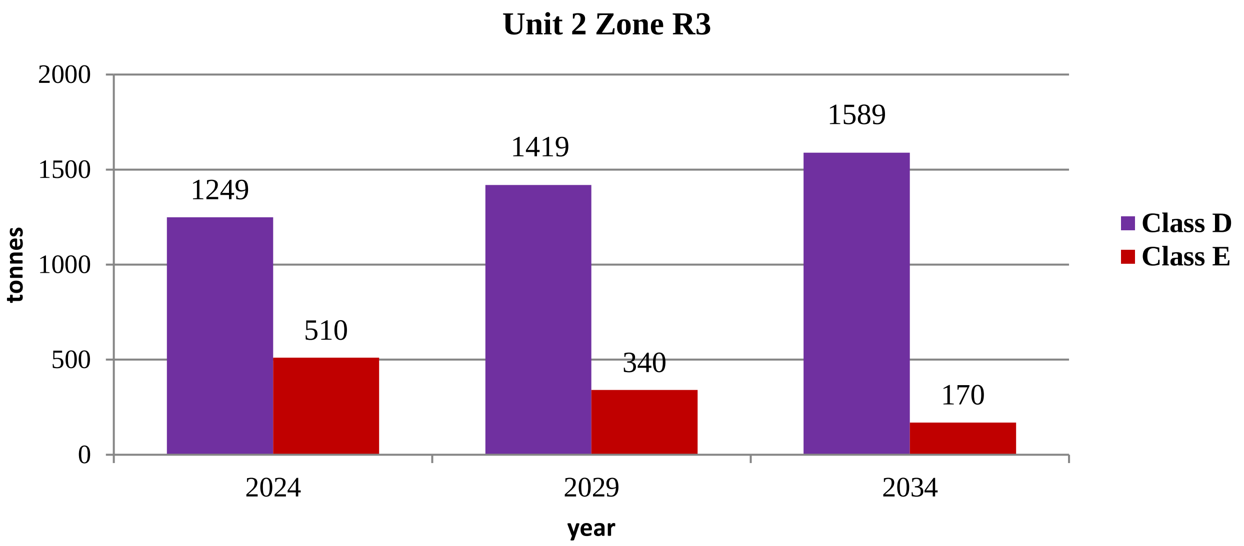


Figure 4. Graphite waste distribution according waste class

All the above-described categories of irradiated graphite shall be transferred to the Reactor Waste Interim Storage Facility (RWISF). The specifications for packaging and characterization of categories (a) and (c) shall be developed under this project. Unless overarching reasons to the contrary emerge in the course of this project, irradiated graphite in category (b) shall be transferred to the RWISF in the drum / F-ANP package.

Of relevance to this project, but excluded from its scope, there are about 55 tonnes of graphite rings and sleeves currently in the old operational waste storages and as yet unquantified minor amount of graphite in the debris at the bottom of spent fuel pools. These rings / sleeves, mostly in small fragments, will be retrieved, loaded into 200-litre drums and placed into ILW-LL storage containers (4 × 200-litre drums per ILW-LL container). The containers will be transferred to the Long-lived Waste Storage Facility (B4L)[3].

[3] Capacity of B4L storage facility is not sufficient for all graphite waste

3.2 Steel waste

Steel waste to be considered under the project is made up of various carbon and stainless-steel components. The total mass of steel waste from both reactor structures will be about 6735 tonnes.

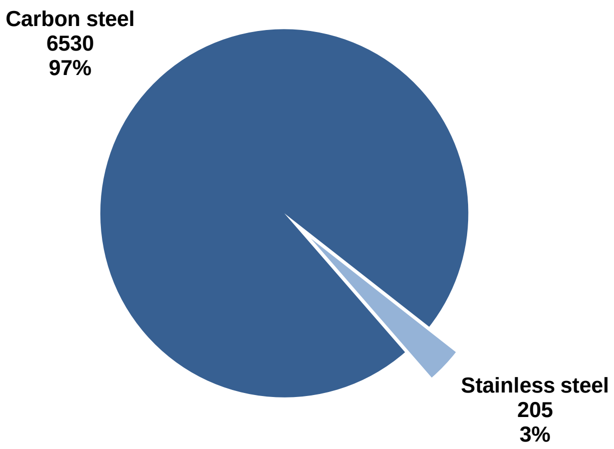
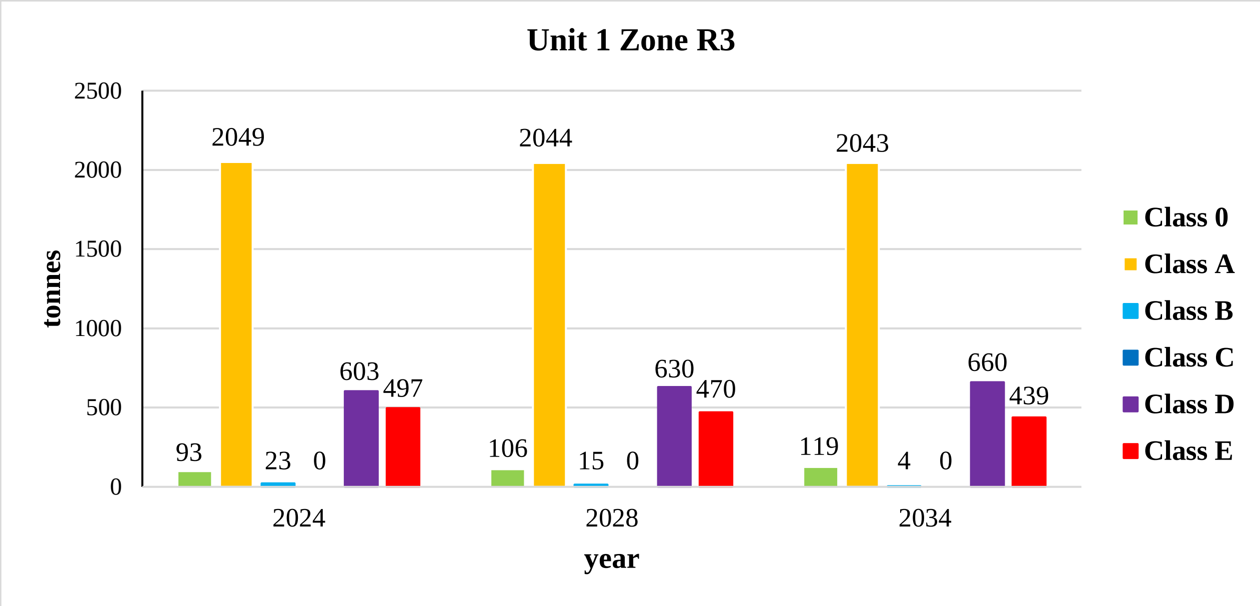


Figure 5. Primary steel waste inventory of Zone R3 for both Units (tonnes)

In addition to the steel arising from Zone R3 dismantling, certain irradiated components from the prior dismantling in Zones R1/R2 are included within the scope of this project. These comprise: 306 Reflector Cooling Channels (153 per Unit) and 2 gas-sampling channels (1 per Unit) from stainless steel which will be temporary placed for decay in storage pools awaiting suitable tools for processing and packaging.

Steel materials in the peripheries of the reactor became contaminated Class A, B and C wastes. Steel materials in the reactor core or close to it became activated, these are classified as Class D and Class E waste. The Zone R3 steel waste inventories and forecasts for radioactive waste distributions are shown in Figures 6 and 7.



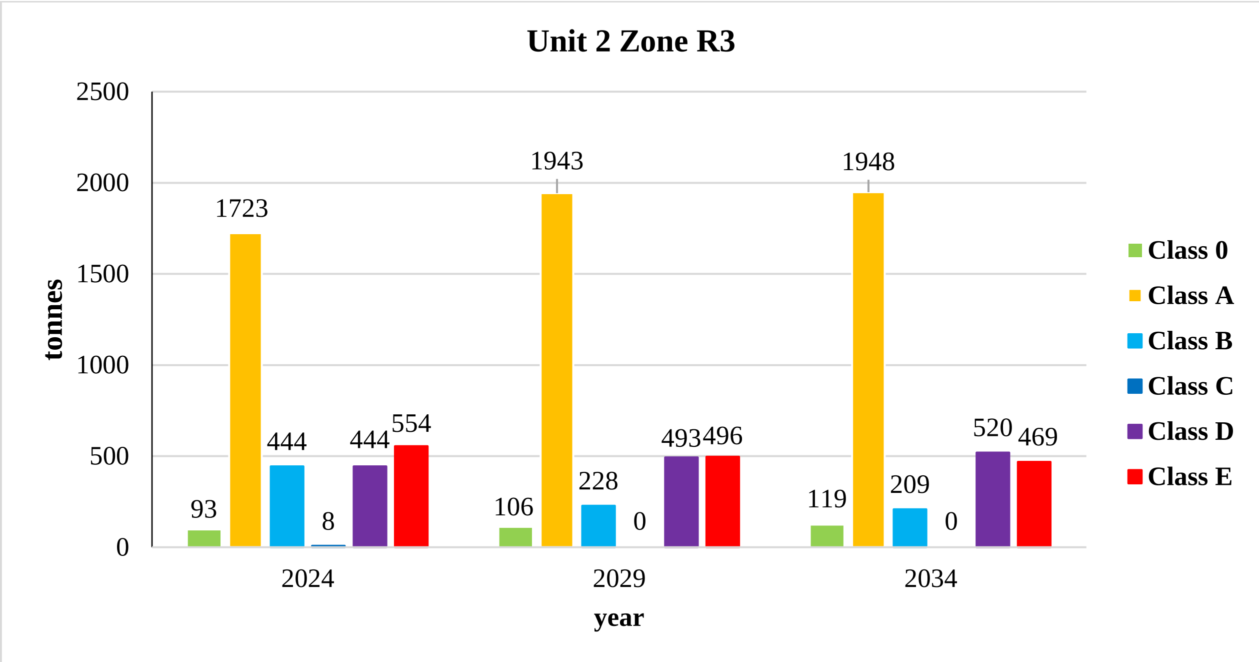
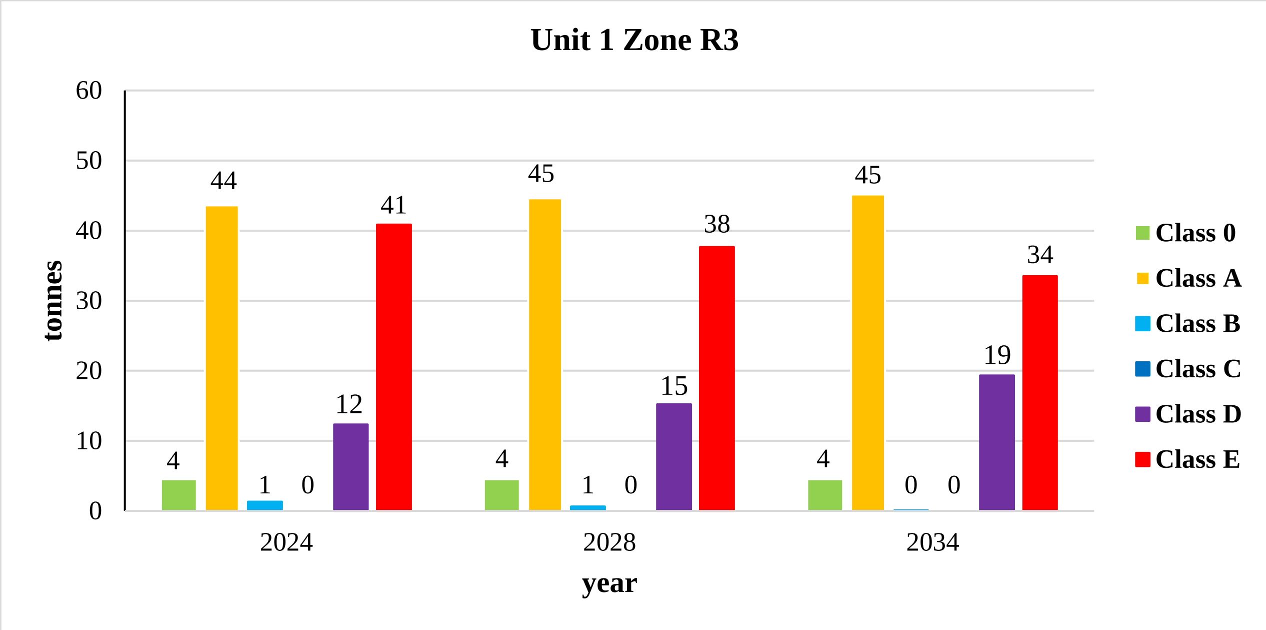


Figure 6. Carbon steel radioactive waste forecast



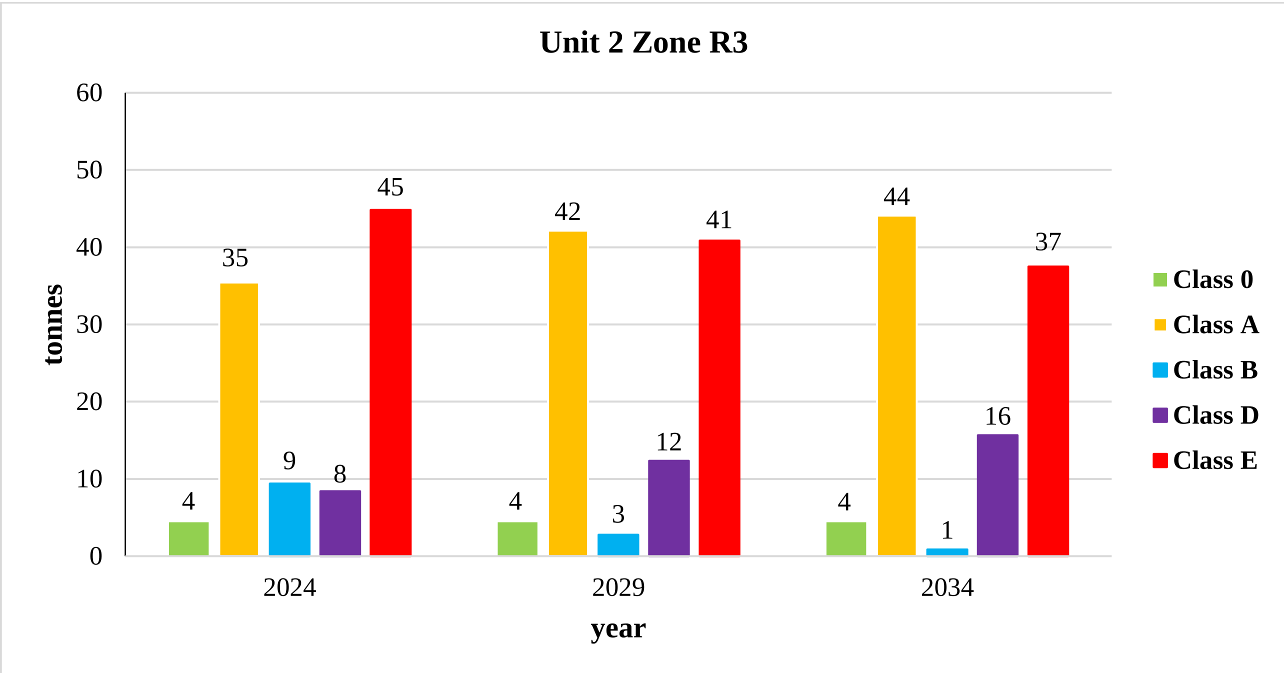


Figure 7. Stainless steel radioactive waste forecast

Class A steel waste (presumed to be ~4074 tons combined total of both Units) shall be evaluated regarding decontamination and de-classification to Class 0.

[Metal waste management workshop (Radioactive Metal Waste Management Facility in Building 130/2) is available at INPP as primary facility for Class A steel waste processing. Equipment at those workshops can perform fragmentation and decontamination of Class A steel waste, which may be delivered in any shape and size (limitations are related only to transport package). Also, in the frame of predecessors' projects workshops for pre-treatment of short-lived waste will be established in reactor building of Unit 1 (in Unit 2 just minimum of such equipment is planned). All this infrastructure shall be reused at the possible extent for processing of waste, arising from Zone R3 dismantling]

Class A steel waste that will not be decontaminated shall be packaged in HHISO containers for Landfill disposal. Characterization equipment for such waste packages is available in the Landfill Buffer Storage Facility. Special attention shall be paid for high density Class A waste (more than ~2000 kg/m^3 when averaged per container) as their radiological characterisation might be technically challenging (for the time being INPP does not have a methodology to perform radiological characterisation of such waste, but it is under development currently) and the HHISO / 1CX container is not an efficient package for disposal of such waste because due to weight limitation (24 t) useful volume of the container (15.3 m^3) will be used only partially (appropriate solutions shall be found in upcoming dismantling project for Zones R1/R2 and this experience shall be applied to the R3 project).

Classes B + C steel waste (presumed to be up to ~247 tonnes) shall be evaluated regarding decontamination and re-classification to Class A or 0. Waste which will not be decontaminated shall be moved to the Solid Waste Management Facility in transport containers for processing and packaging into KTZ-3.6 containers, characterisation, grouting and placement in the Short-lived Waste Storage Facility (B4S) prior to disposal in the Near Surface Repository (NSR). An alternative route (directly to the NSR) might be considered (developed) if such an option proves to be more effective subject to optioneering analysis.

For Class D+E steel waste (presumed to be ~ 2195 tons) processing technology and an interim storage solution shall be developed in the frame of this project (limited capacities are available at B3/4 facility and shall be utilised to the extent possible).

3.3 Filling materials

Filling materials to be considered under this project can be divided into the following three categories:

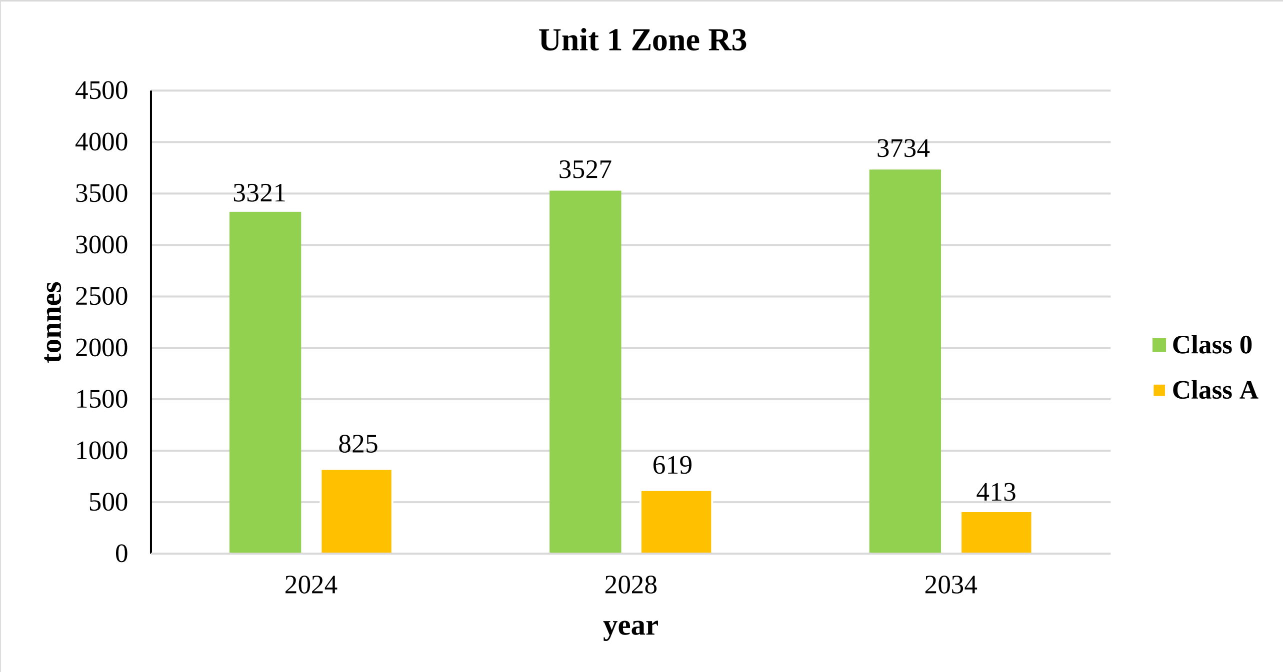
(a) Apertural filling

Filling materials between reactor shaft and reactor metal structures mainly comprises:

- sand - gravel mixture;
- crushed stone and river pebbles.

The mass of apertural-filling materials from both reactors is about 8 942 tonnes.

These filling materials are conditionally non-radioactive waste (CNRW) which presumably meet free-release criteria (i.e. can be classified as Class 0) and Class A waste which are suited for Landfill disposal (see Fig. 8)



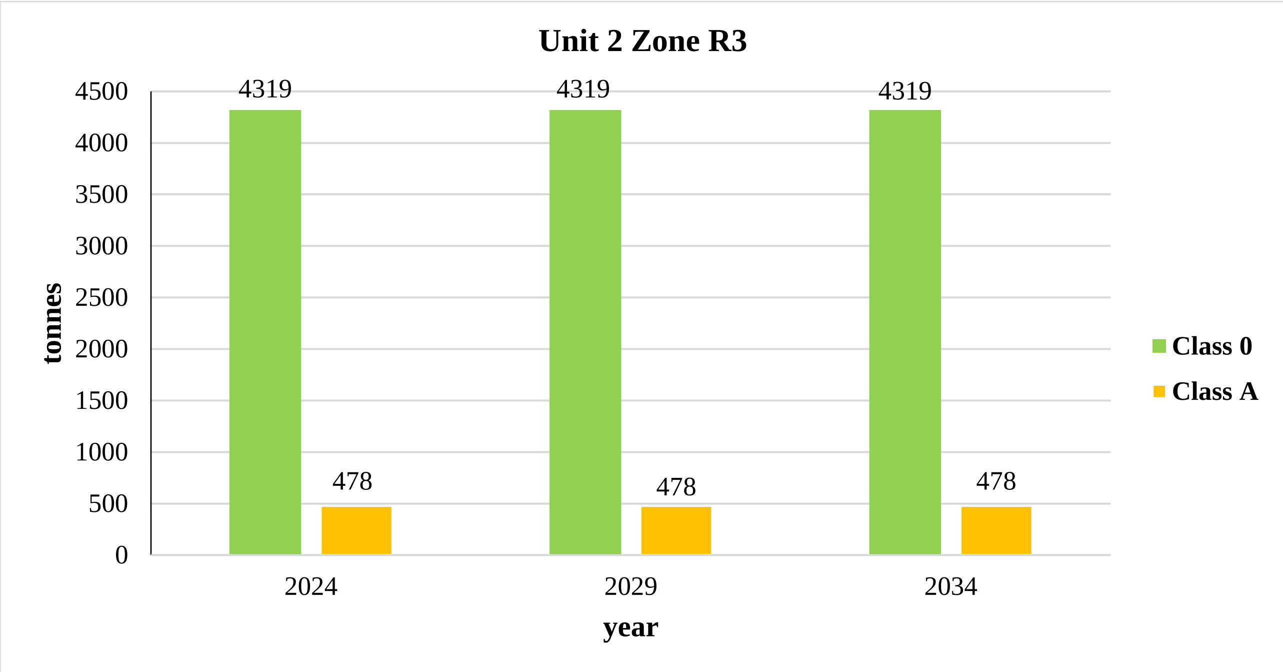


Figure 8. Apertural filling radioactive waste forecast

Additional precautions must be taken regarding four steel drainage tanks located in the top part of the assembly space. These drainage tanks collect contaminated water from the protecting layer of Scheme G. Historically, some leaks occurred from these drainage tanks to the sand filling at Unit 1 (leak marks at Unit 2 were not noticed yet). Precautions must be taken to avoid mixing and contamination of CNRW waste intended for free release.

Equipment for CNRW / Class 0 waste packaging and characterisation is available at INPP; however, it is to be noted that quantities of bulk materials from Zone R3 are much larger than from previous dismantling projects, therefore the capacity of free release facilities shall be considered and possibility to re-use these materials as backfilling material (for the Landfill facility or for empty vaults of the now-disused Bituminised Waste Storage Facility (nearly 10000 m^3 of empty vaults)) must be evaluated.

Class A waste (presumed to be ~1100 tonnes) can be packaged in HHISO / 1CX containers or FIBC and characterized in the Landfill Buffer Storage Facility, then placed into Landfill Repository.

(b) Structural filling

Structural filling materials mainly comprise:

- a mixture of crushed serpentinite stone and serpentinite pebbles from metal structure “E”, structure “OR” and auxiliary cavity “I” (1558 t/unit or 3116 tons in total);
- a mixture of crushed serpentinite stone (14% per total mass) and cast-iron / steel-shot (86% per total mass) from metal structure “G” (800 t/unit or 1600 tonnes in total);
- layers of pebbles and cast-iron / steel shot from auxiliary cavities of structures “E” and “OR” (71 t/unit or 142 tons in total).

The mass of these filling materials from both reactor structures is approx. 4858 tonnes.

These materials are Class 0, Class A and Class D; however, it is to be noted that waste distribution by class is subject to significant uncertainty. Current estimations are as follows:

- a mixture of crushed serpentinite stone and serpentinite pebbles from metal structure “E” and structure “OR”: Class A – 67%, Class D – 33% (2088 tons of Class A and 1018 tons of Class D in total);
- a mixture of crushed serpentinite and cast-iron / steel-shot in metal structure “G”: Class 0 - 90% and Class A – 10 % (1280 tons of Class 0 and 320 tons of Class A in total)[4];
- cast-iron / steel shot from auxiliary cavities of structures “E” and “OR”: mostly Class A (140 tons in total) and minor quantity (2 tons) of Class D.

Class A waste (presumed to be ~ 3500 tonnes) normally should be packaged in HHISO / 1CX or FIBC packages for Landfill disposal, but issues related to disposal of serpentinite (asbestos containing materials) shall be considered (current waste acceptance criteria for the Landfill do not allow to include hazardous materials; however, this limitation is under review and shall be resolved outside of Zone R3 dismantling project). Characterization equipment for this waste is available; however, the volume of such waste shall be considered and special attention shall be paid for high density Class A waste in terms of its characterization.

The quantity of Class B+C waste is believed to be negligible (up to 50 tons at Unit 2 in year 2029), but waste distribution by classes is subject to uncertainty and must be verified in the course of this project. The Solid Waste Management Facility at INPP cannot process bulk waste; therefore, processing, packaging and characterisation solutions for class B + C bulk waste (if any) must be developed in the frame of this project.

The main issues are related to the handling and interim storage of Class D waste. The estimated inventory of such waste generated from Zone R3 of both Units is approx. 1020 tons; however, the inventory must be reviewed in the course of this project. Processing technology and an interim storage solution for such waste must be developed by the Consultant under this project.

(c) Water filling

The cylindrical side tanks (schemes L and D) contain about 800 tons of technological water per Unit. The tanks remain filled with water in order to provide shielding and mitigate internal corrosion of the tanks.

Processing of liquid radioactive waste will be performed by INPP infrastructure (in the existing evaporation and cementation facilities); however, the method for removal of this water and

[4] Shall be noted that likely cast iron and serpentinite mixture probably caked to stone and separation of different materials / different class of waste might be challenging.

timeframe for this activity must be defined by the Consultant in the frame of this project taking into account capacities of water treatment facility and its availability (it is desirable to empty the tanks as early as possible).

3.4 Waste Streams

For the purposes of this project, the above-mentioned materials in their respective radiological class must be considered as waste streams. There are 11 identified waste streams (WS) under this project; however, other streams may emerge due to new scaling factors, different processing requirements and secondary waste, or waste streams may be merged if justified or combined with those from other decommissioning activities. The concept of waste streams allows a structured approach especially in comparing options and scenarios.

Table 2. Principal waste streams

Material / (indicative waste route)	**Class 0** (Free Release)	**Class A** (Landfill)	**Class B + C** (NSR)	**Class D + E** (RWISF)
1. Irradiated graphite				✓
2. Steel	✓	✓	✓	✓ (x 2)
3. Solid Filling Materials	✓	✓	✓	✓
4. Water (after its processing)			✓	

Primary waste management will cause generation of secondary waste. Generation of such waste should be as small as possible. Minimisation of secondary waste must be demonstrated, amounts of secondary waste must be evaluated and their management routes defined in the scope of this project.

4. Interactions with radioactive waste management facilities at INPP

At INPP the following main facilities are available for radioactive waste management:

- Free-Release Measurement Facilities;
- Buffer Storage of Landfill Facility;
- Complex of Solid Waste Management and Storage Facilities;
- Radioactive Metal Waste Management Facility in Bldg. 130/2.
- Storage facility located in Bldg. 158/2;
- Bituminised waste storage located in Bldg. 158

INPP is establishing the following facilities for radioactive waste disposal:

- Landfill Repository;
- Near Surface Repository;

Apart from these main facilities, there are some facilities (already available and under development) located within the main buildings (turbine hall, reactor building) dedicated for primary waste handling (fragmentation, decontamination, accumulation, sorting, etc.).

Buffering places for temporary waste storage are an important issue as they are usually needed in order to manage interfaces between dismantling and waste handling processes. In the context of Zone R3 dismantling and associated waste management, the buffering issue consists of two parts:

- buffering places for waste accumulation before transporting them to waste management facilities at INPP;

- buffering places for temporary storage of long-lived waste awaiting availability of the RWISF.

It is the Consultant's responsibility in the frame of this project to propose and justify appropriate buffering solutions as well as processing, characterisation and interim storage solutions for those types of waste arising from Zone R3 dismantling where unavailable.

4.1 Interactions with Free-Release Measurement Facilities

Conditionally Non-Radioactive Waste (CNRW) is the waste, generated in the INPP controlled area, the contamination levels of which are presumed not to exceed uncontrolled levels of contamination. Confirmation of non-exceeding of uncontrolled levels is made at the free-release measurement facilities according to the requirements of "Identification and Application of Radionuclide Free-Release Levels for Substances and Wastes arising from Nuclear Activities with Sources of Ionizing Radiation", BSR-1.9.2-2018 [4]. After confirmation of not exceeding of free-release levels, these wastes are classified as Class 0 waste.

At INPP, there are two free-release measurement facilities: the main one in Facility B10 and the other in Bldg. 159B. All waste from Zone R3 dismantling, intended for free release, shall be prepared to comply with established free release facilities and procedures. The quantities of materials to be free released are very significant - estimated as 8 000-9 000 tons of filling materials (may be reduced if re-used as backfilling material in INPP's repositories) and steels (current estimation just ~250 tons but potential of decontamination is substantial (all Class A steel waste, up to 4176 tons), therefore significant increase in volume of steel to be free-released is expected).

Essentially, management of CNRW waste at INPP is carried out as follows (the detailed procedure on CNRW management is described in [6] and [7]):

- after equipment dismantling, preliminary measurements of effective dose rate (EDR) and surface contamination of all surfaces is made. According to its results, waste is separated into radioactive waste and CNRW;
- CNRW is transported to places of temporary waste accumulation where it is separated into large-sized waste and small-sized waste;
- large-sized waste is transported to Facility B10 for characterization (characterization also may be done in other places; its selection depends on conditions);
- small-sized CNRW is loaded into containers or drums at the accumulation points according to Requirements on CNRW Packages Generation for Radiological Characterization [5];
- Containers and drums with waste are taken for final radiological characterization to Facility B10 or to Bldg. 159B, measured and dedicated report is issued.

According to CNRW measurement results, Class 0 waste is separated. If waste does not correspond to Class 0 according to the results of CNRW measurements, the container with such waste is taken back by the same route to the accumulation points (buffer storage sites) for resorting.

Standard packages that are used:

- for Facility B10: boxes K-13, K-16 and drums K-14, K-14M[5];
- for facility in Bldg. 159B: box K-15.

Maximum productivity of the facility in Bldg. 159B is 20 K-15 containers per shift. Actual productivity of Facility B10 is 20 drums, 16 boxes and 2 large-sized components in parallel per day.

Requirements for waste packages and their formation:

[5] List of characteristics of containers are presented in Appendix 1 to this Annex 2

- mass of package K-13 and K-16 should not exceed 1140 kg. Container must be filled from 30 to 100% of container height.
- mass of package K-15 should not exceed 975 kg. Container must be filled from 30 to 100% of container height.
- mass of drum package K-14 and K-14M should not exceed 375 kg. Drum must be filled from 85 to 100% of its height.
- waste packed in one standard package should be of the same origin (characterized by one nuclide vector) and homogeneous in chemical composition;
- size of waste fragments in one container should not exceed 300 mm and should not differ more than 15% in size (whereas other limitations and restrictions are not specified). This is achieved by fragmentation of the waste and the relatively uniform package filling throughout the volume (the higher the fragmentation level, the more reliable the measurement).
- loading density in any part of waste package should not differ from average density of all volume of the package by more than 15 %.
- when filling a container with pipes, it is necessary to fragment them into pieces of about 1-meter length, bisect them lengthways, then sort them by the outer diameter for loading into different containers:
  - pipes of diameter up to 60 mm;
  - pipes of diameter from 60 mm up to 180 mm;
  - pipes of diameter from 180 mm and more.
- metal sheets shall be fragmented into parts up to 700x1000 mm. It is allowed to bend thin sheets in order to obtain the specified sizes.
- disassembled valves, electric motors, pumps and their parts should be loaded only after fragmentation until a permissible linear dimension of 300 mm is reached.
- concrete waste shall be crushed in pieces, no more than 300×400×400 mm size.
- all light waste (wood, plastic, paper, i.e. density less than 1000 kg/m^3) shall be sorted according to the composition and the container shall be filled at least 90% in height.
- waste sorting should be performed at the packing formation sites. The gamma dose rate at the waste sorting site (background level) shall not exceed 0.15 μSv/h. The site of packages formation shall be marked and fenced in a way that dismantling works will not cause additional contamination of waste.
- during package formation, gamma radiation and surface beta contamination of each fragment shall be measured (except for bulk materials). To carry out measurements for presence of surface contamination by hand-hold devices the waste should be free of dust and dirt, peeling paint, scale, rust. The presence of oil-products in waste is not permissible. The measurements must be carried out throughout the length and throughout the surface of individual fragments loaded in the package. The dose of gamma radiation at a distance of 10 cm from the object should not exceed – 0.2 μSv/h. The total surface beta contamination at a distance of 1 cm from the object should not exceed 0.2 Bq/cm^2.
- when loading bulk waste, it is necessary to measure dose rate of gamma radiation and the total surface beta contamination of each layer every 0.2 m of waste in the package.
- when formation of the package is completed, it is necessary to measure dose rate of gamma radiation on the package and beta-contamination of its surface. The dose rate at a distance of 0.1 m from the package should not exceed 0.20 μSv/h, beta contamination at a distance of 1 cm from the package should not exceed 0.2 Bq/cm^2.

Radiological characterization of large-sized waste (non-standard packages)

Radiological characterization of large-sized components is carried out by two methods: direct measurement of gamma activity of the entire object (further, the method of direct measurement) and the measurement of the gamma activity of smears taken from the surface of the object (further, the method of smears). Such characterisation is carried out at facility B10.

The method of direct measurements is suitable for solid or hollow large objects that have a regular form (i.e. parallelepiped, sphere, cylinder, cube, flat plate). Deviation from the correct geometric shape cannot exceed 10%.

The method of smears is suitable for any shape, but special attention should be paid to the object's surfaces. They should be:

- not absorbing, without visible irregularities (without cracks, not containing pitting corrosion);
- suitable for smear removing (without sharp and torn edges). All coatings of large CNRW that are not suitable for removing smears (rust, protective pastes, greasing) or concealing the contamination (paint, primer, putty, etc.) shall be removed.

The maximum overall dimensions of large-sized CNRW sent to B10 facility shall not exceed 6x2x2 m and the mass shall be up to 10 tons. Large-sized waste before dispatching to B10 facility for measurement of activities should be checked by hand-held devices for the presence of internal and external surface contamination. Gamma radiation dose of the object is measured at a distance of 10 cm from the surface, and the total surface beta-contamination at a distance of 1 cm from the surface. Gamma radiation dose should not exceed 0.20 μSv / h; the total surface beta-contamination should not exceed 0.2 Bq / cm2.

To prevent contamination, large-sized CNPW shall be sent to the B10 facility packed in polyethylene film or covered by tent.

Radiological characterization of large-sized components at the place of formation may be carried out in accordance with measurement methodology of large-sized equipment and waste for free-release from radiation control [8]. Components' dimensions and mass characterized by this methodology are not limited, but they should not have been exposed to ionizing radiation, which could cause activation of materials.

Before measurements for the presence of internal and external surface contamination by hand-held devices, the component should be cleaned of dirt and dust at the site of formation. Loose paint and peeling slurry (rust) should be removed, and all oil containing contamination cleaned. Such components shall be checked by hand-held devices for internal and external surface contamination before measurements by the mobile gamma spectrometer (i.e. all surfaces should be accessible for measurements). Particular attention should be paid to measuring the joint areas of different surfaces, recesses, cavities, joints, and welds.

The dose of gamma radiation of the object is measured at a distance of 10 cm from the surface, and the total surface beta contamination at a distance of 1 cm from the surface. The dose of gamma radiation should not exceed 0.20 μSv/h; the total surface beta contamination should not exceed 0.2 Bq/cm2.

A summary of requirements to waste packages generation is presented in Table 3 [5].

Free release levels for specific activities are provided in BSR-1.9.2-2018 [4]

Table 3. Requirements to waste packages for free-release measurement

No.	Waste types	Size reduction and surface preparation	Gamma and beta measurements at the place of waste loading into packages	Package type
1.	Pipes	Straight and curved, any diameter, cut along in pieces up to 1 m length	All surfaces during loading	B10 container (К-13, К-16); 159B container (К-15)
		Diameter more than 300 mm, straight, length up to 6 m[6] and mass up to 10 tonnes.	All surfaces[7]	Large-sized waste
2.	Metal plate / sheet	In pieces up to 700×1000 mm	All surfaces during loading	B10 Container (К-13, К-16), 159B Container (К-15)
		Cuttings up to 100×1000 mm	All surfaces during loading	B10 drum (К-14, К-14M)
3.	Valves, electric motors, pumps and other similar equipment	In disassembled condition. Maximum linear dimensions - 300 mm	All surfaces during loading	Container B10 (К-13, К-16), Container 159B (К-15)
4.	Construction waste (concrete, brick, sand, gravel) and thermal insulation	In a split condition with a maximum linear dimension of parts up to 100 mm and sorted by type.	By layers during loading to package	B10 drum (К-14, К-14M)
		In a split condition with a maximum linear dimension of parts up to 300×400×400 mm and sorted by type. Thermal insulation allowed	By layers during loading to package	B10 Container (К-13, К-16), 159B Container (К-15)
5.	Wood	In pieces up to 700×1000 mm	By layers during loading to package	B10 Container (К-13, К-16), 159B Container (К-15)
		Cuttings up to 100×1000 mm	By layers during loading to package	B10 drum (К-14, К-14M)
6.	Paper	In pieces up to 700×1000 mm	By layers during loading to package	B10 Container (К-13, К-16), 159B Container (К-15)
		rolls width up to 750 mm, cuttings up to 100×100 mm	All surfaces during loading	B10 drum (К-14, К-14M)

[6] *Radiological measurements of extended objects are carried out every two meters of an object, therefore it is recommended to cut tubes in segments up to 2, 4 and 6 m without exceeding these values.*

[7] *For pipes of known origin, classified according to the results of preliminary radiological characterization to conditionally non-radioactive waste when measuring internal contamination, it is allowed to carry out two control measurements in the most typical places for possible contamination*

No.	Waste types	Size reduction and surface preparation	Gamma and beta measurements at the place of waste loading into packages	Package type
7.	Polymer materials and thermal insulating sheets	In pieces up to 700×1000 mm	By layers during loading to package	B10 Container (К-13, К-16), 159B Container (К-15)
		Rolls width up to 750 mm, cuttings up to 100×100 mm	All surfaces during loading	B10 drum (К-14, К-14M)
8.	Large-sized equipment (for direct measurement)	The shape of objects shall be as close as possible to: - flat (concrete and metal plates); - cylindrical (drums, tanks, etc.); - ball-shaped (gas holder) - parallelepiped - shaped Surfaces shall be completely cleaned of dirt and dust, oils, greasing and other oil products, as well as loose rust and cinder, shelled protective pastes, paint, soil, coating, etc.	All surfaces	Large-sized waste for measurement at Facility B10 (non-standard package)
9.	Large-sized equipment (for direct smear)	The form of objects of any shape. Surfaces shall be completely cleaned of oils, dirt and dust, as well as of rust, protective pastes, grease, paint, primer, coating, etc. The presence of oil products on waste is not permissible.	All surfaces	Large-sized waste for measurement at Facility B10 (non-standard package)
10.	Large-sized equipment (only after agreement with RSD).	The form of objects of any shape. Objects during operation shell not be: exposed to ionizing radiation, capable of causing activation of materials; Surfaces shall be completely cleaned of dirt and dust, oils, greasing and other oil products, as well as loose rust and cinder, shelled protective pastes, paint, soil, coating, etc.	All surfaces	Large-sized waste for measurement at the place of formation (non-standard package)

4.2 Interaction with Landfill Repository

Solid, short-lived, very low-level radioactive waste (Class A waste) is placed into the Landfill repository. It is estimated that there are 7000-8000 tons of such waste, half of it consists of steels and half of filling materials. Because steel waste, to a large extent, may be decontaminated, significant reduction in quantity of Class A waste is expected.

The Landfill complex consists of a buffer storage (already in operation) and a disposal site, which is under construction and will enter operation in 2020. The purpose of the buffer storage is for radiological characterization and temporary storage of waste (up to 4000 m^3) between disposal campaigns.

Waste directed to the buffer storage / Landfill repository must comply with waste acceptance criteria presented in the Safety Analysis Reports [9] and [1010]. It must be noted that the waste acceptance criteria for Landfill repository [10] will be updated when repository construction is completed.

Waste which is planned for Landfill repository disposal is packed into 6-metre long open-top half-height ISO container (hereinafter HHISO / 1CX), FIBC or bales. Waste must be sorted according to the following parameters:

- activity;
- content of nuclides (scaling factor);
- physical and chemical properties.

Waste in one package should be of the same type in terms of material (steel, aluminium, concrete, heat insulation, cables, etc.) and radioactivity in accordance with the margins specified in [11].

Steel waste generated during Zone R3 dismantling works and intended for disposal in the Landfill repository must undergo preliminarily characterization, be placed in HHISO containers and transported to the Buffer Storage. Waste must be packed in containers on the site in such a way as to avoid enclosed voids of large volume that cannot be filled with backfill material (sand) at the disposal site. The HHISO container should be filled to not less than 70% and not more than 100% of its internal height.

Loose materials (i.e. sand, gravel, serpentinite) generated during Zone R3 dismantling works and intended for disposal in the Landfill repository must be placed in FIBC or HHISO containers.

Compactable waste generated during Zone R3 dismantling works (e.g. secondary waste like personal protective equipment, rags, polyethylene film) and intended for Landfill repository disposal should be collected in polyethylene bags. Filled bags will be transported to the accumulation points and thereafter to the compactor located in the Solid Radioactive Waste Retrieval Facility. The volume of waste will be reduced by compacting; bales will be wrapped in polyethylene film. The dimensions of bales produced will be 1200 × 1100 × 700 mm and weight up to 700 kg (average ~ 400 kg). Radiological characterization of bales will be performed in the Solid Radioactive Waste Retrieval Facility before transportation to the Buffer Storage (or other place for temporary storage). At the time of disposal, bales will be placed in the Landfill repository without additional packaging.

In the frame of predecessor projects, workshops for handling (fragmentation, sorting and loading of fragments into transport containers) and temporary storage of Class A (and CNRW) waste will be established in the reactor buildings of Unit 1 [12] and Unit 2. To the extent technically achievable and economically rational, this infrastructure is to be reused for processing of waste arising from Zone R3 dismantling.

Before shipment to the Buffer Storage, the package must meet the following requirements [11]:

- a preliminary passport should be issued for every package;
- gamma-radiation dose rate on the surface of the container should not exceed values, based on the waste acceptance criteria;
- fractions of different size should be evenly distributed within the container's volume;
- the container must be loaded with waste of Class A with the same nuclide vector (scaling factor);
- waste in one container must be homogeneous in terms of chemical composition - it is not allowed to place together reinforced concrete, heat-insulating materials, pipes, etc.;
- the density of the waste in any part of the package should not differ from the average density of the waste of the total volume of the package by more than 15%, i.e. stainless steel, carbon steel and cast iron can be placed in one container, but steel and non-ferrous metals cannot be placed together;

Special attention must be paid to high density Class A waste (more than 2000 kg/m^3) as its radiological characterisation may be technically challenging (at the moment INPP does not have a methodology for performance of radiological characterisation for such waste) and HHISO container is not efficient package for disposal of such waste because due to weight limitation (24 t) useful volume of the container (15.3 m3) will be used only partially (appropriate solutions shall be found in upcoming dismantling project for Zones R1/R2 and this experience shall be applied to the R3 project).

The waste acceptance criteria for the Landfill repository (e.g. in terms of serpentinite / asbestos containing materials) shall be considered taking into account revised waste acceptance criteria (this limitation is under review and shall be resolved outside of Zone R3 dismantling project). Utilisation of bulk materials from Zone R3 as a backfilling material for HHISO containers or/ and as repository cover layer shall be assessed.

Due to delays in construction of the repository, the capacity of the Landfill Buffer Storage is not sufficient. This has been solved by development of temporary storage sites inside the INPP buildings; such an option may be considered for waste arising from the Zone R3 dismantling project as well.

4.3 Interactions with the Complex for the Management and Storage of Solid Radioactive Waste and with the Near Surface Repository for low and intermediate level short-lived radioactive waste

The complex for retrieval, management and storage of solid radioactive waste (developed as project B2/3/4) is capable of handling waste in classes A, B, C, D, E, F, and consists of two parts: for the Solid Waste Retrieval Facility for recovery of waste from the old substandard operational storages (B2) and Solid Waste Management & Storage Facility (B3/4).

Facility B3/4 consists of a solid radioactive waste treatment complex (B3) and two waste storages: a storage for short-lived low and intermediate level waste (B4S), and storage for long-lived low and intermediate level waste (B4L)). A detailed description of the facility and its functions is presented in safety analysis report [13].

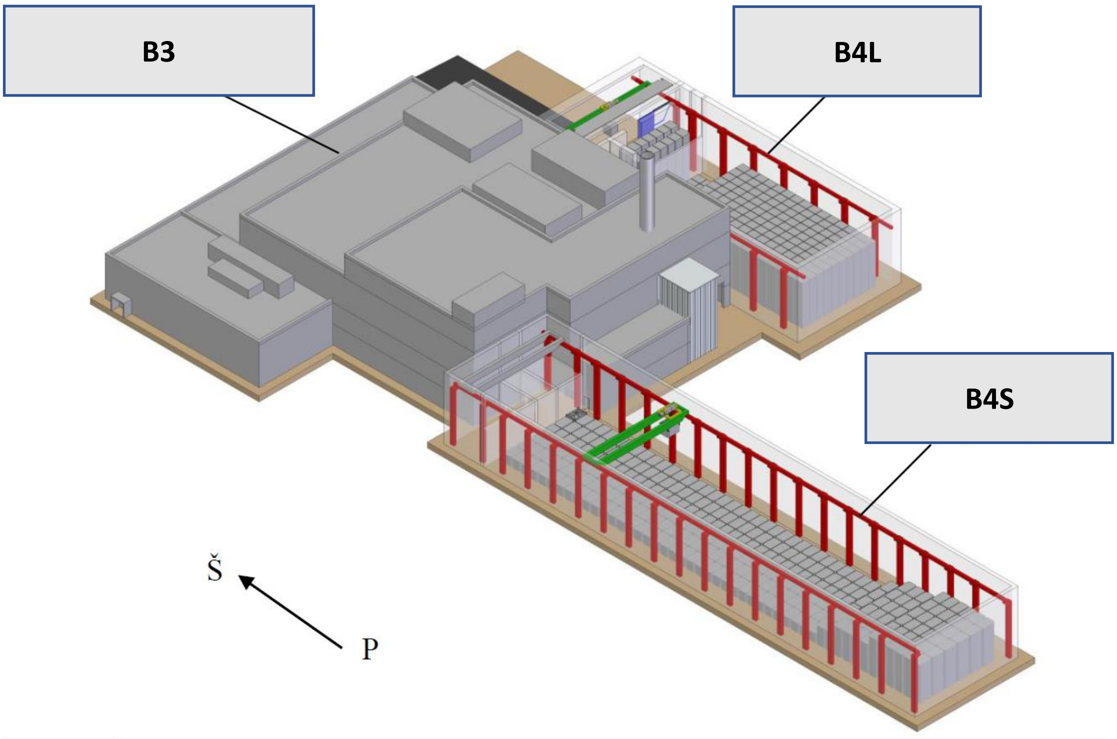


Figure 9. Layout of B3/4 complex

At Facility B3 sorting, incineration, super compaction, packaging, cementing of solid radioactive waste, as well as characterization of packages are carried out.

Facility B4S is for storage of 1152 KTZ-3.6 containers[8]. To the west of it, there is a site where up to three more storage modules equivalent to B4S were foreseen at the initial stage of project development.

Facility B4L is for storage of 904 ILW-LL containers containing long-lived waste, including graphite waste, metal waste (Class D and E), and spent sealed sources of ionizing radiation (Class F). Waste in containers will not be immobilized (possible subsequent processing will depending on the method of disposal which will be selected in the future). The storage was designed in such a way that, if necessary, it can be expanded by adding another 880 ILW-LL container module; however, after starting to load containers with high dose rates, this option became hard to implement.

Class B and C dismantling waste may be delivered to B3/4 in different containers (G-2, K-5, K-100, K-150, K-190, and in 200 litre drums). Capacity of B3 facility is 2.8 m^3 of class II waste (i.e. B+C class) per shift (limited by throughput of sorting process). They are sorted, processed and placed in containers KTZ-3.6. When the container is loaded, the weight and dose rate at a distance of 0.1 m from the surface of the container are monitored and in case of exceeding the settings (56 mSv / h) the container is reloaded. These containers are then sent to the grouting installation in B3, from there to B4S, and then to NSR.

Quantities of Class B+C waste from Zone R3 dismantling are relatively small, but waste distribution by class is subject to uncertainty and must be verified / re-estimated in the course of this project. It is to be noted that the Solid Waste Management Facility B3 can process various types of waste (steel, filters, combustible waste, etc.); however, it cannot process fillings (loose materials) such as sand and serpentinite.

Solid Waste Management Facility B3 is intended for processing of class D+E waste. Its capacity is 0.9 m^3 of class III waste (i.e. E class) per shift and such capacity may not be enough for

[8] Design capacity might be marginally increased subject to justification

class E waste arising from Zone R3 dismantling (about 1300 tons of steel and graphite).

Shall be noted that to a large extent facility B3 will be occupied by waste coming from the old storages, Zones R1/R2 dismantling and operational waste handling). Considering its limitations (throughput, waste type, sequence of waste management processes) this facility may not be able to handle all the waste from the R3 dismantling. The consultant should investigate the applicability of this facility and suggest appropriate solutions for the processing of R3 waste in due time.

B4L facility is for storage of class D+E waste, however its capacity (904 places for ILW-LL containers) is not sufficient for waste arising from Zone R3 dismantling (to a large extent it will be occupied by waste coming from the old storages, Zones R1/R2 dismantling and operational waste handling – in total there will be ~840 ILW-LL containers of such waste).

In summary, solutions for processing and interim storage of long-lived waste (~3766 tonnes of graphite, ~ 2200 tonnes of steel and ~1000 tonnes of serpentinite) from Zone R3 must be developed in the course of this project taking into account the possibilities and limitations of B3 and B4L facilities. It is expected that some of Class E materials (such as reflector cooling channels from highly activated stainless steel) can be handled in Facility B3 and placed for storage in Facility B4L; however most Class D and E waste will have to be managed in facilities developed in the scope of the Zone R3 dismantling project.

Design development and licensing of the Near Surface Repository (NSR) for short-lived low and intermediate level radioactive waste was performed in the frame of project B25. Construction of the NSR should start in 2020; the planned date of commissioning is 2024.

The design capacity of the NSR is 100 000 m^3 of F-ANP and KTZ-3.6 containers. Construction of 3 concrete vault-groups was foreseen in the technical design, but in view of the smaller amount of waste of this type, only 2 vault-groups is currently.

The NSR will include a Technological Building for accepting and characterisation of waste packages[9], and grouting of F-ANP and KTZ-3.6 containers prior to loading into the disposal vaults.

Waste acceptance criteria (WAC) for NSR are defined in its Preliminary Safety Analysis Report [14], developed in accordance with the regulatory document [15]. The WAC are being revised and the Final SAR will be developed together with the construction of the repository.

The NSR is for disposal of Class B+C waste (the possibility to allow minor quantities of Class F and D waste are under review). The quantities of such waste from Zone R3 dismantling are assumed to be minor and their processing will be carried out before delivery to the NSR; therefore, in this respect on the Zone R3 dismantling project and NSR do not have direct interfaces. However, waste distribution by class is subject to uncertainty and an increase in Class B+C waste quantities cannot be ignored. If the quantities of Class B+C waste increase and Facility B3 processing rates are not sufficient to cope with it, then the possibility to prepare packages for disposal in other Facility than B3 must be investigated.

5. Reactor Waste Interim Storage Facility

The Reactor Waste Interim Storage Facility (RWISF) that does not currently exist and is required for long-lived waste arising from Zones R3 dismantling must accommodate:

- Class D graphite waste (~ 3766 tonnes /~ 2808 m^3);
- Class D+E steel waste (~2195 tonnes / ? m^3 (volume will depend on applied processing / packaging technology));

[9] very limited capacity of buffering, also NSR will work by campaigns and it makes restrictions for direct RW stream from Units to NSR

– Class D filling waste (~1018 tonnes / ~600 m^3).

It is to be noted that the indicated masses / volumes are preliminary and must be verified / re-estimated in the scope of this project. If serpentinite, attributed to Class A, B, or C will not be suitable for disposal due to the WAC of the Landfill and NSR, then all this material must go to the RWISF.

The interim storage of these long-lived wastes subdivides into three main issues:

- technologies and equipment for waste handling and characterisation to be incorporated;
- container(-s) to be used for waste packages[10]; and
- the facility (building) in which to handle waste and store the waste packages.

The facility must be suitable for the storage of long-lived waste in general (e.g. shielding, structural stability over a long (at least 50 years) storage period), for chosen containers in particular (e.g. cranage, transportation vehicle(s), dose rate from package) and for processing of particular type of waste.

The storage facility may be created by: (a) the repurposing of an existing building; (b) the construction of a new building or buildings; or, (c) any justified combination of (a) and (b). However, it is a requirement that the RWISF must be on the Solid Waste Management and Storage Facilities (B3/4) site to take advantage of the existing infrastructure (e.g. road network, utilities, physical protection, etc.) and, to some extent, facilitated licensing due to licensing carried out previously. To the extent technically achievable and economically rational, processing of the waste is to be performed using existing facilities. Solutions for missing / insufficient facilities should be developed inside of the main buildings of the Units (preferably close to the place of origin of the waste) or, failing this, inside / next to the RWISF.

The only candidate building according to option (a) is Facility B4S – the temporary storage facility for short-lived waste stored in KTZ-3.6 containers pending their disposal in the Near Surface Repository. Assuming that the NSR enters operation in 2024 and both Facility B3 and the NSR operate as planned, Facility B4S should be emptied by 2037[11].

[10] Existing (used at INPP) containers to be considered at the first instance
[11] There is inevitable uncertainty about volume of the wastes concerned and about date when this facility will be emptied.

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Appendix 1. List of waste containers used at INPP

Designation	Present Purpose(s)	Fabrication	Waste Class(es)	Internal Volume (m^3)	External Volume (m^3)	Gross Weight (tonnes)*
Container-box	Transport box of conditionally non-radioactive waste/solid radioactive wastes of dismantling to the pre-treatment workshops	carbon steel	0 /A	0.58	0.62	1.00
К-4	Transport box of collection and transportation of luminescent lamps	stainless steel	0	0.70	1.04	0.31
К-11	Transport box of conditionally non-radioactive waste for free-release radiometry facility in building 159B	carbon steel	0	~ 0.42	-	1.62
К-12	Transport cage box of conditionally non-radioactive waste for free-release radiometry facility in building 159B	carbon steel	0	~ 0.42	-	0.58
К-13	Transport box of conditionally non-radioactive waste for free-release radiometry facility in B10 facility; Transportation of conditionally non-radioactive waste (pipes, sheet metal, valves, electric motors, pumps, electrical, lighting, ventilation and other equipment, construction waste) to Facility B10	carbon steel	0	~ 1.00	-	1.24
К-13 (reinforced)	Transport box of conditionally non-radioactive waste for free-release radiometry facility in B10 facility	carbon steel	0	0.97	-	1.49
К-14Ж	Transport drum of conditionally non-radioactive waste for free-release radiometry facilities	carbon steel	0	~ 0.20	-	0.48
К-14М	Transport drum of conditionally non-radioactive waste for free-release radiometry facilities	carbon steel	0	~ 0.20	-	0.48

K-15	Transport box of conditionally non-radioactive waste for free-release radiometry facility in building 159B; Transportation of conditionally non-radioactive waste (Pipes, sheet metal, valves, electric motors, pumps, electrical, lighting, ventilation and other equipment, construction waste) to bld. 159B	carbon steel	0	~ 0.80	-	0.97
K-16	Transport box (K-13 modified container)	carbon steel	0	~ 1.00	-	1.27
K-17	For accumulation of galvanic cells	stainless steel	0	0.06	-	0.10
Container 1 tonn	Transport Container	stainless steel	0	0.92	-	1.23
Container 10 tonn	Transport Container	stainless steel	0	7.3	-	10.56
K-19	Transport box for solid radioactive Class A waste with high bulk density, including radiological measurement	carbon steel	A	~ 1.00	1.44	3.47
K-8	Transportation of pressed bales	stainless steel	A	1.7	2.08	1.20
K-9	Transportation and collection of waste oil and oily rags	stainless steel	A	0.55	0.56	0.69
K-10	Transportation and collection of waste oil and oily rags	stainless steel	A	1.35	-	1.26
K-1	Transport container for solid radioactive waste; Collection and transportation of class A compressible waste from comp. 613, 143 (161 / 1,2) to the complex B2	carbon steel	A	~ 3.00	5.30	4.80
K-2	Transport container of solid radioactive waste (SRW)	carbon steel	A	~ 2.00	2.91	3.00
K-3	Transport container of solid radioactive waste in bulk; Transportation of compactible solid radioactive wastes of Class A to the compaction facility (Facility B2)	stainless steel	A	~ 3,10	-	6.56
K-6	Transport container of aerozol ventilation filters	carbon steel	A	0.88	~1,04	0.30

FIBC	Landfill disposal (Transportation of bulk waste of Class A (concrete rubble) to Facility B19 (Buffer Storage of Landfill Facility; collection and transportation of compactible solid radioactive wastes of Class A to the compaction unit (Facility B2)	Woven plastic fibre	A	~ 1.00	-	1.50
1CX (HHISO)	Container for transportation and storage of SRW; Landfill Disposal	carbon steel	A	15.3	19.5	24.00
1CX with doors (HHISO)	Container with doors for transportation and storage of SRW	carbon steel	A	15.3	19.5	24.00
1CC (ISO Container)	Container with doors for transportation and storage of SRW	carbon steel	A	32.8		24.00
G1	Transport cask (from Facility B2 to Facility B3)	carbon steel container with stainless steel basket	A	2.95	-	6.30
G2	Transport cask (from facility B2 and Reactor Buildings to Facility B3); Transportation of Oily rags that have radioactive contamination, to Facility B3	carbon steel container with stainless steel basket	B / C	2.95	-	9.20
G3	Transport cask (from Facility B2 to Facility B3)	carbon steel container with stainless steel basket	D / E	0.33	-	7.30
K-3-2101	Transport modified container of solid radioactive waste in drums (graphite rings and sleeves)	stainless steel	D	~ 3,10	6.35481	6.56
Drum	Interim accumulation (graphite rings and sleeves) drum; interim storage of hazardous waste (asbestos) in Facility B4	carbon steel	D / E	~ 0.20	-	0.42
K-5	Transport cask (from Spent Fuel Hot Cell to Facility B3)	stainless steel/steel parts	D / E	~ 0.06	-	6.65

K-7	Transport cask (from Spent Fuel Hot Cell filter facility to Facility B3)	gray cast iron with stanless steel parts	D / E	~ 0.16	-	~ 1.88
K-100	Transport cask (from Reactor Buildings to Facility B3) for dismantled channels waste	gray cast iron with stanless steel parts	D / E	~ 0.5	-	4.00
K-150	Transport cask (from Long-Items Segmentation Facility to Facility B3) for dismantled channels waste	gray cast iron with stanless steel parts	D / E	0.3	-	5.05
K-190	Transport cask (from Long-Items Segmentation Facility to Facility B3) for dismantled channels waste	gray cast iron with stanless steel parts	D / E	0.04	-	4.28
ILW-LL/LLS	Interim storage (in Facility B4L) of long-lived waste (as bulk or in drums) and spent sealed sources (in drums)/ transportation operations of spent sealed sources (K-100 or in drums)	carbon steel	D / E	3.24	4.08	8.00
F-ANP	NSR disposal (cemented waste)	reinforced concrete	B / C	3.7	5.8	12.8
	Accumulation of operational Pt catalyst alloy in building 158/2		0/A			9.55
	Transportation, accumulation and (graphite rings and sleeves in 8 drums) container in building 158/2		D / E			
KTZ-3.6	NSR disposal; Intermediate storage of classes B and C waste in B4S storage	reinforced concrete	B / C	3.6	6.42	15.00

*) technological factors, dose rates and activities may influence on the waste mass