Technological Solutions of SF Storage in the World

1. ACTUAL TRENDS OF SF MANAGEMENT

In the previous decades, the nuclear industry has gathered a lot of experience in operation of nuclear power plants as well as a lot of spent fuel. In the last 50 years, most part of SF has been safely stored in wet interim storage facilities. New calls for extending the service life of the existing and new storage facilities request to provide safe storage for a much longer period than the originally planned one, i.e. for a period of 100 and more years.
SF wet storage is considered an advanced technology. Dry storage has been intensively developed in particular in the last decades and at present, it is considered an advanced technology of SF storage.
Today, there are various licensed storage systems, which are built in both the European and American continents.

2. DESCRIPTION OF SF MANAGEMENT IN CERTAIN SELECTED EU AND IAEA MEMBER STATES

Selection and Substantiation of the Countries

For the retrieval, the following criteria have been selected for the selection of ten EU or IAEA countries with respect to the comparison with the adopted strategy of SF management in the Slovak Republic:

- economic maturity and size of the country;
- nuclear programme size;
- experience in VVER-440-type fuel or other LWR type fuel.

Based on the above criteria, five European Union Member States and five other IAEA member states were selected and described. The countries are mentioned and briefly described in the following table. The countries that have experience in VVER-440 type fuel, are highlighted in the table.

Annex No.4

EU			IAEA		
NPP Units in operation 65		Units under decommissioning 7	NPP Units in operation 84		Units under decommissioning 12
AR Wet storage	**FRANCE** Reworking	AFR Dry storage	AR Wet storage	**USA** Direct disposal	AFR Dry storage
NPP Units in operation 8		Units under decommissioning 11	NPP Units in operation 35		Units under decommissioning 4
AR Wet storage	**GERMANY** Deep repository	AFR Dry storage	AR Wet storage	**RUSSIA** Reworking/ Deep repository	AFR Wet-dry storage
NPP Units in operation 6		Units under decommissioning 0	NPP Units in operation 15		Units under decommissioning 0
AR Wet storage	**CZECH REPUBLIC** Deep repository	AFR Dry storage	AR Wet storage	**UKRAINE** Direct disposal	AFR Dry storage
NPP Units in operation 4			Units under decommissioning 2		
AR Wet storage		**SLOVAKIA** Deep repository		AFR Wet storage	
NPP Units in operation 4		Units under decommissioning 0	NPP Units in operation 2		Units under decommissioning 4
AR Wet storage	**HUNGARY** Planned deep repository	AFR Dry storage	AR Wet storage	**BULGARIA** Deep repository	AFR Dry storage
NPP Units in operation 4		Units under decommissioning 0	NPP Units in operation 1		Units under decommissioning 0
AR Wet storage	**FINLAND** Direct disposal	AFR Wet storage	AR Wet storage	**ARMENIA** Direct disposal	AFR Dry storage

Tab. 1 Selected countries and their brief description according to selected criteria

2.1 Description of SF Management in Selected EU Member States

2.1.1 France

2.1.1.1 Brief Description of Nuclear Programme

France has 65 active reactors, most of them are PWR type with an average supplied electrical power of about 1190 MW. The nuclear power plant Phénix situated in the South-East of the country is an exception - it owns one FBR-type reactor with a capacity of 233 MW.

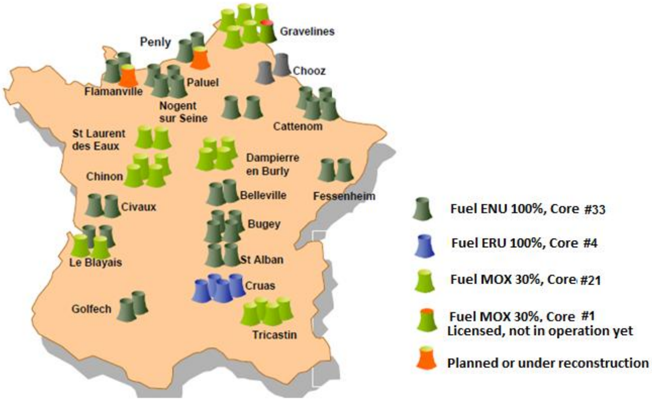


Fig. 1 Nuclear installations in France (AREVA, 2010)

2.1.1.2 SF Management Brief Description

After the removal from the reactors, SF is cooled for at least three years in the pools filled with water, which are situated in the reactor halls. Then, SF is transported by railway and by trucks to the reworking plant at La Hague. Before reworking, SF is again stored in massive cooling pools for several years. After the reworking, SF is divided into three main products: uranium, plutonium and high-level radioactive wastes. The high-level radioactive wastes are placed into the dry interim storage facility at La Hague.

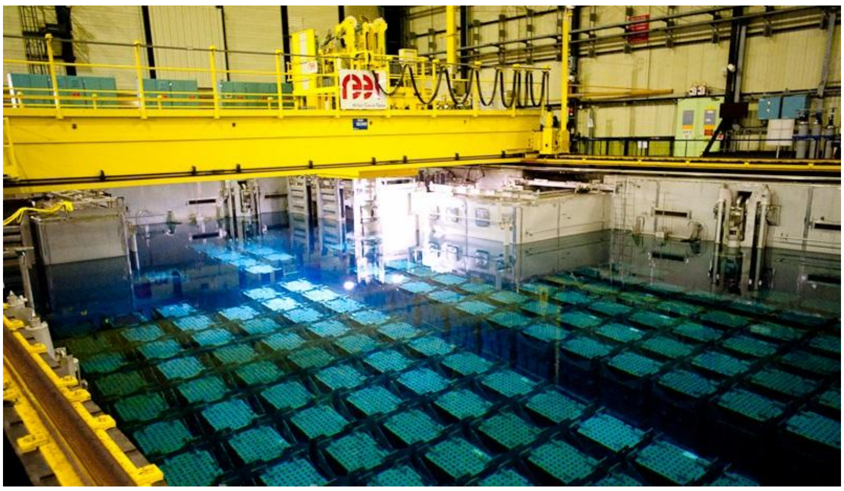


Fig. 2 Storage pools of the reworking plant at La Hague (AREVA, 2011)

2.1.2 Germany

2.1.2.1 Brief Description of Nuclear Programme

At present, Germany has eight active nuclear reactors, mostly PWR type ones with an average electric power of 1390 MW. It also has four BWR type reactors with an average electric power of 840 MW. It is necessary to mention the nuclear power plant Greifswald that transformed nuclear energy to electric energy in the period 1974-1990. *It worked with four VVER-440/V230 reactors and one VVER-440/V213 reactor*.

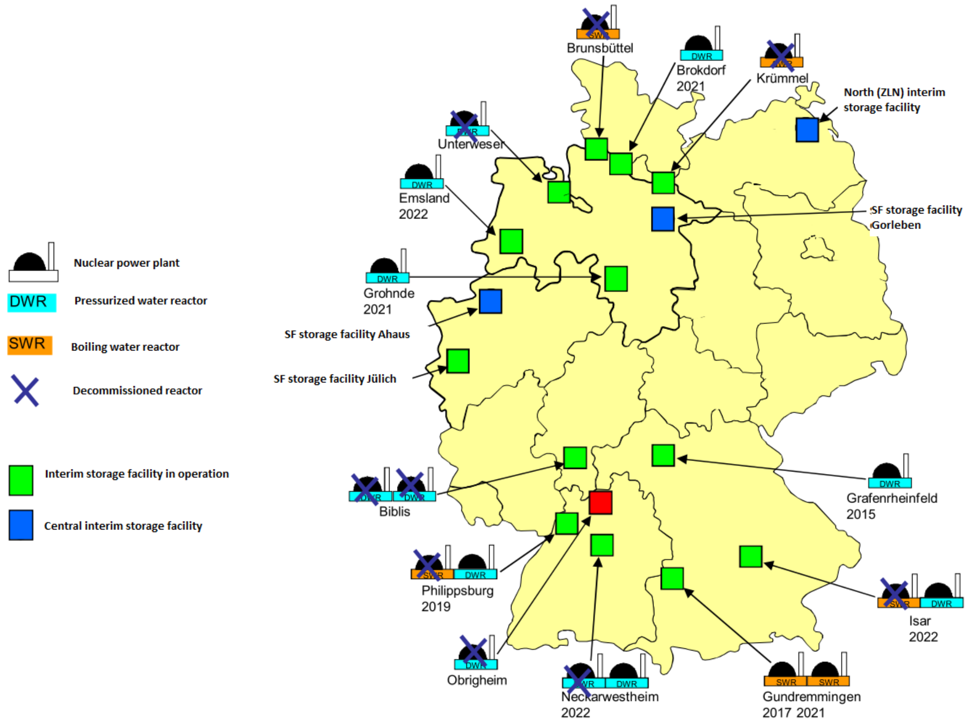


Fig. 3 Nuclear installations in Germany (Center, 2006)

2.1.2.2 SF Management Brief Description

After the removal from the nuclear reactor, SF is immersed into the interim storage facility - a pool full of water. Here it is stored for at least three years. In the interim storage facilities, fuel assemblies are placed in CASTOR type containers (HAW28M and V/19 from GNS) or TN type containers (85 and 24E from AREVA Transnuclear) and they are cooled by the surrounding air the whole time.

Fig. 4 Spent nuclear fuel storage facility in Gorleben (GNS, 2010)

2.1.3 Czech Republic

2.1.3.1 Brief Description of Nuclear Programme

There are two nuclear power plants in the Czech Republic:

- Dukovany NPP: it is situated in the South of the republic near the Dukovany municipality and it operates four VVER 440/V213 type reactors with a capacity of 500MW;
- Temelín NPP: it is situated in the South-West of the country near the Temelín municipality, each of the two Units (Temelín 1 and Temelín 2) has one VVER 1000/V320 PW type reactor with a capacity of 1013 MW.

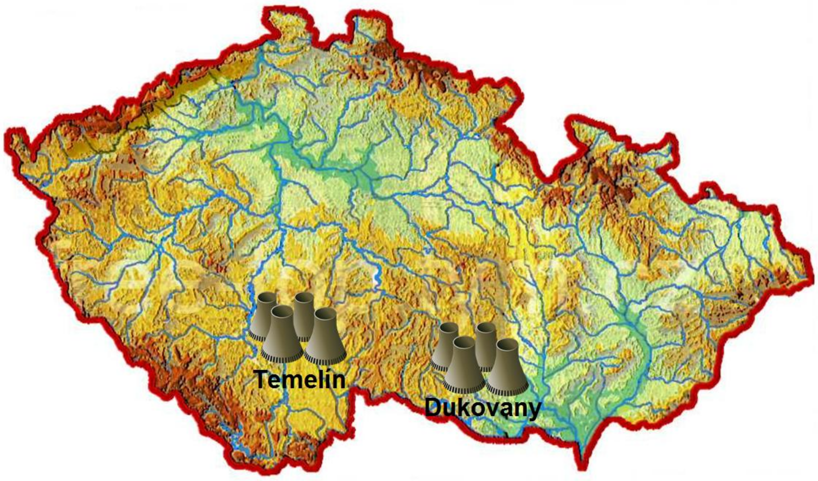


Fig. 5 Nuclear installations in the Czech Republic (ZTS VVÚ Košice a.s., 2014)

2.1.3.2 SF Management Brief Description

After the removal from the reactor, SF is transported under the water surface through a channel to the SF pool, which is situated in the reactor hall near the reactor. The fuel assemblies are stored there underwater for several years (at least for three years). Afterwards, the assemblies are put into CASTOR type metal transport and storage containers (from the company GNS) and they are transported to the dry interim SF storage facility.

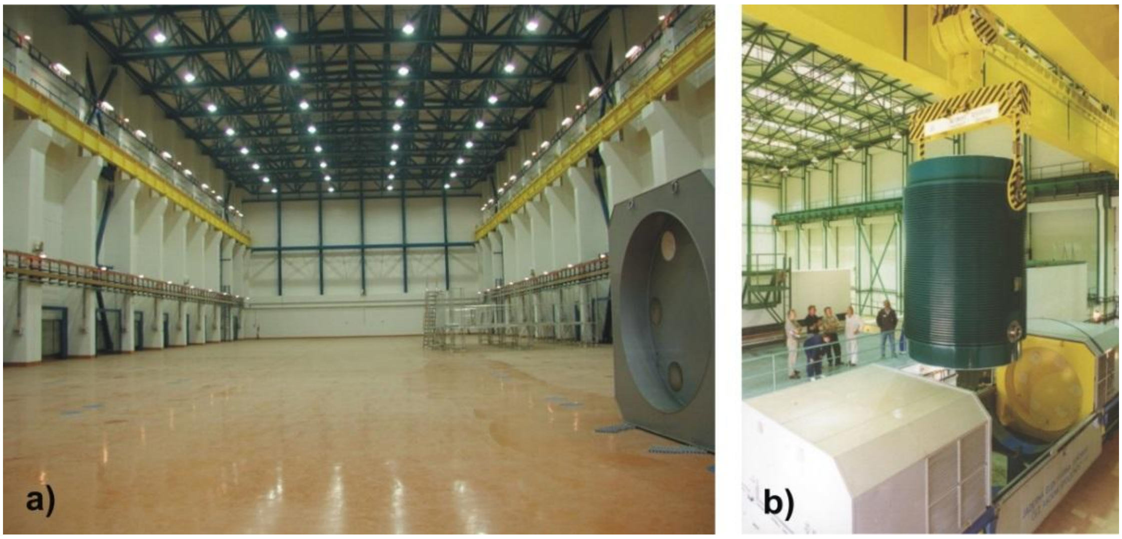


Fig. 6 Dry interim storage facility at the Dukovany NPP (ČEZ, 2012)

2.1.4 Hungary

2.1.4.1 Brief Description of Nuclear Programme

Hungary has only one nuclear power plant in the town of Paks situated in the Tolna County, approximately in the centre of the country. It has four active Units, each with one VVER 440/V213 type reactor with a capacity of 500 MW. In the future, the construction of two more Units is planned.

Fig. 7 Nuclear installation in Hungary (ZTS VVÚ Košice a.s., 2014)

2.1.4.2 SF Management Brief Description

The dry interim SF storage facility was commissioned in 1997 and it is situated near the premises of the nuclear power plant Paks, it is connected to its southern side. After the burn-up, SF is placed into the pool near the reactor, where it will remain for at least three years. Then, the assemblies are transported to the dry interim storage facility where they are dried and placed into thick-walled hermetic steel casings. Radiant heat is removed through the ventilation system. A modular vertical system of dry storage (MVDS from the company GEC ALSTHOM) is applied at Paks.

Fig. 8 Complete storage facility at the Paks NPP (RHK, 2009)

2.1.5 Finland

2.1.5.1 Brief Description of Nuclear Programme

Finland has four active reactors, two of them are VVER 440/V213 type reactors (supplying a power of 510 MW) and two are BWR type reactors with a capacity of 860 MW.

Fig. 9 Nuclear installations in Finland (POSIVA, 2012)

2.1.5.2 SF Management Brief Description

After the removal from the reactor, the fuel assemblies are placed into the pools in the reactor hall, where they will remain for several years (at least three years). Then they are transported in transport containers to the interim storage facility, where they are stored in water-filled pools for 40 years.

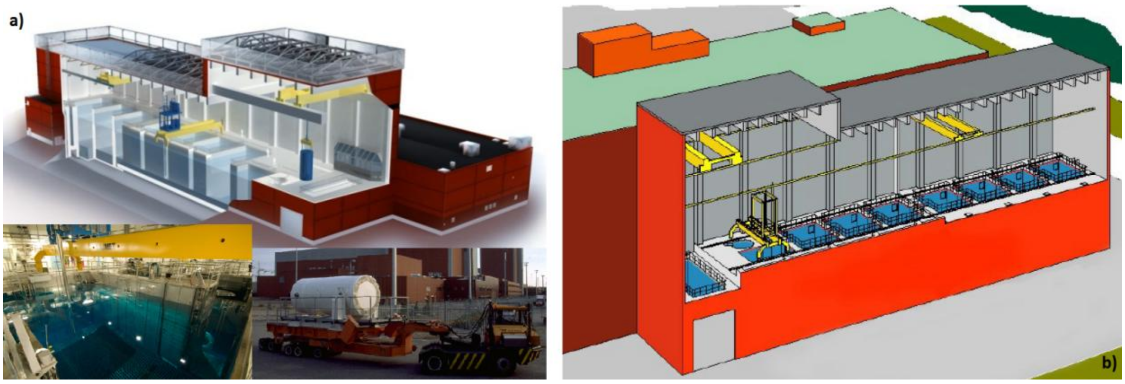


Fig. 10 Interim storage facility at the Olkiluoto NPP (on the left) and at the Loviisa NPP (on the right) (POSIVA, 2013)

2.2 Description of SF Management in Selected IAEA Member States

2.2.1 United States of America

2.2.1.1. Brief Description of Nuclear Programme

The United States dispose of total 84 active reactors. They are mostly PWR type reactors with an average electric power of 1050 MW, then BWR type reactors with an average electric power of 957 MW and at the Hope Creek NPP, New Jersey, one GE-5 reactor is operated with an electric power of 1059 MW.

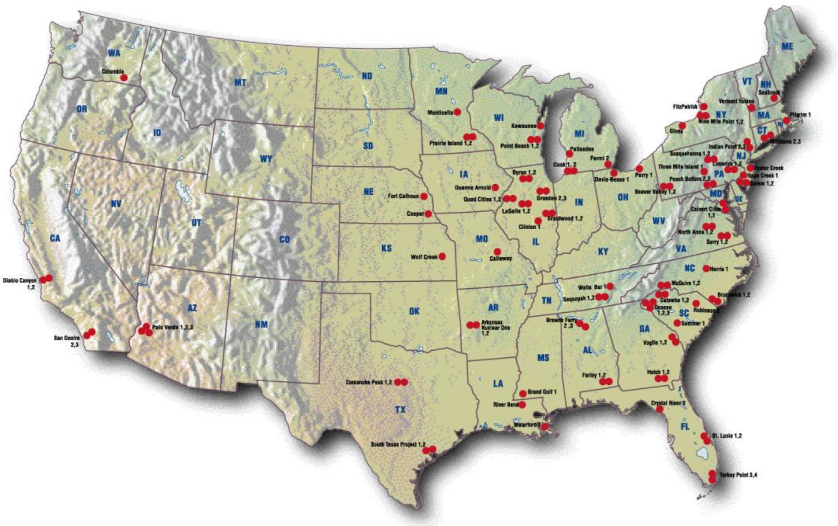


Fig. 11 Nuclear installations in the USA (WNA, 2013)

2.2.1.2 SF Management Brief Description

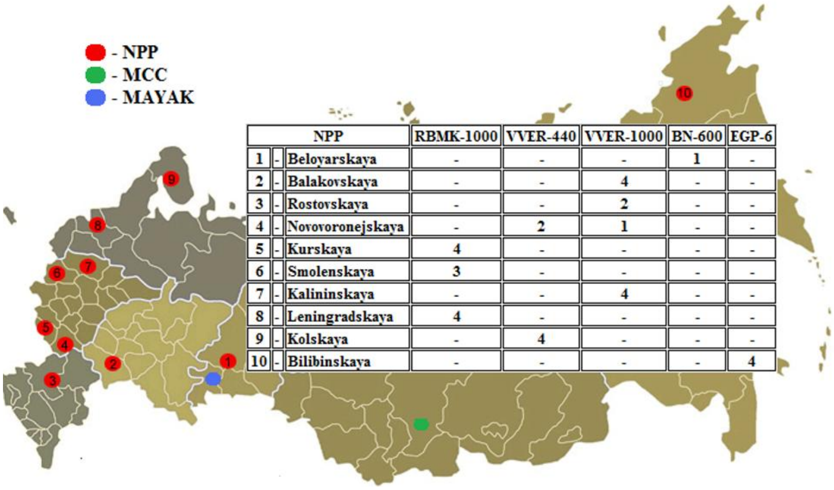
In the United States, spent nuclear fuel is considered nuclear waste. At present, almost all SF remains on the premises of nuclear power plants. When the cooling pools at the NPP are completely full, the oldest fuel assemblies are relocated to air-cooled storage containers that are placed in an open area.

Fig. 12 Open interim storage facility at the Vermont Yankee NPP (Toby Talbot/AP/File, 2010)

2.2.2 Russia

2.2.2.1 Brief Description of Nuclear Programme

Russia has 35 active nuclear reactors, six of them are VVER-440 type reactors (two of them V230, two V213 and two V179). There are eleven VVER-1000 type reactors and the other reactors are RBMK-1000, BN-600 and GBWR-12 or EGP-6.



		NPP	RBMK-1000	VVER-440	VVER-1000	BN-600	EGP-6
1	-	Beloyarskaya	-	-	-	1	-
2	-	Balakovskaya	-	-	4	-	-
3	-	Rostovskaya	-	-	2	-	-
4	-	Novovoronejskaya	-	2	1	-	-
5	-	Kurskaya	4	-	-	-	-
6	-	Smolenskaya	3	-	-	-	-
7	-	Kalininskaya	-	-	4	-	-
8	-	Leningradskaya	4	-	-	-	-
9	-	Kolskaya	-	4	-	-	-
10	-	Bilibinskaya	-	-	-	-	4

Fig. 13 Nuclear installations in Russia (IAEA, 2006)

2.2.2.2 SF Management Brief Description

After the burn-up, SF is placed into the pool near the reactor, where it will remain for at least three years. Then, SF from VVER-440, BN-350 and BN-600 reactors is transported to the reworking plant. After the reworking, uranium is obtained that is used in thermal neutron reactors (VVER-440, VVER-1000, RBMK-1000) and plutonium that is used in fast neutron reactors (BN-350, BN-600). After conditioning, the radioactive waste is transported into a deep repository. Other process takes place for SF from RBMK-1000 reactors. After at least three years of cooling in the pools near the reactors, the SF is transported to interim storage facilities.

Fig. 14 Reworking plant RT-1 (Rosatom, 2009)

2.2.3 Ukraine

2.2.3.1 Brief Description of Nuclear Programme

Ukraine owns 15 active reactors, mostly VVER-1000 type ones. The Rivne NPP in the North-West of the country works with two VVER-440 type reactors (one of them with a capacity of 361 MW and the other one 384 MW).

Fig. 15 Nuclear installations in Ukraine (INS, 1999)

2.2.3.2 SF Management Brief Description

At the Zaporizhzhya NPP, SF is in storage pools for at least three years, from there it is transported to ventilated vertical concrete storage containers placed on a concrete foundation. SF from VVER-440 produced at the Rivne NPP is transported to Russia for reworking. The fuel assemblies from VVER-1000 from the power plants Chmelnycky, Rivne and Southern

Ukraine are stored in Russia, which costs Ukraine about 100 mil. dollars per year. That is why the construction of a central dry interim storage facility at Chernobyl was approved.

Fig. 16 Interim storage facility at the Zaporizhzhya NPP (Energoatom, 2010)

2.2.4 Bulgaria

2.2.4.1 Brief Description of Nuclear Programme

At present, Bulgaria has the only one operating nuclear power plant Kozloduy in the North of the country with two VVER-1000 type reactors in operation. It also owns *four VVER-440 reactors* that are out of operation today.

Fig. 17 Nuclear installation in Bulgaria (INS, 1999)

2.2.4.2 SF Management Brief Description

In May 2011, a dry interim SF storage facility was open at the Kozloduy NPP. After the removal from the storage pool at the power plant units (after at least three years), SF is transported to the interim storage facility, where it will be stored for 50 years in CONSTOR type containers.

Fig. 18 CONSTOR type containers in the interim storage facility Kozloduy (IAE, 2005)

2.2.5 Armenia

2.2.5.1 Brief Description of Nuclear Programme

Armenia has one nuclear power plant Metsamor in the West with two VVER-440 type reactors, one of them was shut down already in 1989.

Fig. 19 Nuclear installation in Armenia (INS, 1999)

2.2.5.2 SF Management Brief Description

A dry interim SF storage facility is in operation in the Metsamor power plant. Fuel assemblies in metal hermetic canisters are transported from the cooling pools in the reactor hall to concrete storage modules.

Fig. 20 NUHOMS system at the Metsamor NPP (AREVA, 2011)

3. GENERAL DESCRIPTION OF DRY SF STORAGE TECHNOLOGY TYPES

This chapter describes the available storage and transport packaging sets of various versions intended for dry storage, divided according to the design and purpose of application. All the packaging sets must provide sufficient physical protection against external impacts, biological protection against ionising radiation and residual heat removal usually through the passive system, i.e. natural circulation of the surrounding air around the canister of container surface. In specific cases of underground packaging sets, the air is conducted through a system of special channels. The following table shows various most frequent methods of dry storage.

Type	Heat transmission	Packaging set	Shielding	Application	Example
Metal container (cask)	Conduction through the body wall	Double lid system with metal sealing and inert gas in the cask	Metal wall	Two-purpose packaging set	CASTOR, TN,
Concrete	Air	Welded	reinforced	Vertical	TSC,

container (silo)	circulation around the canister	canister, inert gas in the canister	concrete, concrete with steel sheathing	placing of fuel assemblies	CONSTOR, HI-STORM, HI-STAR
Concrete module	Air circulation around the canister	Sealed canister, inert gas in the canister	Concrete wall	Horizontal placing of fuel assemblies	NUHOMS, MPC-UMS, MAGNASTOR
Vault	Air circulation around the box	Box, intert gas in the box	Concrete wall		MVDS, MACSTOR, CANSTOR
Tunnel (channel, shaft, well)	Conduction through soil	Canister with inert gas	soil	Underground storage	

Tab. 2 Types of dry storage sets

The basic differences between the packaging sets in Europe and in America consist in the consideration of the fuel reworking possibility. Based on the design of the packaging sets, they are divided into containers:

- on the basis of canisters – they contain a hermetically closed canister, which provides tightness and resistance as well as subcriticality, (Holtec - MPC systems, NAC - TSC systems, TN - DSC systems);
- on the basis of casks (without canister) – they contain an open fuel basket and the hermetic tightness is provided by a special system of container lids (GNS – CASTOR, CONSTOR).

The following figure shows the transport and storage container on the basis of casks (AREVA TN) and a storage canister-based container (HOLTEC HI-STORM).

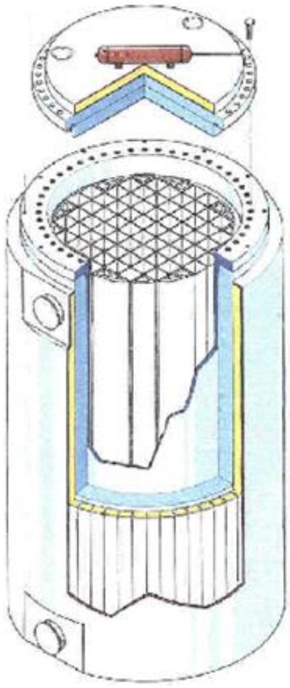
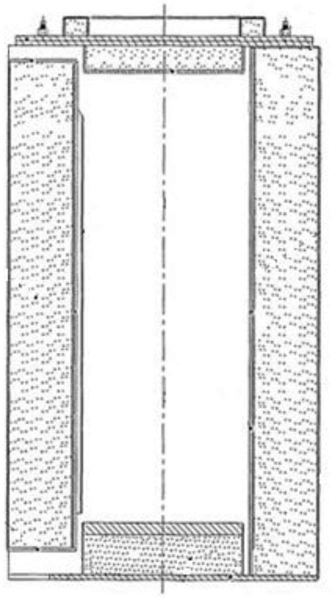



Fig. 21 Vertical storage container with screwed lid and with welded lid

In comparison with the cask-based systems, the systems on the basis of welded canisters do not require canister tightness monitoring during storage. However, they do not allow an easy access to check the fuel assemblies, necessary, for example, in case of storage before fuel reworking.

The design of the packaging set bodies as well as of the closure systems are various. The following figure shows an example of canister storage in a horizontal storage module with screwed lid and in a vertical storage module with welded lid.

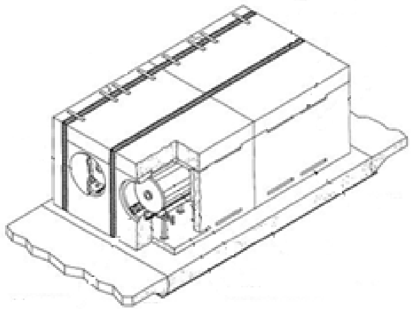
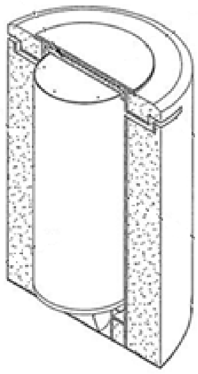



Fig. 22 Concrete storage module with screwed and welded closure

3.1 The Most Frequently Used Packaging Sets for Dry Storage of SF

The below text describes the most frequently used currently certified packaging sets according to the producer.

3.1.1 CANDU

MACSTOR – modular air-cooled silo-type storage system for fuel from PHWR reactors using natural uranium. It consists of reinforced ferro-concrete modules in two versions – module 200 and module 400. Every module contains 20 metal boxes, each for 10 casks with spent fuel. The fuel basket is made of stainless steel. The designed service life of the module is 50 to 100 years.

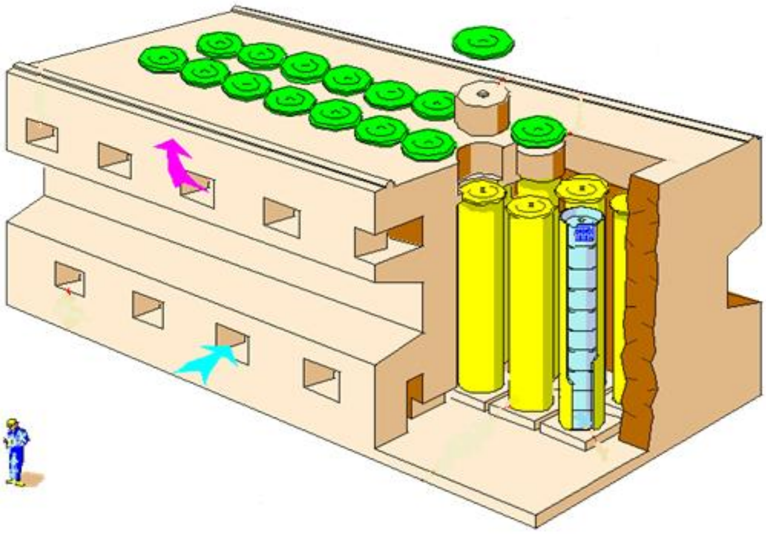


Fig. 23 MACSTOR 400 system principle (CANDU, 2013)

3.1.2 Energy Solution

In 2006 the company purchased BNG FuelSolutions and became licence holder for VSC-24 canisters. These are used in the USA. It is a system of concrete containers for 24 PWR type fuel assemblies. The basis is a multi-purpose steel welded canister equipped with CarboZinc paint a placed in a vertical concrete container. Natural air circulation cooling is provided by four input and four output openings. The container provides a sufficient biological protection.

Fig. 24 VSC-VVER, Zaporizhzhya – Ukraine

3.1.3 GEC ALSTHOM – (under licence of Foster Wheeler Energy)

MVDS is a system of vertical dry fuel storage in storage hermetic boxes filled with inert or active gas (helium, nitrogen, carbon dioxide) under a so-called modular vault. Heat is removed by the air flow entering through a channel and the heated air exits through the exhaust stack. Biological proterction is provided by the vault-type concrete structure.

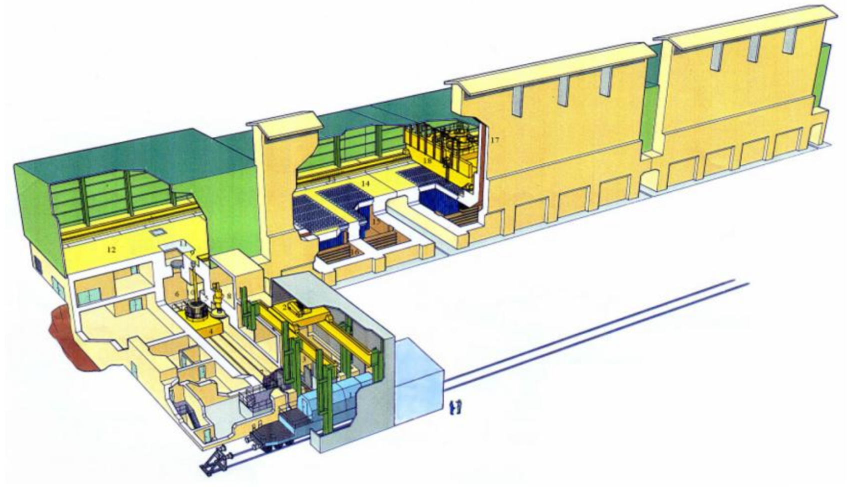


Fig. 25 MVDS system principle

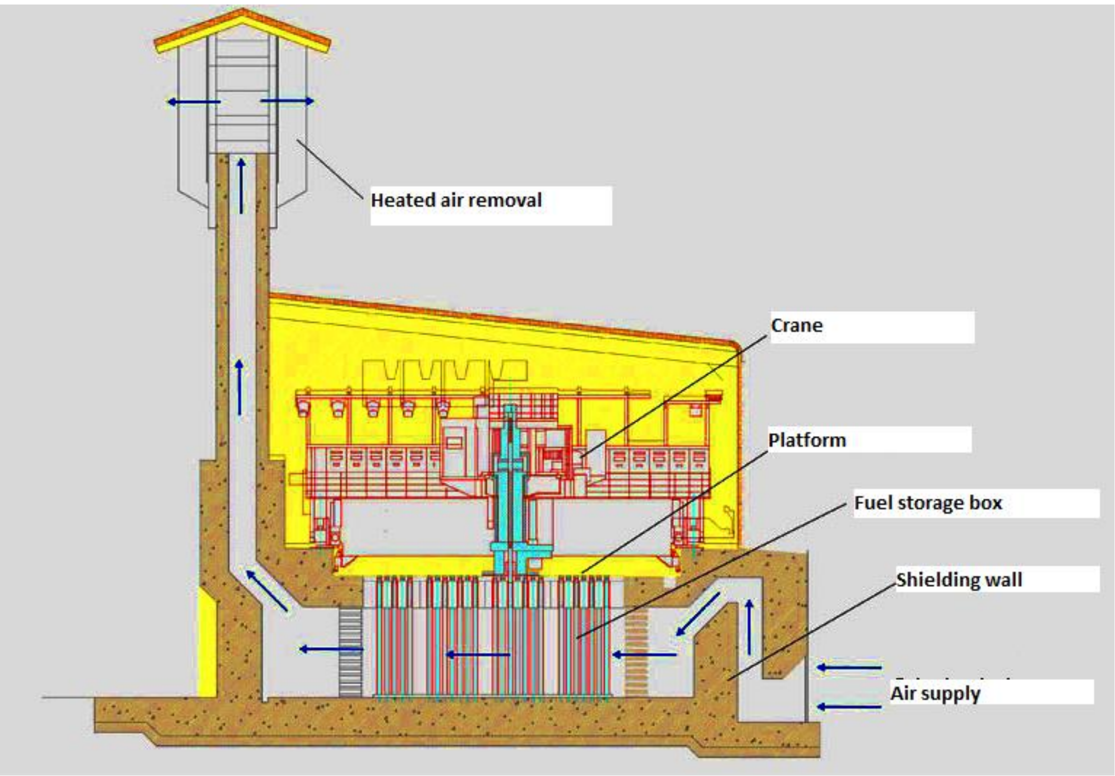


Fig. 26 MVDS, Paks (RHK, 2008)

The MVDS was designed from the very beginning in a way as to withstand the thermal load produced by the fuel assemblies immediately after the removal from the reactor. Fuel can be placed in the MVDS system already after five years of cooling in the wet storage facility and it can be stored for at least 100 years.

The fuel storage boxes used for the MVDS system are either containers (FSC) for the storage of several fuel assemblies (Great Britain, USA) or tubes (FST) for the storage of one fuel assembly (Hungary). These are essential round-shaped tubes made of carbon steel, on both ends they are equipped with flanges, to which the upper and lower lids are connected by means of O-rings. In case of handling, a protective plug is connected to the upper lid, which, during container storage, is placed in the storage module above the canister.

3.1.4 General Nuclear Systems

CASTOR is a two-purpose transport and storage metal container. The thick-walled vessel is made of 25 to 45 cm thick ductile iron. It is sealed by a couple of stainless steel lids screwed by means of elastomer and metal sealing. Shielding is provided by a cast-iron wall along with polyethylene rods inserted in the container walls. The external surface is equipped with ribs for better heat transfer. The interior contains a basket for fuel assemblies. It is made of boron stainless steel. The internal surface is nickel-coated and the external surface is equipped with resistant epoxy coating. Four pins are used for handling. The container includes a system of pressure sensing in the interspace between the primary and secondary lids (tightness monitoring).

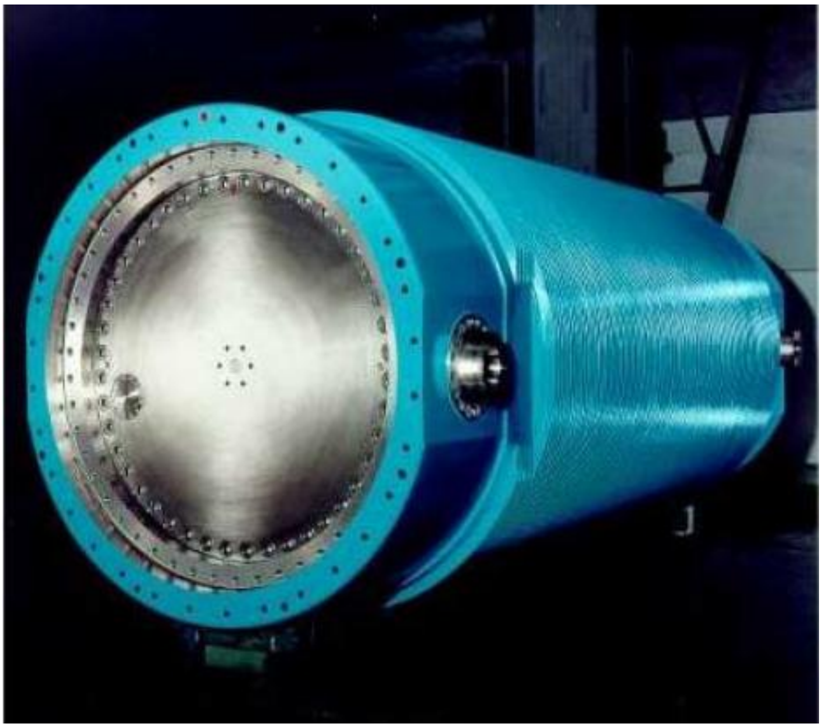


Fig. 27 CASTOR® 440/84M (GNS, 2011)

CONSTOR is a concept based on the current period of cheaper transport and storage containers. The sandwich-type body has an internal stainless steel layer, an external layer made of fine-grained carbon steel and the interspace is filled with heavy concrete with the name CONSTORIT (cement + metal granulate). The fuel basket is made of stainless steel and borated aluminium. The closing system consists of a couple of stainless steel lids and the space between them is filled with helium. Due to the high thermal load on the container and for sufficient heat conduction, reinforcement is inserted in the CONSTORIT layer to conduct heat to the external surface of the container.

Fig. 28 CONSTOR® (GNS, 2011)

Fig. 29 CASTOR® at the Dukovany storage facility in the Czech Republic (CEZ, 2011)

3.1.5 NAC International

STC – a metal storage container is produced from a multilayer jacket, where the internal (3.8 cm thick) and external layer (6.7 cm thick) are made of stainless steel. The interlayer is from chemical lead 8.1 cm thick. The internal and external jacket are mutually connected on their ends by sealing rings and stainless steel plates. The upper end of the cask is closed by a lid with a detachable screw joint.

Fig. 30 NAC MPC system at YANKEE ISFSI (Hoedeman, 2008)

3.1.6 Holtec International

The packaging sets are based on the system of multi-purpose canister with the designation MPC. It is a welded cylindrical canister with a basket for fuel storage. It consists of a jacket, basic plate, lid and closing ring. All MPC components are made of aluminium alloys (neutron absorber) and stainless steel.

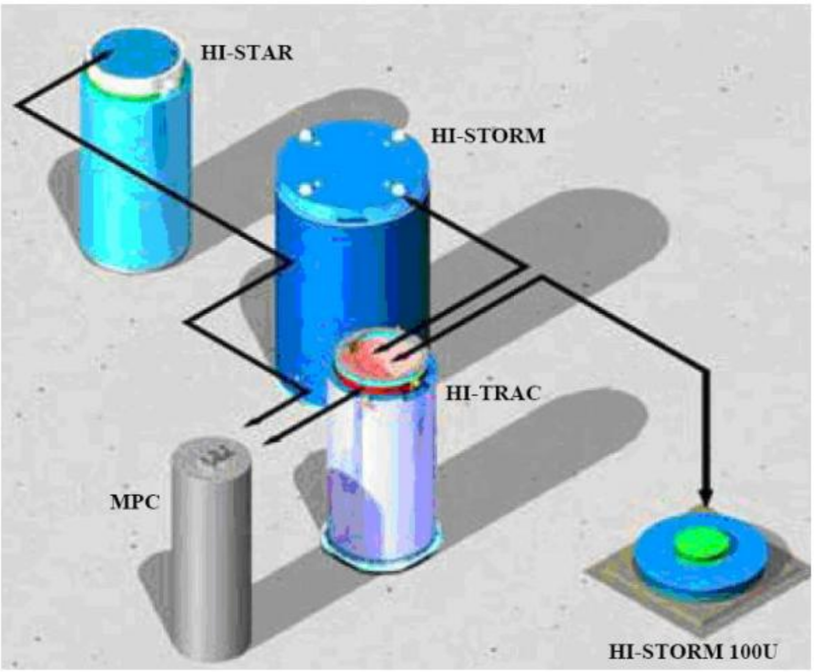


Fig. 31 Holtec MPC system (Holtec, 2011)

The HI-STORM system is a storage concrete container intended for SF storage in a multi-purpose canister (MPC) in vertical position. The ferro-concrete package provides biological protection as well as protection against external influences. The container lid contains four cooling air outlets and the body contains four inlets in the lower part for natural cooling air circulation. The packaging set can be placed on a seismically resistant concrete storage surface.

Fig. 32 HI-STORM 100 at the ASCO NPP (Holtec, 2013)

HI-STAR – a transport and storage container intended for multi-purpose canister (MPC). It is a thick-walled cylindrical forged vessel with welded bottom. The internal surfaces have a specific shape for canister placing. The container is filled with helium and closed by a bolted lid.

Fig. 33 HI-STAR, Dresden – United States of America

3.1.7 Transnuclear Inc. (AREVA)

The metal containers designated by the TN abbreviation (TN-24, TN-32, TN-40, TN-68) are metal transport and storage packaging sets for PWR and BWR fuel assemblies storage. They are designed on the principle of two-purpose packaging sets.
The container body consists of a vessel with screwed lid, fuel basket, shielding layer, pins, pressure monitoring and protecting cover. The lower part of the body is represented by a welded steel structure with an external carbon steel package around it.

Starting from 2014, metal storage passive-type containers with vertical storage of closed welded canisters with the name TN® NOVA will be supplied to Switzerland. It is a new patented system with a metal matrix (a composite called MMC) and shielding made of steel sheets and resin plates. Another type of metal container, TN® DUO, is under development.

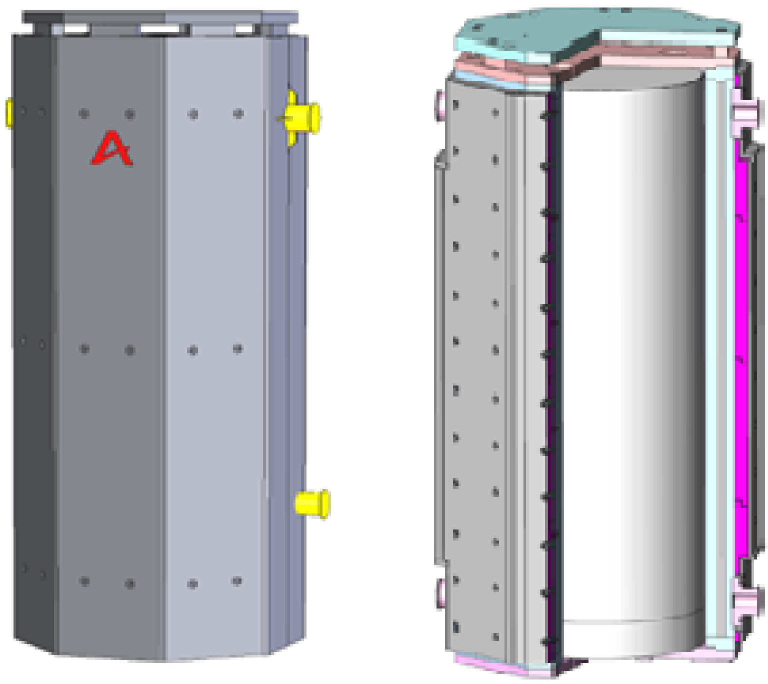


Fig. 34 TN® NOVA (AREVA, 2013)

NUHOMS storage system is a dry storage technology for PWR, BWR and VVER type fuel in concrete horizontal modules. The main component is a dry shielded canister (DSC) made of stainless steel, with an internal basket, a horizontal storage module (HSM) providing physical and biological protection and a transport package serving for DSC transportation to the HSM.
The DSC consists of a box with an integrated lower covering plate, lower shielding plug, guiding ring, upper shielding plug, upper covering plate and the fuel basket providing subcriticality and support during the loading of fuel assemblies. The HSM is a ferro-concrete unit with openings placed in the upper and lower parts intended for air circulation.

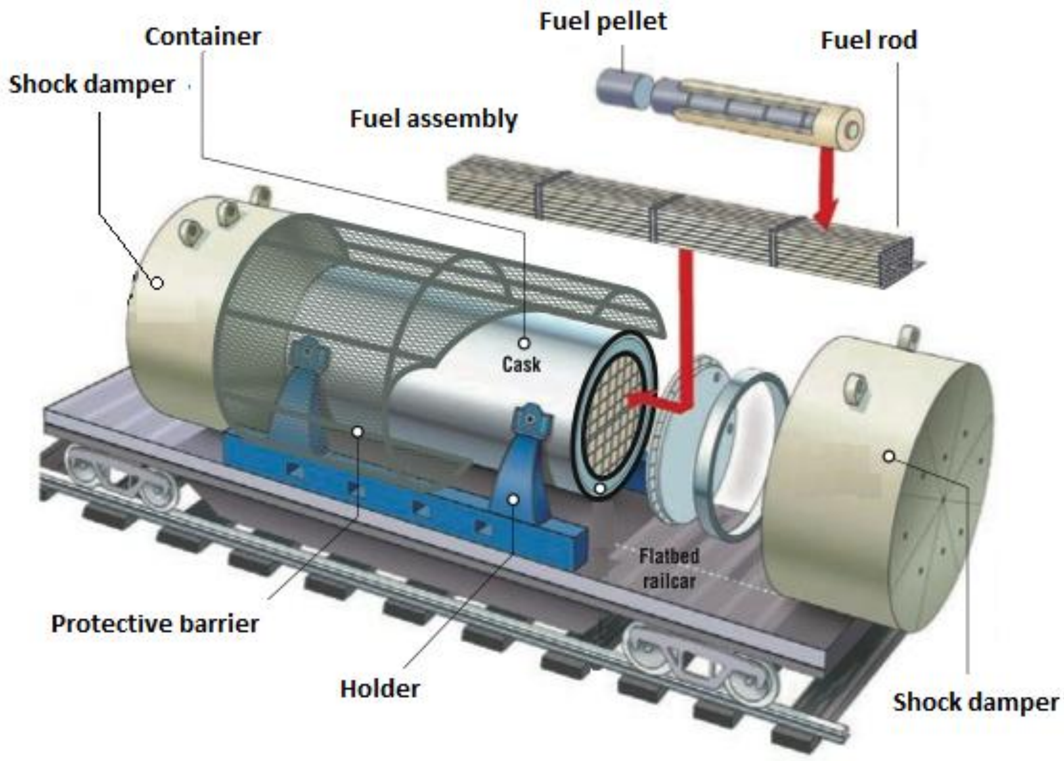


Fig. 35 HSM system diagram (Transnuclear, 1998)