Proceedings of the 17th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

SIGRID –THE FIRST PART OF THE RENEWAL OF THE SWEDISH TRANSPORT SYSTEM

Jenny Holmström
Project Manager Transports
Swedish Nuclear Fuel and Waste Management Co (SKB)

1 Abstract

After more than 25 years of successful operation Swedish Nuclear Fuel and Waste Management Company (SKB) late 2010 took the first step of the renewal of the transport fleet in Sweden by signing a new building contract for a new INF-3 ship.

The renewal programme will continue until 2020 when SKB in addition to the new ship, also expects to have replaced also the transport casks for transport of spent fuel and the terminal vehicles which are used for the local transports to and from the harbours.
In writing moment the new building project only have a few weeks until delivery and the start of operation of the ship, named Sigrid, is expected in fall 2013.

SKB has in close cooperation with the building yard, the Swedish Transport Agency and the Classification society designed the INF-3 ship to fulfil the needs of SKB and the Swedish Nuclear Power Plants for the next 30 years.

The ship has an extensive and optimized radiation shield to minimize the yearly dose to the crew of the ship. The radiation shield consists of approximately 700 tonnes of concrete, steel and polyethylene. To both the concrete and polyethylene boron has been added in order to improve the shielding.
In addition to the extensive and heavy radiation shield the ship for example has an extra high freeboard height to increase security. To achieve these two key (radiation protection and security) features and still fulfil the stability criteria for the ship have been a great challenge for the Naval Architects.

The paper will give a general overview of the key features of the new Swedish INF-3 ship. The paper will include a description of the radiation shield on the ship and an overview on how security issues have been considered in the design of ship.

2 Introduction to SKB

Nuclear power companies in Sweden jointly established the Swedish Nuclear Fuel and Waste Management Company (SKB) in the 1970s. SKB's assignment is to manage and dispose of all radioactive waste from Swedish nuclear power plants in such a way as to secure maximum safety for human beings and the environment. Twelve nuclear power reactors have been built in Sweden and ten of them are still in operation.

SKB is responsible for a system of facilities used to handle all waste from the Swedish nuclear power plants. These facilities today include a central interim storage facility for spent nuclear fuel (Clab) near Oskarshamn, and a final repository for short-lived radioactive waste (SFR) in Forsmark. In figure 1 an overview of all existing and planned facilities in the Swedish system for waste management is described.

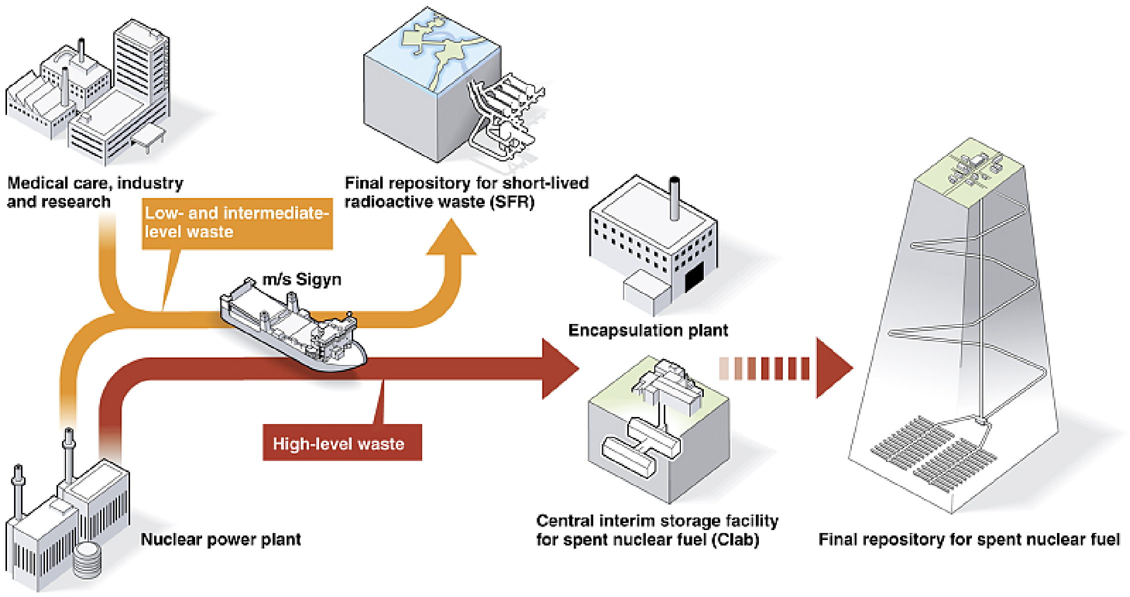

Figure 1 The Swedish system for management and disposal of radioactive operational waste and spent nuclear fuel. The encapsulation plant and the final repository for spent nuclear fuel are not yet constructed. The other plants are already in operation.

Nuclear fuel from all Swedish nuclear power plants is stored at SKB´s interim storage facility, Clab, in two storage pool systems 30 metres down in the bedrock. Today approximately 5,000 tonnes of spent nuclear fuel are temporarily stored in the facility. This is done with constant supervision and control. The facility has been extended since the millennium shift and has a current total capacity of 8,000 tonnes.

After radioactivity decrease and cooling in interim storage, the spent nuclear fuel is ready for encapsulation and will be transferred to SKB's coming encapsulation facility and placed in impermeable copper canisters with ductile iron inserts. They will subsequently be transported to the final repository that SKB is planning to build in Forsmark. The canisters with the spent fuel will then be lowered into a system of horizontal tunnels, at a depth of about 450 metres in the crystalline bedrock.

The radioactive waste from nuclear power plants consists largely of low- and intermediate-level operational waste, such as used protective clothing and replaced parts from the power plants. The waste is deposited in rock vaults at our Forsmark facility (SFR).
The Forsmark facility was commissioned in 1988 and was the first of its kind in the world at that time. This waste is packaged in metal or concrete containers and stored at a depth of 50 metres in rock vaults that are kept under surveillance. After approximately 500 years most of the radioactivity from this waste is gone.
In the future it will also be necessary to handle the waste, such as the scrap metal and construction material, that is generated when nuclear power plants are decommissioned. An extension of SFR is in the planning stages and expected to be operational by 2023. The final repository including the extension will have a waste storage capacity of 200,000 cubic metres.

3 The Swedish Transportsystem

All Swedish nuclear power plants are located along the coast and have their own harbours. Therefore radioactive waste and spent nuclear fuel are mainly transported by sea in Sweden. To efficiently perform the transports of the spent fuel and waste from the nuclear power plants to the storage facilities a transport system with its key components: ship, transport casks and vehicles was created 30 years ago.

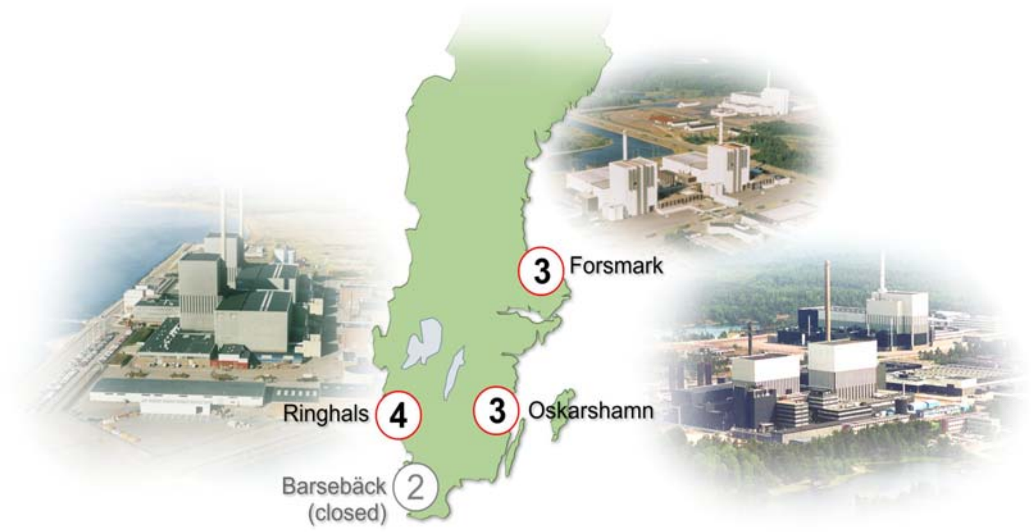

Figure 2 All Swedish Nuclear Power Plants are located along the coast

Main components of the Swedish Transport system are;

- 1 INF-3 ship
- 5 vehicles for local transport to and from harbours
- 10 transport casks with frames for spent nuclear waste (TN 17)
- 2 transport casks with frames for reactor internals and control rods (TN 17cc)
- 28 transport casks with frames (5 different types) for low and intermediately level waste.
- 10 TEU containers

All components of the Transport system including the INF 3 ship are owned by SKB. For operation and crewing of the ship SKB have contract with a management company but all planning of transports and maintenance of casks are done by SKB.

SKB will replace its current fleet of transport casks for spent fuel, which were built 1982-1984, as soon as possible. The new fleet will, as the current, be part of SKB's sea and land transport system. The new cask fleet will be used to transport the spent fuel and ideally also core components. A feasibility study has been done to determine what is possible to achieve regarding technical solutions but also to determine what the best alternative would be for SKB and the nuclear power plants.

The vehicles that are special designed and used for the short land transport between the nuclear power plants and the harbours and between SKB facilities and the harbours was delivered between 1982-1989. SKB have started with preliminary studies in order to plan for the renewal of also the vehicles.

Sigyn, the first INF-3 ship owned by SKB, was built in France and delivered to Sweden in 1982. After over 25 years of successful operation the board of SKB finally in November 2010 took the decision to replace her with a new and improved INF-3 vessel.

4 The new INF-3 ship

The successor of Sigyn is named Sigrid and was built in Galati, Romania by Damen Shipyard. Contract was signed in December 2010 and the system design started in January 2011. Nine month later the steel work started and in October 2012 the vessel was launched in to the water of Danube River, 200 km from the Black sea. In writing moment the vessel will be handed over to SKB within a few weeks and after that, during fall 2013, operation in the Swedish Transport System will start.

4.1 What is an INF-3 ship?

All aspects of a ships construction, equipment, manning and operation must comply with domestic and international regulations. Since 2001 the INF-code (International code for the Safe Carriage of packaged irradiated Nuclear Fuel, Plutonium and High Level waster on Board ships) is mandatory for ships transporting radioactive material. Depending of the activity and amount of radioactive material the INF-code stipulates three different categories INF-1, INF-2 and INF-3 where an INF-3 ship can carry irradiated nuclear fuel, high level radioactive waste and plutonium with no restriction on the aggregate radioactivity of the material.
An INF ship need to fulfil special criteria's, on top of normal regulations for ships, regarding:

- Damage stability
- Fire protection
- Temperature control of cargo spaces
- Cargo securing arrangements
- Electrical supplies
- Radiation protection equipment
- Structural strength
- Management, training and emergency plans

4.2 Why did SKB need a new ship?

After 25 years of successful operation of the first INF ship of SKB, Sigyn SKB made extensive feasibility studies on the technical and economical disadvantages and advantages on doing major reinvestment in the old ship or building a new ship. It was not an easy choose to justify a new building only based on cost. But since the feasibility studies also showed that it never would be possible to achieve a ship fulfilling SKB wishes and new regulations on security and environmental performance without building a new vessel SKB managed to get the board to take the decision.

Figure 3 Sigyn – The old INF-3 ship of SKB

Figure 4 Sigrid – the new INF-3 ship of SKB

4.3 How should we design the new ship?

The operation and design of the old INF-3 ship, Sigyn, has been very successful and effective. There for SKB in principle have used her as the baseline for the new INF-3 ship. No major changes have been done to that affects loading, unloading or tie down of the cargo.

Summary of the basic requirements from SKB on the new ship

The ship shall be an INF-3 ship
Even if the future transports in the Swedish system and the characteristic of the spent nuclear fuel carried will only need an INF-2 ship SKB wanted to fulfil the requirement of INF-3 to achieve full flexibility in the future.

The ship shall be both Ro-Ro and Lo-Lo and have a clear height of 7 m. The flooring of the cargo hold should be totally flush.

Even if SKB always use the stern ramp (Roll on -Roll off) for loading and unloading the ship we once again wanted the full flexibility to also have lift on - lift off function of the ship to be able to take contract cargo and large non- or very low-active components from the nuclear power plants. All lashing fittings are removable which is a beneficial both when SKB is having exhibitions for the public in the cargo hold and when taking contract cargos.

The capacity of the cargo hold shall be at least 8 casks
A capacity study showed that 8 positions for cask would be more than enough for the Swedish Transport System.. The old ship, Sigyn, has 10 positions for casks but seldom more than 4 of them are used. After basic design of the new ship we ended up with 12 positions of which 8 fulfil INF-3 criteria's and 4 fulfil INF-2 criteria's. The main reason for adding on 4 casks was that the combination of a clear height of 7 m and 8 casks (a shorter ship) couldn't be achieved due to stability reasons.

The ship should have a basic design that contributes to the security of the ship.
Focus should be on design a simple and robust ship which fulfils basic security demand. The freeboard height, exterior design and layout are impossible or very costly and difficult to re-build later. Technical security related systems and administrative procedures can always be upgraded or installed later.

The crew should have a good working environment from the viewpoint of radiation
The cargo hold has a comprehensive and customized shielding against residential areas and workplaces.

The ship should have good ice going properties
As the Baltic Sea is largely covered by ice during the winter the ship must be safe to operate in ice. The ship will not break thicker ice on its own but meets Ice class 1A (Swedish-Finnish) and can safely sail in broken ice after a icebreaker and on its own break up to a thickness of at least 0.5 m.

The ship should have very good redundancy and a completely separated propulsion system
Many systems onboard are doubled or tripled to ensure redundancy. Sometimes different brands (especially for navigation and communication) equipment are used to reduce risk of systematic failures. The ship has two completely separate engine room with two engines each and totally separated cable ducts. All four engines can produce electricity and the ship can safely be sailed to harbour with only one engine.

The ship should be at the forefront when it comes to environmental performance
The ship has a catalytic converter and runs on low sulphur diesel. All fuel and oil tanks are protected by the double hull. Hydraulic system has been avoided almost completely and the ship is equipped with the world's first electrically powered stern ramp. Sewage and waste systems are designed so that everything is pumped ashore and treated in land-based facilities instead of being discharged into the sea. The vessel is equipped with ballast water treatment. The arrangement with four engines smaller engines instead of two more powerful will give the ship great possibility to sail in low speed and still use the catalytic converter.

The ship should have good manoeuvrability
The five harbours that the ship regularly traffic are small and shallow therefore requires very good manoeuvrability of the ship. The ship has also, for security reasons, high freeboard and hence a large windbreak. Therefore, the ship is equipped with two relatively large spade rudder and two powerful thrusters.

The ship should be an attractive workplace and provide a good working environment
Besides being protected from radiation, great efforts have been put into creating comfortable and spacious areas for the crew including recreation areas, cabins and mess room.

5 Radiation protection and security implemented in the basic design of the ship

5.1 The radiation shield

The requirements from SKB were that the shielding should be designed to manage the following dose rates with a conservative data for the cargo;

- max. 0,1 - 1 μSv/h at the bridge and deckhouse
- max.5 - 10 μSv/h in machinery spaces

SKB have chosen to install a concrete shield around the cargo hold. Part of the lo-lo cargo hatches (ceiling of the cargo hold and the stern ramp are not protected. In addition to the concrete, polyethylene has been used to improve the shielding.

The new ship is equipped with instrumentation for monitoring dose rates and measurements of airborne activity. The crew will wear personal dosimeters when the ship has radioactive cargo.
The deckhouse, machinery spaces and cargo hold is equipped with probes for measuring both gamma- and neutron radiation and can be monitored from a panel at the bridge. There is also equipment to measure airborne activity in the cargo hold.

5.2 Material of the radiation shields on the ship

Three different materials are used in the radiation shields on the ship;

- Concrete
- Polyethylene
- Steel

The concrete contains 2% boron and polyethylene contains 3% boron. Materials are chosen for their good radiation characteristics in combination with their weight in order to be able to guarantee the ship's stability. The total weight of the radiation shield is 633 tons.

The concrete has a density of 2.35 g/cm3 and protects against both gamma and neutron radiation. The added boron reduces the amount of secondary gamma rays, neutrons, then the low energy trapped by boron and forming lithium and helium. Boron has been added in the form of boron carbide (B 4 C) and SKB has had a thorough quality control sampling and analysis to ensure that the amount and distribution of boron is sufficient in the concrete.

Polyethylene has lower density (1 g/cm3) and contains significant amounts of hydrogen, which effectively reduces neutron radiation. The added boron reduces the amount of secondary gamma radiation. The low density of the polyethylene gives less protection against gamma radiation than steel and concrete.
Steel has a density of 7.8 g/cm3. The high density allows the steel is an efficient and space saving protection against gamma radiation.

5.3 Design of the radiation shields on the ship

The radiation shields on the ship are in principle a sandwich construction consisting of;

- Borated concrete enclosed on one or two sides of steel
- Borated polyethylene combined with steel
- Borated concrete enclosed on one or two sides of steel and borated polyethylene

Selection of material and its thickness vary in horizontal and vertical direction along the cargo hold walls/bulkheads.

The forward part of the ship where the crew mainly are staying is protected by a concrete wall with a thickness varying with the height to compensate for the distance to the load. The thickness varies between 130 to 350 mm of concrete surrounded by 10 mm steel. The shield is sized to limit the dose to 0.001 mSv / h at maximum exposure scenario. To have a concrete bulkhead protecting the deckhouse, where the crew spend most of their time, is an improvement compared to the old ship. At Sigyn a water filled tank protect the deckhouse from radiation. In case of a collision or a fire a concrete bulkhead still will keep its integrity while a water tank is likely to be damaged and drained from water.

The radiation shielding of the ship is designed with very conservative assumption in respect to dose rate of the transport cask, the number of transport cask in the cargo hold, nuclear fuel characteristics and exposure time in the reactors. Therefore SKB can expect dose rates to the crew to be much lower than 6 mSv/year, probably closer to 0 mSv/year

5.4 Design of the physical protection on the ship

The ship was design with security and physical protection as fundamental prerequisite and was one of the main reasons that the decision was taken to build a new ship instead of re-invest in the old ship. It would also never have been possible to improve the security and physical protection at the old ship to reach the same level as was possible with a new ship.

The regulation, recommendations and treats around an INF-3 ship is constantly changing and it is impossible to design and build a ship to fulfil both excising and future requirement. Also technology for security and physical protection system constantly changes and improves. During the design phase of the project also maritime safety all the time had to be weighed against security and physical protection. The maritime regulation are, when it comes to escape ways, evacuation and extinguishing fires, much stringent compared to the corresponding regulation for land based buildings. Also seaworthiness had to be taken in consideration all the time since the weight and centre of gravity of a ship is a very essential and critical design parameter. All reinforcement of the ship for security reasons (walls, doors etc.) always had to be consider together with the stability and weight of the ship.

During the design phase for the ship SKB put priority to the parts of the physical protection that are impossible or very difficult to change later. For examples issues related to ship's hull, layout of the ship, machinery or if there are requirement in regulation already now.

Second priority during design phase was physical protection system that is possible but often difficult or costly to change in the future. For instance; location and design of doors, windows, hatches and large on-board systems.

Third priority was security systems that are relatively easy to improve or install in the future and security systems were technology will change and improve rapidly. For example, intrusion detection and intrusion alarm system

Of course some of the security features are easily seen from the outside of the ship. For instance the exterior of the ship which is designed with special consideration to delay attempts of unauthorized boarding. The ship has as high freeboards as possible, few and small openings and a smooth surface with few protruding items.

M/S SIGRID – NUCLEAR CARGO VESSEL

General description

M/S Sigrid has a deadweight at design draught of 1600 ton . The vessel is an INF-3 nuclear cargo vessel with ice breaking capabilities including an ice breaking bow. It is a combined Ro-Ro and Lo-Lo vessel with one even cargo deck.

The vessel has two rudders and two controllable pitch propellers. Each propeller is driven by two medium speed diesel engines facilitating optimisation of engine load and fuel consumption. Engines and steering gears are fitted in separate compartments giving full redundancy thus enabling the ship to function with one steering gear and one engine room disabled.

The vessel is fitted with a Selective Catalytic Refining system comprising six separate catalysts, one for each engine (including auxiliary diesel generators), thus reducing NOx and fulfilling MARPOL Tier III.

Principal dimensions

Length	o.a	99.5 m
Length	b.p	90,97 m
Breadth	mld	18.6 m
Depth	mld	6.5 m
Design draught		4.5 m
Corresponding deadweight	abt.	1600 ton
Scantling draught		5 m
Corresponding deadwieght	abt.	2300 ton
Gross tonnage (International)		6694 GT
Netto tonnage		2008 NT

Classification

100 A1, Roll on Roll off cargo ship, *IWS, LI, LMC, PSMR*, UMS, CCS, IFP, NAV 1, IBS, EP, ICE-1A FS, CAC 2, INF-3, SCM , Green passport

Speed and range

Service speed	abt	12 knots
Range at design speed	abt	7000 Nm
Endurance at design speed	abt.	20 days

Other main tank capacities

Marine diesel oil, MDO	abt.	480 m³
UREA	abt.	35 m³
Ballast water	abt.	1078 m³
Fresh water incl. techn.	abt.	120 m³

Complement

Total	21 persons
Captain class, single cabin	2 pcs
Crew class, single cabin	19 pcs

Hull equipment

Provision crane	1.25 ton @ 16.2 m
Rescue boat	Diesel with jet propulsion
Life boat	Free fall

Mooring and anchor equipment

Combined anchor / Mooring winches	2 pcs, 10 ton pull
Mooring winches	5 pcs, 8 ton pull
Mooring winch with warping head	2 pcs, 8 ton pull

Cargo hold

Height	7,0
Length	66,9 m
Breadth	10.4 m
Capacity INF-3	8 casks
Capacity INF-2	4 + 8 casks
Capacity TEU container	40 pieces

Cargo equipment

Stern ramp 12x10.4 m, capacity	400 ton
Cargo hold inner door, INF-3 separation	A-60
Hatch covers	Lift away

Main engine and auxiliary machinery

Main engines MAK 6M20C	4x825 kW
Auxiliary engines Caterpillar C18	2x417 kW
Shaft alternators	2x850 kW
Emergency generator Caterpillar C18	1x417 kW
Bow thruster	2x550 kW

Propeller, 2 pieces

CP propeller with four blades, diameter	3.0 m

Rudder, and steering gear, 2 pieces

Steering gear, type	Rotary Vane
Angle	+- 60 deg.
Area, per rudder	8,5 m²

Svensk Kärnbränslehantering AB