Development, Implementation, and Experiences of the Swedish Spent Fuel and Waste Sea Transportation System

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INTRODUCTION

In Sweden, electrical production from the first commercial nuclear plant commenced in 1972, i.e. 17 years ago. There are now 12 nuclear reactors in operation, the last two were connected to the grid in fall 1985. These 12 reactors produce about 50% of the present electrical demand in Sweden. The remaining 50% are mainly covered by hydro power stations. The operating record for the Swedish reactors has generally been very good. Nevertheless - as you probably have heard - the Swedish parliament has taken a decision, that nuclear power shall be phased out from the Swedish system not later than the year 2010. Many of us - to use a mild expression - question the wisdom of this decision. The efforts in the waste management area will, however, be given a continued high priority.

The primary responsibility for the management of nuclear waste lies with the waste producer. In order to achieve a good coordination and an effective management the four Swedish nuclear power utilities have delegated these responsibilities to the jointly owned Swedish Nuclear Fuel and Waste Management Co, SKB. This means that SKB is responsible for all measures required for the implementation of the national nuclear waste management programme such as planning, design, construction and operation of waste facilities including the necessary R & D work.

The responsibility of the nuclear power utilities also includes the financing of the waste management programme. A special funding system, controlled by the authorities, has been established for this purpose.

Since all the Swedish nuclear power stations are located on the coast, as well the central storage facility for spent fuel (CLAB) and the final repository for reactor waste (SFR), it was natural to develop an integrated sea transportation system (ISTS) for all types of nuclear waste. The planning and design of the ISTS started already in 1978 and has been in operation since early 1983. In July 1985 CLAB commenced active operation and regular transports of spent fuel started. SFR at Forsmark went in operation in April 1988, when also transports of such waste started.

The Swedish nuclear power programme with 12 reactors will produce 1 900 TWh electrical energy and will generate about 7 800 tonnes of spent fuel and 90 000 m^3 of low and intermediate level reactor waste. The decommissioning of the nuclear facilities at the end of their useful lives will result in about 120 000 m^3 of radioactive waste.

The locations of the nuclear power plants, CLAB and SFR are shown in figure 1 below.

Figure 1. Location of Swedish nuclear power plants, CLAB and SFR.

Essential parts of the Swedish nuclear waste management system are already in operation. The main effort is now concentrated on R & D for the final repository for spent fuel. An important item in the geoscientific investigations is the planned Hard Rock Laboratory, HRL, near Oskarshamn. In the HRL-facility geological investigations will be performed at repository depth and site characterization methods will be tested.

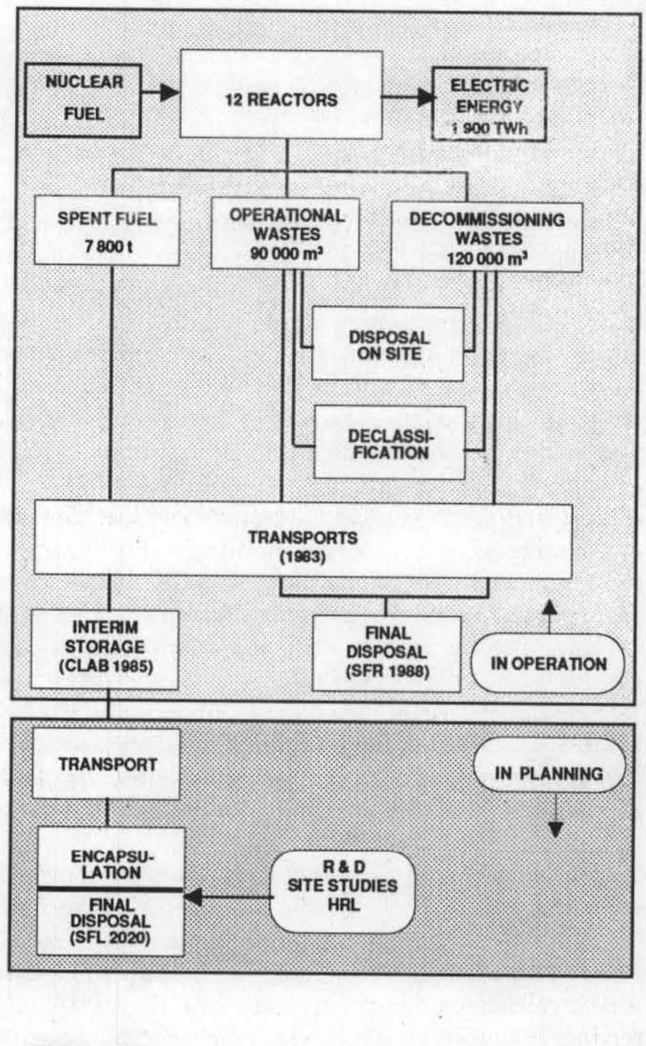

Figure 2
Main facilities in the Swedish Nuclear Waste Management System

DEVELOPMENT AND DESIGN

General

The need for transport of spent fuel from the nuclear plants to a reprocessing plant or an away from reactor central storage plant was foreseen at an early stage in the programme. As all nuclear power station are located on the coast and have harbour facilities of their own it was natural to develop an integrated sea transport system (ISTS) for all types of waste. The planning and design of the ISTS started already in 1978 and has been in operation since early 1983. Six transports of spent fuel, about 57 tonnes, from Swedish reactors to La Hague at Cherbourg were made during 1983-84 when CLAB still was under construction. CLAB became operational in June 1985. In April 1988 the final repository for reactor waste, SFR, became operational. Since then the ISTS is used both for transport of spent fuel and reactor waste. From mid 1989 transports will commence from Studsvik research center to SFR of waste coming from hospitals, industries and research facilities at Studsvik.

The spent fuel is transferred to CLAB, at Oskarshamn, for about 40 years storage before being encapsulated for direct final disposal in the bedrock at about 500 m depth. The low- and intermediate short lived reactor waste is transferred to the final repository SFR.

The transport routes between reactor plants, Studsvik research center, SFR, CLAB and the planned final repository for spent fuel, SFL are shown in figure 3.

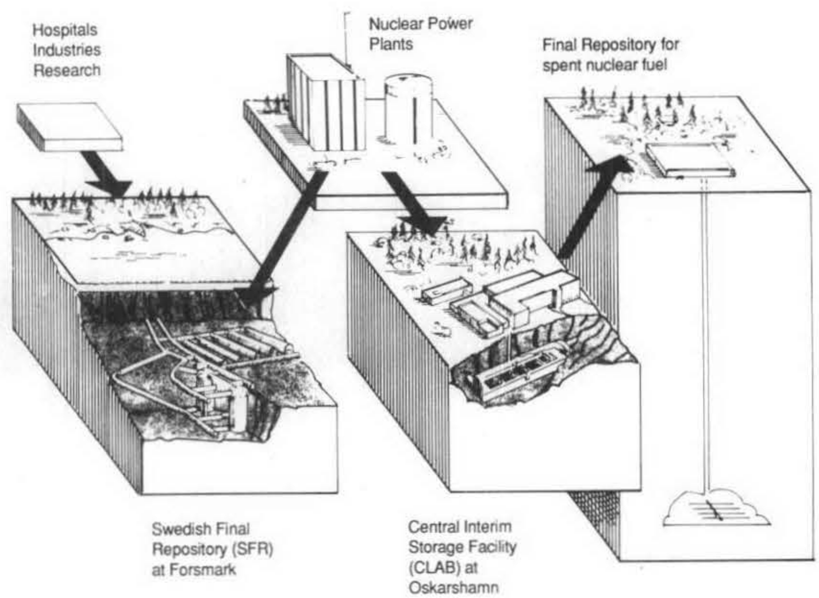

Figure 3 Principle transport routes for spent fuel and waste

The Swedish ISTS consists of a specially designed ship (M/S Sigyn), ten transport casks for spent fuel and two casks for core components; four diesel and one diesel/electrical powered terminal vehicles for local transports at CLAB, reactor sites and SFR. 27 ILW containers are used for transport of reactor waste between reactor sites and SFR.

M/S Sigyn

M/S Sigyn was designed by Salen Technologies AB, Saltech, and built by the French shipyard Societe Nouvelle des Ate'liers et Chantiers du Havre, ACH. She was ordered in January 1981 and delivered in October 1982. She is specially designed for transport of spent fuel and radioactive waste and meets IMO regulations for type I ship. Accordingly, she has a double bottom and a double hull. Machinery and electrical equipment are duplicated. The ship is a combined roll-on/roll-off and lift-on/lift-off vessel. Normally the cargo is driven on board. The fuel casks and waste containers for ILW are to be secured to the deck of the cargo hold by means of simple and robust locking devices.

The single hold is 57 m in length with a free breadth of 10 m and a free height of 5.6 m and can accomodate 10 fuel casks or 10 ILW-containers or a combination of fuel casks and ILW-containers. 10 ISO-containers with low level waste can also be transported at the same time in the aft of the hold.

Main data for M/S Sigyn are given below:

-	Overall length	90.60 m	-	Dead weight, max	2,044 tonnes
-	Length	82.07 m	-	Cargo capacity	1,200 tonnes
-	Breadth moulded	18.00 m	-	Machinery output	2 x 993 kW
-	Depth moulded	6.65 m	-	Speed	12.5 knots
-	Draught fuel loaded	4.00 m	-	Crusing range	23 days or 6,000 nautical miles

Figure 4 M/S Sigyn

M/S Sigyn was built to comply with both Bureau Veritas and Lloyds' Register of Shipping and meet the requirements of both French and Swedish authorities. She is reinforced to Baltic ice class 1 A, with a double hull, ice breaking bow and ice knives aft of the rudders, and is expected to be capable of breaking 0.4 m thick ice. The crew is protected from radiation by 900 mm thick transverse water tanks across the forward end of the cargo hold and extending from the bridge tank down to the tank-top. There are also 150 mm thick concrete shields arranged longitudinally between the hold and the machinery spaces in the wings. Radiation measurement instruments are provided in the hold and the main engine rooms. Air and water samples can be analyzed in the laboratory.

A detailed description of the transportation system was provided in a document, entitled "Transportation System for Spent Nuclear Fuel, Preliminary Safety Report". This PSR together with a specification of the vessel was submitted to SKI, the Swedish Nuclear Power Inspectorate; SSI, the National Institute of Radiation Protection, the National Administration of Shipping and Navigation and the appropriate French authorities in spring 1980. The Final Safety Report was submitted to the Swedish and French authorities in April 1982. The first transport of spent fuel from Sweden to La Hague in France was carried out in May 1983.

Spent fuel and core component casks

The transport system holds ten TN 17 Mk2 casks for spent fuel and two simplified versions of the TN 17 Mk2 without neutron shielding for core components.

The TN 17 cask was designed by the French company of Transnucleaire and licensed by the French authorities. Of the ten fuel casks seven casks have been manufactured by UDDCOMB Sweden AB, Karlskrona. UDDCOMB has also manufactured the two core component casks. The remaining three fuel casks are manufactured by KOBE STEEL in Japan. All casks have been in use since 1984.

The TN 17 Mk2 cask holds 7 PWR or 17 BWR fuel assemblies and has a total weight of 80 tonnes. The shipment of fuel is performed dry, i.e. the free space in the cask is filled with inert gas and under reduced pressure. The cask is checked after loading but prior to shipment to make sure it meets the required surface dose rate.

The TN 17 Mk2 casks have an IAEA type B (U) license. A certificate was issued by the French Ministry of Transportation in June 22, 1981. Approval from SKI was obtained on July 6, 1981, and the casks are thereby approved for use in both Sweden and France. These casks are relicensed each fifth year.

Transport containers for ILW

SKB has designed transport containers for ILW that meet the requirements for an Industrial Package 2 (IP2) according to IAEA publication - "Regulations for the Safe Transport of Radioactive Material", edition 1985. The surface dose rate on the ILW-container (ATB = Swedish abbrevation) shall be less than 2 mSv/h and the dose rate at 2 metres shall be less than 0.1 mSv/h. Due to the size of the ATB the 2–metre-value is governing. To meet the maximum dose rate of 0.01 mSv/h in the terminal vehicle driver's cabin, however, additional shielding is required.

The containers are welded to the load carrier of the same dimensions as those used for spent fuel casks. ATB and fuel casks can therefore be handled in the same way by the terminal vehicles and on board the ship. The gross weight of an ATB is limited to 120 tonnes.

The ILW consists mainly of ion exchange resins, which are solidified with cement or bitumen in concrete or steel moulds or 200 litre drums. At two stations the powder resins from the condensate polishing plant are collected and dewatered in large concrete tanks. This means that the ILW-packages are of three different types:

- concrete or steel moulds, outer dimension - 1,2 x 1,2 x 1,2 m
- 200 l steel drums, outer dimension - Ø 0.6 x 0.9 m
- concrete tanks, outer dimension - 3.3 x 1.3 x 2.3 m

200 liter drums are also used for solid waste such as metal scrap and trash that must be deposited in SFR. LLW which requires no shielding is transported in standard ISO-containers to SFR.

The ILW-containers designed and manufactured are consequently of mainly three types:

- ATB - 12 K that can hold 12 moulds or 48 drums. The 130 mm thick steel walls of the container allow a surface dose rate of the individual package up to 60-70 mSv/h.

- ATB - 16 K that can hold 16 moulds or 96 drums. The 70 mm thick steel walls of the container allow a surface dose rate of the individual package up to 5-6 m Sv/h.

- ATB - 3 T that can hold 3 concrete tanks. The 70 mm thick steel walls of the container allow a surface dose rate of the tanks up to 7-8 mSv/h. As the concrete tanks are handled with fork lift trucks this type of ATB has doors but all others have a lid. The waste and the lid are handled with overhead cranes.

For testing of an ATB with handling equipment for the lid and waste packages a prototype container, ATB-P, has been manufactured. A complete test programme was carried out mid 1985 including a transport test with a terminal vehicle in the deepest part of the SFR-tunnel and 120 tonnes container weight. One special ATB for transport of ILW from Forsmark NPP to SFR has also been manufactured. That ILW-container, ATB-4 K can only hold 4 moulds or 16 drums. The 200 mm thick steel walls of the container allow a surface dose rate of the individual package up to 500 mSv/h.

Main data for ILW-containers are given below:

Type	No manu-factured	Wall thichness mm	Container internal dimensions L x B x H m	Weight empty tonnes	Acceptable package dose rate mSv/h
ATB-12 K	10	130	3.99 x 2.57 x 2.45	68	60 - 70
ATB-16 K	10	70	5.29 x 2.66 x 2.66	50	5 - 6
ATB-3 T	5	70	4.29 x 3.42 x 2.80	58	7 - 8
ATB-P	1	80	3.94 x 2.60 x 2.75	47	7 - 8
ATB-4 K	1	200	2.64 x 2.57 x 1.25	56	500

All together SKB now operates 27 ILW-containers. If waste packages in the future will have higher doserates and activity contents, containers with thicker steel walls have to be designed.

Terminal transport vehicles

The fuel casks and ILW-containers are handled between reactor sites and harbours by a diesel driven 14 axles with 28 wheels heavy load transporter. The vehicle load frame can be moved up and down with hydraulic which makes the handling of the fuel cask load carriers and ILW-containers very simple and quick. Four diesels and one diesel/electrical powered terminal transport vehicles are now in operation. The diesel/electrical powered vehicle is used at SFR where the diesel engine powers the hydraulic system above ground and the electrical motor in the tunnels and repository area. The SFR vehicle is also equipped with an automatic control system for remote operation when electrical driven. The gross weight of the vehilce with a fuel cask is about 125 tonnes and with a ILW-container about 155 tonnes. The maximum slope of the tunnels is 1:8 and the velocity of the vehicle is restricted to maximum 3 km/h. Above ground the velocity of these vehicles is about 10-15 km/h.

Figure 5. Terminal transport vehicle with a fuel cask

EXPERIENCES

Experiences from operation

Trial operation with the transport system started as early as November 1982 at the different reactor sites. These tests also included complete cask handling cycles at the reactor units. At an early stage it was found that some of the entrance channels to the harbours were too narrow an had to be enlarged. In order to educate the crew on board the ship and to optimize the system, computer simulator programmes were developed for the different harbour facilities. After successfully terminated trial operations M/S Sigyn started her maiden voyage to France in late January 1983 loaded with four casks with PWR fuel from Ringhals and two casks with BWR fuel from Barsebäck.

Only minor modifications were necessary on the handling equipment at the reactor units. The satellite navigation and communication system for the ship have proven to work well. The satellite communication system plays a very important role in the physical protection arrangement during transports.

Before starting shipments of ILW-containers the cargo deck of the ship had to be strengthened in order to accept the increased load from the ILW-containers, 10 x 120 tonnes instead of 10 x 85 tonnes for the fuel casks.

The first shipment of ILW-containers to SFR was done in November 1987. SFR got its first operation licence in April 1988 and routine transports of ILW-containers have been carried out after that date. Minor modifications have been carried out on ILW-containers, handling equipment for container lids and waste packages. The operations connected with ILW-containers have functioned without trouble especially considering that they are new development. The diesel/electrical powered terminal vehicle at SFR is still in its trial operation. The electrical motor and the automatic control system for remote operation in the repository area are still causing problems.

CLAB received totally 104 casks during 1988. 76 casks contained BWR and PWR fuel, 9 casks contained core components, 8 casks contained MOX-fuel from West Germany and 11 casks contained fuel from Ågesta NPP which earlier had been stored at Studsvik. Totally the operating experiences with casks correspond to about 300 cask movements or approximately 1,000 tonnes of uranium. SFR received totally 61 ILW-containers during 1988. 45 were transported with M/S Sigyn and 16 came from Forsmark NPP. Totally the operating experiences with ILW-containers correspond to about 150 container movements. During 1988 M/S Sigyn has been 161 days at see and sailed 30,127 nautical miles and made 94 departures from the different reactor site harbours. The ship crew, 25 persons, received during 1988 a collective dose burden as low as < 1 mmanSv, which proves that the system as such is well optimized. The SFR-personnel received 1.75 mmanSv and CLAB-personnel received 70 mmanSv.

Experiences from maintenance

M/S Sigyn - The maintenance of the ship is carried out according to normal practice for ships of this size. Routine maintenance is carried out by the crew but for some equipment specialists may be called in for the work. Major overhaul of the machinery, painting and corrosion protection of the hull will be done at a suitable shipyard every third year.

Terminal vehicles - Routine manintenance is done by the staff at CLAB and SFR. The main hydraulic systems with oil pumps, wheel engines, hydraulic cylinders etc will be maintained or overhauled under supervision of Scheuerle. The diesel engine will, when needed, be repaired by a diesel motor workshop.

Fuel and core component casks - Routine maintenance is carried out by the staff at CLAB. This is presented in reference 2 to this paper. The fuel and core component casks are routinely taken for preventive maintenance and inspections. A general inspection is carried out after 8 to 10 transport-cycles and a more extensive inspection is carried out after 30 to 40 transport-cycles. These inspections are then repeated by routine. However, due to the good experiences up to now it will be discussed to increase the the time between inspection to 15 respectively 60 transport-cycles. About 15 working days are needed for these inspections per cask.

ILW- containers - These will require limited maintenance for the locking device for lids and doors and that will be carried out by the staff at SFR. Repainting may be required after about 10 years in use and that is planned to be carried out at a suitable shipyard.

INVESTMENT AND OPERATING COSTS

The investment costs for the total ISTS is in the order of 250 MSEK (40 M$ US). The yearly operating and maintenance cost is in the order of 15 MSEK (2.3 M$ US). In 1988 the total fee collected for covering the fuel cycle back-end cost varied between 0.017 - 0.022 SEK/kWh. Only 8 per cent of this fee referred to ISTS' costs.

SUMMARY

The ISTS is now in routine operation with about 30 trips per year with M/S Sigyn. 15 are with spent fuel to CLAB and 15 with ILW containes to SFR. Up to now about 1,000 tonnes of spent fuel have been transported to CLAB and about 2,500 m^3 of reactor waste to SFR. This corresponds to about 300 casks and 150 ILW container movements. The transport and handling of the spent fuel casks have up to now proved to be very safe and reliable. The same can be said about the ILW transports. The previously experienced very low dose committment to the ship crew has increased only slightly even with transport of higher burnt up fuels.

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