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Parameters controlling the design of a sea transport system

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Abstract

Swedish Nuclear Fuel and Waste Management Co. (SKB) owns and operates a sea transport system for spent nuclear fuel, core components and other radioactive waste. The system has been in use since 1985. Spent nuclear fuel in Sweden is continuously transported from the nuclear power plants to the national intermediate storage, Clab. The lack of a reliable transport system would shortly have a severe impact on the operation for all nuclear power plants since the fuel pools on the sites are quite small. The ability of transporting spent fuel continuously is therefore essential to the operation of the nuclear power plants in Sweden.

Due to new requirements and aging the sea transport system has to be replaced completely. Two key components of the system are already designed, the ship and the spent fuel/core components casks. Safety, security, capacity, redundancy, policy, economy and environmental issues all play important roles for the design. Since the system and its operation are quite complex few people have the detailed knowledge of how the different disciplines interact and impact on the design.

This paper will outline on a simplified and comprehensible layman level the main choices and considerations which were made by experienced experts in different disciplines to achieve an optimized sea transport system for SKB.

Introduction

An increasing demand of the nuclear power was foreseen in the late sixties in Sweden. During the period 1965 to 1972 one commercial nuclear power reactor was ordered every year. Totally, twelve nuclear power plants were designed and ten of them are still in operation. A decision was recently made to close down four power plants in the next four years for economical reason. SKB (Swedish Nuclear Fuel and Waste Management Co) was formed 1973 as a co operational organisation for common interests of the power plant owners. SKB is responsible for taking care of the Swedish nuclear waste and for planning of this work funding.

In 1985 an interim central storage for spent nuclear fuel in Oskarshamn, the Clab facility was taken into operation. The fuel is stored wet underground in large pools for 30-40 years to reduce its residual heat and radioactivity before being encapsulated and deposited in the final repository, yet to be constructed. In 1988 a final repository for short-lived low and intermediate level waste in Forsmark, the SFR facility, was taken into operation. The waste is deposited underground in rock vaults. Both the Swedish nuclear power plants and SKB:s facilities are located at the coast. To efficiently transport the fuel and radioactive waste from the nuclear power plants to the Clab and SFR facilities the transport system was created in the 1980's with its key components: ship, casks and vehicles. In fig 1 an overview of all existing and planned facilities in the Swedish system for waste management is described.

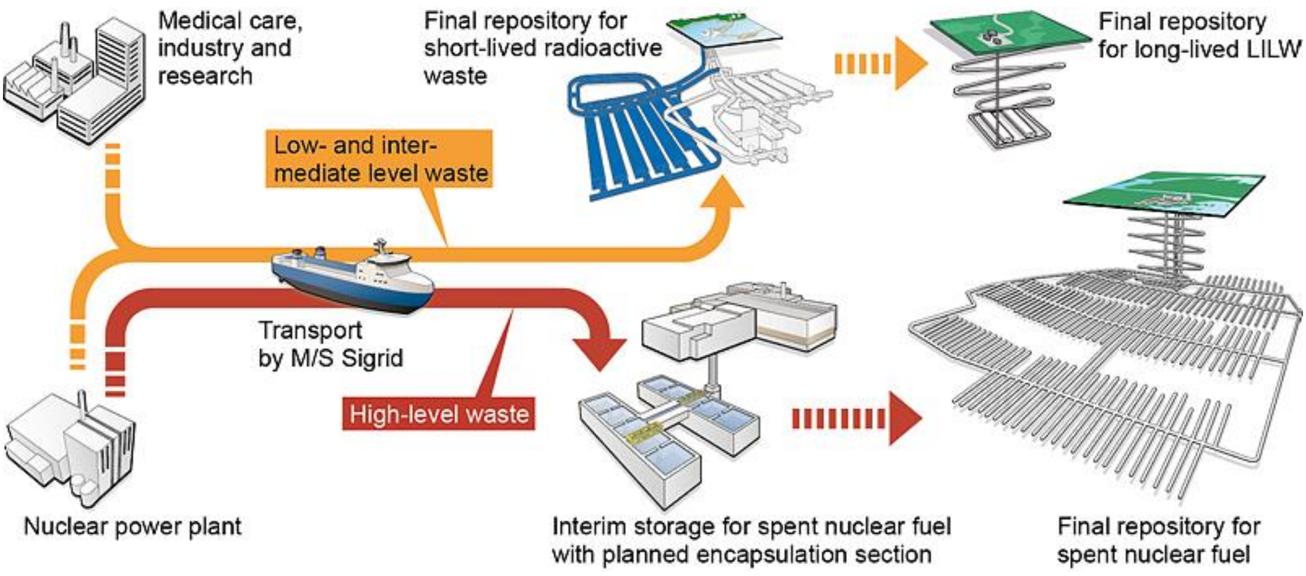

Figure 1 The Swedish system for management and disposal of radioactive operational waste and spent nuclear fuel. The encapsulation plant, the final repository for spent nuclear fuel and long-lived LILW are not yet constructed. The other plants are already in operation. Source: SKB.

Renewal of the transport system

Due to new requirements, regulations and aging equipment a total renewal of the transport system is on going. A new INF-3 ship, m/s Sigrid, was taken into operation in 2014 and design and licensing of new type B casks for SNF and core components is soon to be completed. A feasibility study of renewal of the transport vehicles has been performed and a renewal project will start in September 2016. The current transport system has been working remarkably well with none or small adjustments. It has had a very high capacity and availability during 30 years of operation. Therefore, it is a great challenge to renew such a well functioning system and try to foresee all demands of the future.

All parts in the transport system have limitation regarding safety, capacity, redundancy, policy, economy and environment. In the renewal of the transport system an optimization has been done to try to maximize the capacity and minimize the cost, personnel dose and the need of modification of existing facilities and equipment. Economic consequences of not only the initial investment cost but also the total life cycle cost for maintenance and operation have been taken into account when the design decisions have been made. An optimization against technical, authority and policy requirements have been done during the design of the new transport system.

Optimizing the design of the new ship

In 1982 the INF-3 ship m/s Sigyn was taken into operation in the Swedish transport system. The ship was replaced in 2014 by the new INF-3 ship m/s Sigrid, see fig 2. The ship is owned by SKB but crew and technical management is hired by a ship operator, Furetank Rederi AB.

Figure 2 The INF-3 ship m/s Sigrid was taken in operation in the Swedish transport system in 2014. Photo: Damen. Source: SKB.

Designing a ship is very much about controlling weight

Some import requirements tend to add to weight which result in bigger displacement. The displacement is the volume of the hull beneath water simply the product of length*width*depth which is limited by the existing harbours. In other words some important requirements have a direct impact on the weight of the ship which must be limited.

A policy decision was to make the ship able to enter Sweden's biggest lake through a water lock limiting the width of the ship. For the ship to be able to operate in the narrow harbours of the NPP's the depth is a strict limit but also the length has to be limited somewhat in order to operate smoothly in the harbours. Below requirements will be pointed out that add to weight. Some add much more than others to weight and have a bigger impact on the design of the ship.

Logistics and Capacity

Up to now the ship has seldom been fully busy on a yearly basis. The available over capacity is therefore offered on a commercial basis for heavy transports or other class 7 cargo to external customers.

The ship and its cargo capacity of 12 casks is never the limiting component of the transport system. Only analysing the need of transport capacity the new ship has an over capacity and a smaller ship would have been enough to fulfil the normal transport needs from the Swedish NPP's. Due to other requirements mentioned later the size of the new ship Sigrid was however increased compared to the old ship Sigyn, and the loading capacity of the new ship is 20% higher.

Apart from the current transports (spent fuel from the nuclear power plants to Clab, LLW and ILW from the nuclear power plants to SFR) the ship was decided to have the capacity to transport the future waste from decommissioning of the power plants to SFR, and also copper canisters with spent fuel from Oskarshamn to Forsmark. Furthermore it was also decided to give the ship the ability to transport large components for renewed or decommissioned nuclear power plants, for example low pressure turbines and steam generators. This requirement gave the cargo hold its height which added to the ship's weight.

Physical Protection

From the beginning the old ship m/s Sigyn was equipped with an alarm and communication system that used satellites. Since then the routines regarding physical protection have constantly been reviewed and updated. The level of security and awareness has been high. Since "9/11" this area has been more in focus and the whole nuclear industry and new requirements and regulations have been introduced.

In the design process of Sigrid an improved physical protection was of great importance. The higher the sides of the ship and the faster the speed of the ship are the more difficult will a boarding of the ship be. Higher ship sides add to the weight of the ship. The speed and the capacity of the engines have a big impact on the cost both as an investment cost but also as an operational cost during the whole life time of the ship.

Of course a lot of other improvements in the physical protection have been implemented in Sigrid but those have not been limiting in the optimization of the transport system and are therefore not mentioned in this paper.

Radiation Protection

The experience from operating the old ship m/s Sigyn was very good concerning dose rate to the crew. In fact there has been no registered dose to the crew during the whole life time of m/s Sigyn. One of the design criteria for Sigrid was therefore to maintain the good work environment for the crew with the very low radiation levels during transports of radioactive waste.

Due to a development of the nuclear fuel with higher enrichment and higher burn out a decision was made to design a robust shielding around the cargo hold with borated concrete, steel and also polyethylene for both gamma and neutron shielding. The shielding was designed taken into account the future development of nuclear fuel and a maximum load of high burn-out fuel in the cargo hold and also the future working hours for the crew in different areas of the ship. The shielding with heavy concrete adds very strongly to the ship weight. Due to SKB’s high ambition the best possible shielding of Sigrid was designed. In fact over 600 tonnes of concreted is surrounding the cargo hold.

Also other improvements has been implemented in the new ship regarding the radiation protection but those have not been limiting in the optimization of the transport system and are therefore not mentioned in this paper.

Comfort of the crew

A ship is not only a place of work. It is also the home of the crew since they are aboard 24-7 during their working period.

For SKB one important design criteria was to create an attractive ship when it comes to comfort for the crew. The goal was to design a ship where the crew feel at home and wants to work for many years. This criteria has however not been limiting for the transport system. The crew of the old ship and also the management company operating the ship were given the opportunity to share experiences and propose improvements for the new ship. A lot of proposals were raised during this process and the limitations in this area where due to economy.

With smart and cost efficient solutions big improvements regarding the comfort for the crew was achieved. The crew cabins are light and spacious, common lounges and offices are available and the galley is designed to improve the work environment of the cook steward.

Environmental requirements

The old ship m/s Sigyn was equipped with NOX-reduction system and low sulphur oil was used. Even though the ship is by far the single biggest polluter within all the SKB’s activities it is not a big polluter compared to other ships. Primarily for not being fully busy but also for being small and running short distances.

However there is a way to design new ships with conventional diesels reduce the pollution substantially. Due to its time table, the Sigrid is often free to choose its speed. By broadening the efficient power range with a number of combined engines the fuel consumption per distance could be brought down. To create opportunities to decrease the release of carbon dioxide Sigrid is equipped with four smaller engines to be able to adjust the speed depending on the time table of the ship. A slower speed of the ship means less fuel consumption and as a consequence less release of carbon dioxide.

However the fuel consumption is not only dependent on the speed. The requirements from physical and radiation protection with added weight and bigger displacement also impacts the fuel consumption of Sigrid. However the new ship has maintained good environmental performance even though the size of the ship is increased compared to the old ship.

Optimizing the design of the transport casks for SNF

In 1985 ten TN17 casks for SNF were taken into operation in the Swedish transport system. The casks are licensed according to IAEA requirements from 1985. Due to new IAEA requirements in 1996 of double containment against water intrusion new casks for SNF, HI-STAR 80, were ordered in 2013. The license review is current on going and the first cask is to be delivered to SKB in 2019. A transport cask for spent fuel is a complex product. Given the right conditions the cask could be optimized in several different and linked areas such as criticality, residual heat, shielding, mechanical resistance, handling and maintenance. The challenge was to maximise the capacity of the cask and minimize the impact on already existing plants.

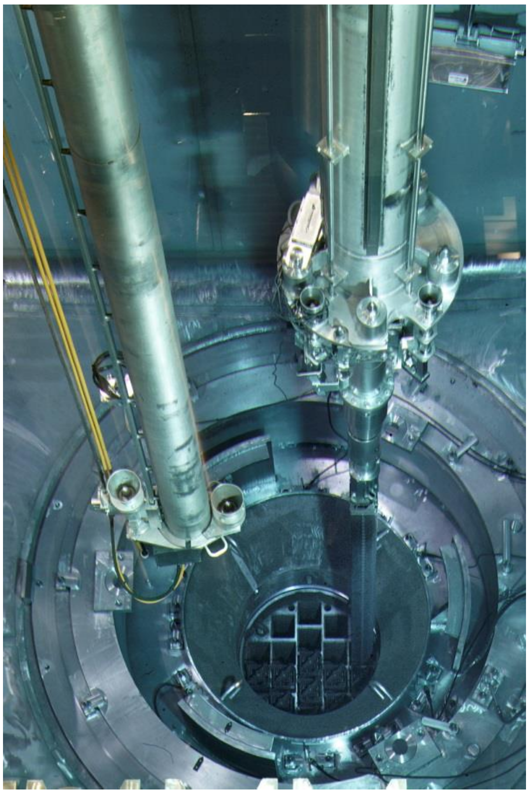

Figure 3 Handling of spent nuclear fuel in Clab. Photo: Curt-Robert Lindqvist. Source: SKB.

Designing a cask is very much about controlling weight

Some import requirements tend to add to weight. Normally weight is a strict limitation in most facilities. Both the floors and the overhead cranes of existing facilities could be very limiting regarding weight. In other words some important requirements have a direct impact on the weight of the cask which must be limited.

Capacity

A high capacity of the cask is important for several reasons. With a higher capacity fewer casks are required in the system to fulfil the transport need of SNF from the power plants. Fewer casks also mean fewer sea transports and lower environmental impact from Sigrid. A fleet of fewer casks also require less time for handling and maintenance and also less time for dose rate exposure to the personnel. Summarized this has impact on the total life cycle cost of the cask fleet.

An increased capacity also means increased cask weight which alternatively could be used for shielding. Since doses to staff already are low it will decrease doses more to use the weight for a capacity increase due to the much less number of casks that will be handled. To minimize impact on the existing plants lifting capacity of overhead cranes and geometrical limitations in the fuel pools at the power plants has to be taken into consideration. For SKB:s transport system the short cool down periods at the power plants may be the greatest technical challenge with a capacity increase. It is very challenging to design a high capacity cask, keeping the weight low and still fulfil requirements both regarding residual heat dissipation and radiation shielding.

SKB has been successful in the design of the new casks and the capacity will be twice as high as the capacity of the old casks. The weight and width increase of the new casks are about 15 % which is possible to handle without any major changes in the existing power plants.

Criticality and Heat

The current fleet was designed for SNF with much lower enrichment levels and much lower burn up than the nuclear fuel actually used today. The change of content is significant, both the level of enrichment and the level of burn up have more than doubled since the commissioning of the fleet in 1985. The new casks are designed to efficiently handle fuel with a burn up level up to 70 MWD/kgU and an enrichment level of 5%. Both the double capacity of the casks and also the higher performance of the fuel are challenging when it comes to criticality and heat calculations.

However with modern calculation models, high computer capacity for complex calculations, introduction of material with better heat transfer properties the new cask with double capacity can meet the criticality and heat requirements in the regulations. The margins have even increased compared to the old casks.

Handling and Shielding

The experience from 30 years of operating TN17 casks is very good considering dose to personnel. Geometrical limitations and weight limitations in the existing power plants have been taken into consideration in the design of the shielding of the new cask. The shielding has been increased to the extent possible with regards to weight limitations at the facilities. Even though the capacity has increased the dose rate levels are predicted to be in the similar range as the existing casks. However since half the number of casks are too be handled yearly in the future the collective dose to the handling personnel will probably be lower than today.

All though a doubled capacity of the casks contributes to the most significant cut in operating costs and doses to personnel it is still of great importance to enhance and facilitate all steps of a transport cycle. Both drying the content and decontamination of the cask are time consuming why it makes it important to design the cask in a way that speeds up and facilitates that work. Especially improved decontamination could further cut doses to the staff. The new casks are therefore designed with smooth surfaces, endurable paint, easy draining and avoiding water traps.

Conclusions

When a transport system is to be optimized a lot of different aspects need to be considered. What is a big improvement in one area might create problems in another area.

During the renewal of the Swedish sea transport system the ALARA aspect has been of great importance and much effort has been made to design a system with low dose rate level and low predicted doses to the personnel.

Both the new ship m/s Sigrid, in operation since 2014, and the new casks for SNF, to be delivered in 2019, have been designed with maximum possible shielding. The goal to have a reasonable impact on existing harbours and power plants have set the limitations for the shielding of both the new ship and the new casks due to limitations in weight. Many other big improvements have been achieved with limited efforts and costs but the shielding could not have been enhanced any further with reasonable efforts and costs.

Nevertheless has the design been successful and doses to personnel are predicted to be in the same range or lower even though the future fuel will have higher burn up. This will be possible mainly due to the higher the capacity of both the ship and the casks.