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REVIEW

SEA TRANSPORTATION OF IRRADIATED FUEL BY SKB

PART I

IRRADIATED FUEL STOCKS AND SEA TRANSIT MOVEMENTS

CLIENT: GREENPEACE SWEDEN

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Large & Associates The Gatehouse 1-2 Repository Road Ha Ha Rd Woolwich London SE18 4BQ

☎ 44[0]181 316 4236 44[0]181 317 2860 44[0]181 317 2859 07971 088 086 e-mail largeassociates@msn.com

SEA TRANSPORTATION OF IRRADIATED FUEL BY SKB

PART I - IRRADIATED FUEL STOCKS AND SEA TRANSIT MOVEMENTS

ABSTRACT

Sweden's irradiated fuel management strategy involves moving spent fuel from each of the nuclear power stations to a central fuel storage facility (CLAB). Spent fuel will remain at CLAB until it can be transferred to a deep disposal repository (SFL) some time after year 2008. All fuel movements from the NPPs to CLAB, except for the Oskarshamn reactors nearby, are by the specially adapted ship *M/S Sigyn* using internationally approved transportation flasks.

At this time, the location of the SFL deep repository has yet to be determined, although SKB have stated that the present experimental site at Äspö, nearby CLAB, is unsuitable for future SFL development. The assumption is that, if developed at all, SFL will be at some other coastal site, necessitating further movement of the fuel from CLAB by sea. Since SKB are developing a spent fuel encapsulation plant at CLAB, future movements of fuel from CLAB to the SFL site will have to be undertaken in a specially designed flask – this flask has yet to be fully developed and approved under the International Atomic Energy Safety Series 6 Regulations, as adopted by Sweden for such fuel movements.

During the present operational run-down and future decommissioning programme, sea movements of highly radioactive spent fuel around Sweden's coastline will comprise transport from the nuclear power plants to CLAB then, some years later, the transport of encapsulated fuel from CLAB to the final disposal repository at some yet to be determined site. Fuel movements to CLAB commenced in 1985 and, so far (1996) about 2,300 tonnes of fuel have been delivered to CLAB. If the Swedish nuclear programme operates to a 25 year service life scenario, the remaining tonnage to CLAB will be about 4,000 tonnes, or for a 40 year life scenario about 7,000 tonnes. Translated into flask movements, future fuel transport to CLAB and from CLAB to the SFL will require about 5,000 or 8,000 flask loads or, if *M/S Sigyn* and its successor is dedicated solely to fuel transport, about 850 to 1,330 voyages which will occupy 20 or 33 years (all for 25 and 40 year life scenarios respectively).

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PART I - IRRADIATED FUEL STOCKS AND SEA TRANSIT MOVEMENTS

The highly radioactive, irradiated or spent fuel withdrawn from the Sweden's four nuclear power plants (NPPs - comprising 12 reactors in total)[a] is transported in containers or flasks by the specially constructed ship[1,2] *M/S Sigyn* via coastal sea lanes to the central fuel store (CLAB) at Simpevarp, Oskarshamn.

Fuel transfer from the NPPs commenced in or about 1985 and, since that time, the traffic rate has been about 250 Ut (uranium tonnes) per year. This is equivalent to 80 to 100 flasks carried as cargo each year with, on average, *M/S Sigyn* undertaking about 30 to 40 voyages[b] each year. In near future years, total transfers of spent fuel will most probably increase to 300Ut/y or 100 or more flasks per year, continuing beyond the time that all 12 reactors have ceased operation in order to clear the backlogs of irradiated fuel held in the power station fuel storage ponds.

M/S Sigyn is a ro-ro, stern loading ship of 90m length, 18m beam drawing 4m fully laden, and of 4,166 tonnes gross (2,044t deadweight). Operation of *M/S Sigyn* is sub-contracted by SKB to Rederiaktiebolaget Gotland which provides two, 12 strong sea crews.

At or some years following 2008,[3] it is intended to commission a deep repository for irrdisposal of all of the irradiated fuel arisings from Sweden's nuclear power programme. On the basis that Sweden will not commission any further nuclear power plants, about 6,500 to 10,000 tonnes of fuel will have to be transferred from CLAB to the repository site. Although the repository site has yet to be chosen, it is unlikely to be at or nearby Oskarshamn, thus it is most probable that the final movement of spent fuel will be by sea voyage by *M/S Sigyn* or its successor.

IRRADIATED FUEL - RATES OF ARISING AND NPP ON-SITE STORAGE

Swedish nuclear power stations are light water reactor (LWR) plants utilising the following types of reactor fuel:-

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[a] The transports from the power plants to CLAB also include relatively small volumes of some highly active reactor core components and, possibly, control rod assemblies, both of which are not considered here – irradiated fuel from Oskarshamn is transported overland since the reactors are on the adjacent site.

[b] *M/S Sigyn* also transfers intermediate-level radioactive waste (not irradiated fuel) from the power plants to the SFR facility at Forsmark, this aspect of transportation is not considered here but, obviously, the dual use of M/S Sigyn could extend the total period over which irradiated fuel transfers are made.

TABLE 1 FUEL PERFORMANCE AND RETENTION CHARACTERISTICS

CHARACTERISTIC	IRRADIATED FUEL/REACTOR TYPE	
	BWR	PWR
FUEL TYPE	dioxide pellets	dioxide pellets
ENRICHMENT %	1.5/3.7	1.6/6.6
FUEL CLADDING	zirconium alloy	zirconium alloy
BURN-UP MW_ed/t	6/40,000	32/48,000
SWEDISH MW_ed/t	0.78 @ 38,000[c]	0.73 @41,000
REACTOR CORE LIFE YRS	3	3
PRE-DECAY POND	1-5 years	1-5 years

Present and future stocks of spent fuel held at CLAB and at various Swedish nuclear power plants[d] are estimated to be as follows:-

TABLE 2 SWEDISH NUCLEAR POWER PLANTS

LOCATION	REACTOR TYPE	DESIGN MWe	START YEAR	CORE Ut	REFUEL Ut/YR	LIFETIME FUEL Ut ALL 40 YEARS	2010	25 YEARS	SPENT TO DATE[A]
Barsebaeck 1	BWR	615	1975	80	18	630	450	720	432
Barsebaeck 2	BWR	600	1977	79.6	18	594	450	720	396
Forsmark 1	BWR	1004	1980	122.3	26	780	650	1040	494
Forsmark 2	BWR	1004	1981	122.3	26	754	650	1040	468
Forsmark 3	BWR	1090	1985	126	27.34	684	684	1094	383
Oskarshamn 1	BWR	460	1972	87.4	15	570	375	600	405
Oskarshamn 2	BWR	617	1974	89	15	540	375	600	375
Oskarshamn 3	BWR	1200	1985	126	29	725	725	1,160	406
Ringhals 1	BWR	780	1976	117	25.3	860	633	1,012	329
Ringhals 2	PWR	840	1975	68	15	525	375	600	210
Ringhals 3	PWR	960	1981	82.1	20	580	500	800	360
Ringhals 4	PWR	960	1983	72.2	15	405	375	450	240
					TOTALS[B]	**9,722**	**8,317**	**11,911**	**4,498**
						{7,700}	*{6,380}*	*{9,500}*	*{3,213}*[C]

Notes: A Assumed life of 30 years of continuous operation.
B Total spent fuel quantities based on design data and for guidance only – actual fuel throughput may vary considerably.
C Fuel figures enclosed thus *{}* are SKB data for 1996 and all fuel figures do not include for the deduction of 197 tonnes of fuel exported for reprocessing, about 20 tonnes of Agesta fuel and 23 tonnes of German MOX fuel, with the latter being exchanged for the 57 tonnes of Swedish fuel shipped to COGEMA – emboldened *{}* totals are higher because original (lower) reactor design fuel burn-up ratings adopted – these figures are used in subsequent analysis..

c Burn-up rate cited here is for 1992 - it is expected that fuel burn-up would have increased steadily in future years.

d The Agesta PHWR (about 20 tonnes) and the R2 and R2-0 R&D reactor and Kritz pile fuels are subject to a different storage/disposal management route.

TRANSPORTATION OF IRRADIATED FUEL

There are two phases of irradiated fuel transportation.

The first phase is the present movements of spent fuel assemblies from the NPPs to the central fuel storage facility (CLAB). This transport is undertaken in presently available spent fuel flasks without special treatment (encapsulation, etc) of the fuel assemblies being required.

The second stage, not yet undertaken, is the movement of the fuel stored at CLAB to the final disposal repository (SFL). For final disposal to the SFL, the fuel elements will be encapsulated, with the presently preferred scheme of the fuel assemblies placed within a copper cylinder.[4] However, the location of the encapsulation plant (either at CLAB or at the head of the SFL) has yet to be finally determined so, if encapsulation is at CLAB then a new transportation flask will have to be provided to move the encapsulated fuel to SFL, whereas if encapsulation is at the SFL then the unencapsulated fuel would be moved from CLAB in the existing type of flask.[e]

A quantity of Swedish fuel was contracted for overseas reprocessing,[5] some of which may have been dispatched to the reprocessor and some subject to an ‘exchange’ deal involving a quantity of German MOX fuel – the quantities involved here are relatively small and should not markedly revise the following estimates of irradiated fuel movements.

Irradiated Fuel Transportation Flasks – NPPs to CLAB

From 1972 up to 1985, or thereabouts, SKB deployed TN3, TN 11 and Excellox 3A flasks to move about 136 tonnes of fuel from the Oskarshamn power station,[f] thereafter the flask type adopted seems to have been, exclusively, the TN17 Mark II dry flask which was first introduced in 1982 by the jointly owned BNFL-COGEMA subsidiary Nuclear Transport Ltd.[6]

Fuel types are PWR and BWR:

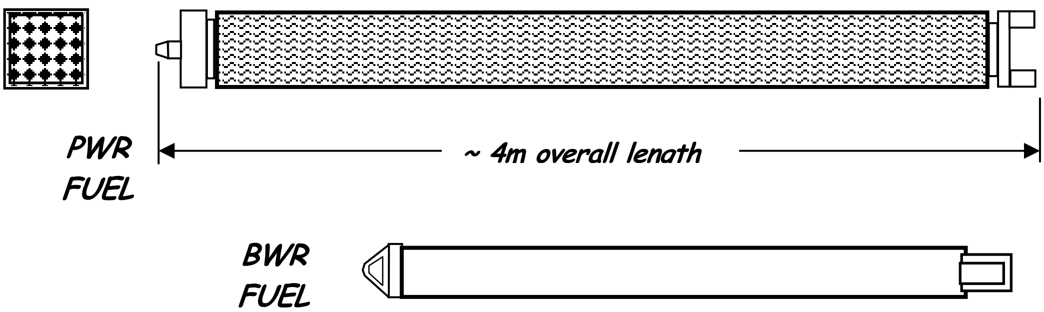


FIGURE 1

[e] It seems that the encapsulation plant is to be built at CLAB.
[f] Most probably, the Swedish contracted fuel to BNFL Sellafield for reprocessing.

FIGURE 1

Spent fuel transportation flasks are monolithic, carbon steel fabrications, approximately 6m length by about 2m diameter, weighing approximately 75 tonnes and capable of carrying 2 to 3 tonnes of irradiated fuel:

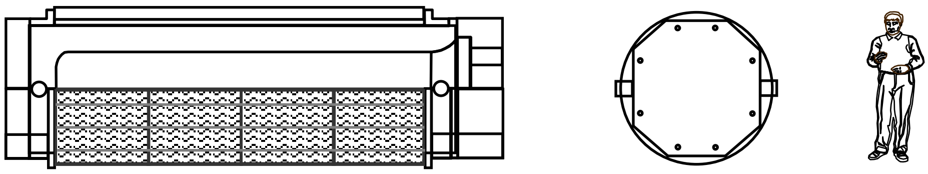


FIGURE 2

The spent fuel assemblies are racked within the flask fuel cavity in (usually) a boron steel cage or basket fabricated to suit the different types of fuel - a PWR rack will hold maximum of 7 fuel assemblies and a BWR rack 17 fuel assemblies.[g]

Flask Loading and Unloading

The fuel loading procedure for an empty flask varies with the particular power station but, generally, the flask is up-ended and lowered into the fuel pond. When fully immersed, with the lid removed to access the inner basket,[h] the individual fuel assemblies are inserted into the basket and the flask lid replaced and sealed.

The final operation is to inject nitrogen gas through a penetration valve to purge out the water within. The gas charge is then reduced to a sub-atmospheric pressure for the transportation phase, the penetration valve is closed and the flask lifted from the pond and external surfaces decontaminated and dried before transfer from the pond area.

For the transport of failed and/or damaged fuel, it is necessary to prevent the release of fuel fission products into the flask cavity. Damaged fuel is placed inside a separate and sealed capsule or bottle (called a multi-element bottle or MEB) which is put inside the flask.

Occasionally, fuel is transported from the nuclear power station site in a 'short-cooled' condition. Samples of irradiated fuel are periodically required for post-irradiation examination and for this it is necessary to return fuel to a specialised facility (sometimes back to the fuel manufacturer) without excessive delay. Such short-cooled

g The Oskarshamn TN3, TN11 and Excellox 3a flasks included a sealed fuel bottle within and are water filled – all fuel movements from Oskarshamn have now switched to TN 17/2 dry-filled flasks.

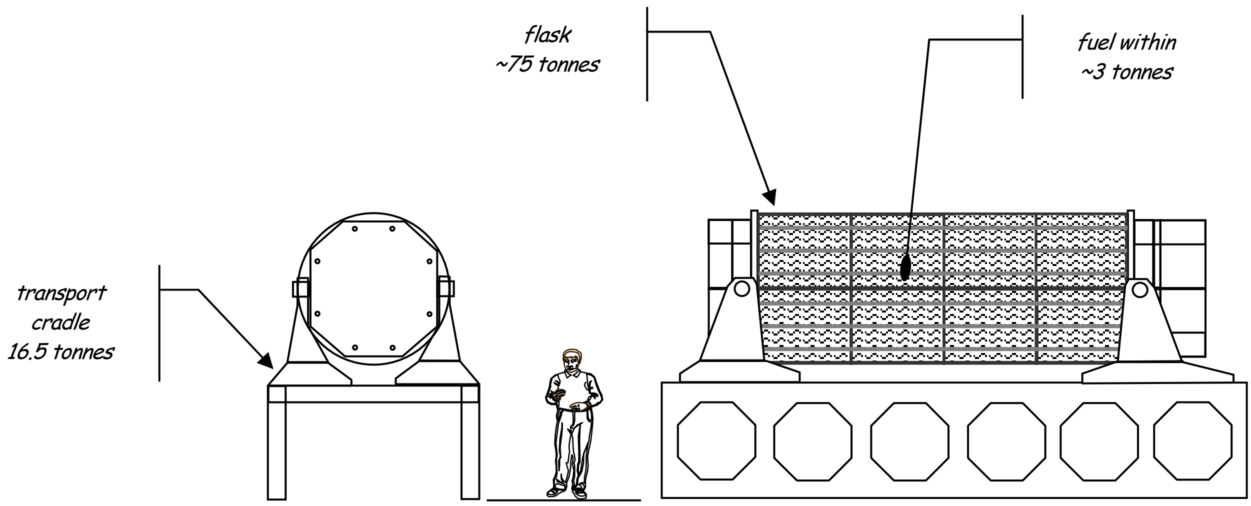
h The inner basket for dry-filled flasks, such as the N17/2, there is a substantial aluminium alloy block in which fuel channels are machined.

fuel is dispatched from the power station with the minimum of delay, usually at about 150 days following withdrawal from the reactor core. Like damaged fuel, short-cooled fuel is sealed within a capsule fitted within a standard flask but because the fuel heat generation rate is high, the capacity of a flask carrying short-cooled fuel is much reduced.

The final operation in preparation for transportation is to fit the flask with shock absorbers. Two shock absorbers, each comprising either a bulk of balsa wood or aluminium alloy honeycomb within a stainless steel wrap, serve to cap each end of the flask.

The flask, complete with shock absorbers, is slung by its trunnions in a transportation cradle – a low-back road vehicle moves this cradle from the flask pond/drying area to the ro-ro hold of the *M/S Sigyn*. Within the hold, the transport cradle locates in deck mounted brackets and is further strapped in position by a series of deck pivoted yokes.

At CLAB, the flask and cradle are unloaded from *M/S Sigyn* by a road vehicle, which transfers it to the CLAB building air lock. Thereafter with the shock absorbers removed, the flask is up-ended, moved to a cooling cell, and fitted with a jacket or skirt which permits an external cooling circuit to be operated around the flask. The flask internals are flooded and second stage cooling undertaken. Finally, the flask is transferred under water to a fuel reception bay where the individual fuel assemblies are removed and loaded into storage racks that are subsequently moved to the main holding pond of CLAB.



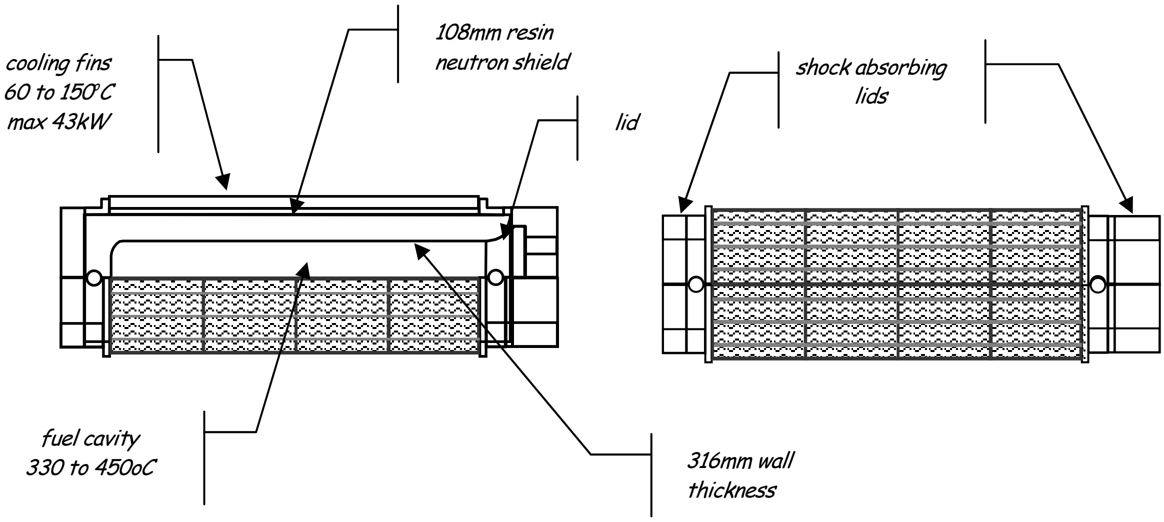


FIGURE 3

Encapsulated Fuel Movements – Clab to SFL

Assuming that the encapsulation plant is to be built at CLAB then, prior to transfer, the PWR/BWR fuel assemblies withdrawn from the CLAB storage pond, are to be dried and loaded into a segregated cast steel rack or insert which is placed and sealed within a copper canister.[7]

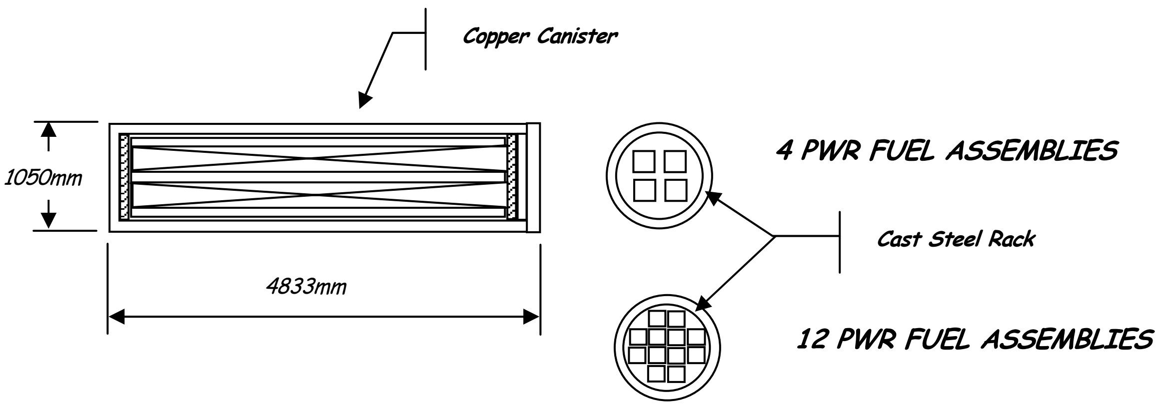


FIGURE 4

At this time, a proven transportation flask is not available for the CLAB-SFL fuel transfer, although analysis and outline flask design has been undertaken for this transport,[8] suggesting the following flask:

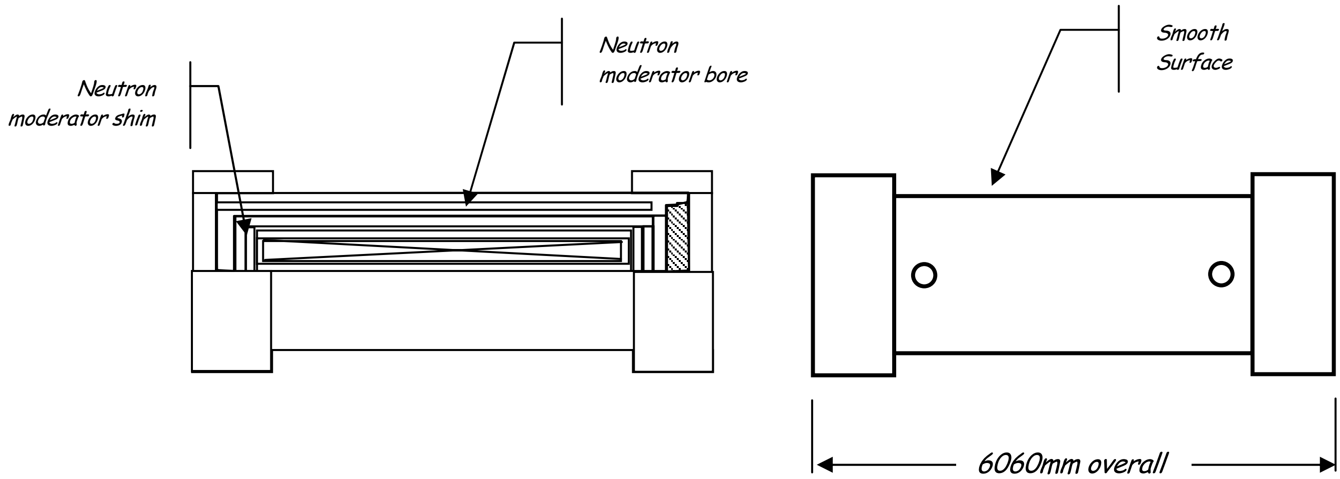


FIGURE 5

The main differences between this proposed encapsulated fuel flask design and the (unencapsulated) TN17/2 flask include a reduction in flask fuel capacity (from 7 to 4 PWR and from 17 to 12 BWR fuel assemblies), the thermal rating is reduced to 1.33kW$_t$ /Ut[i] for which the flask does not require external cooling fins, and that (although it is not entirely clear from the proposal) the flask is to be transported within a 'hood' or some form of slide- back cover.

Transportation of the flask is likely to be via the cradle carriage shown on FIGURE 2.

Number of Flask Movements

Although this review specifically relates to irradiated fuel movements, these should be placed in the context of all movements of radioactive wastes arising from the Swedish nuclear power programme overall. Sources and transfers of radioactive materials, undertaken if the proposed spent fuel deep repository disposal scheme (SFL) is implemented, will be:-[j]

[i] PWR at 1.33kW/Ut or 2.48kW/flask load and BWR at 1.3kW/Ut or 2.855kW/flask load.
[j] Excludes medical/research, etc., radioactive waste.

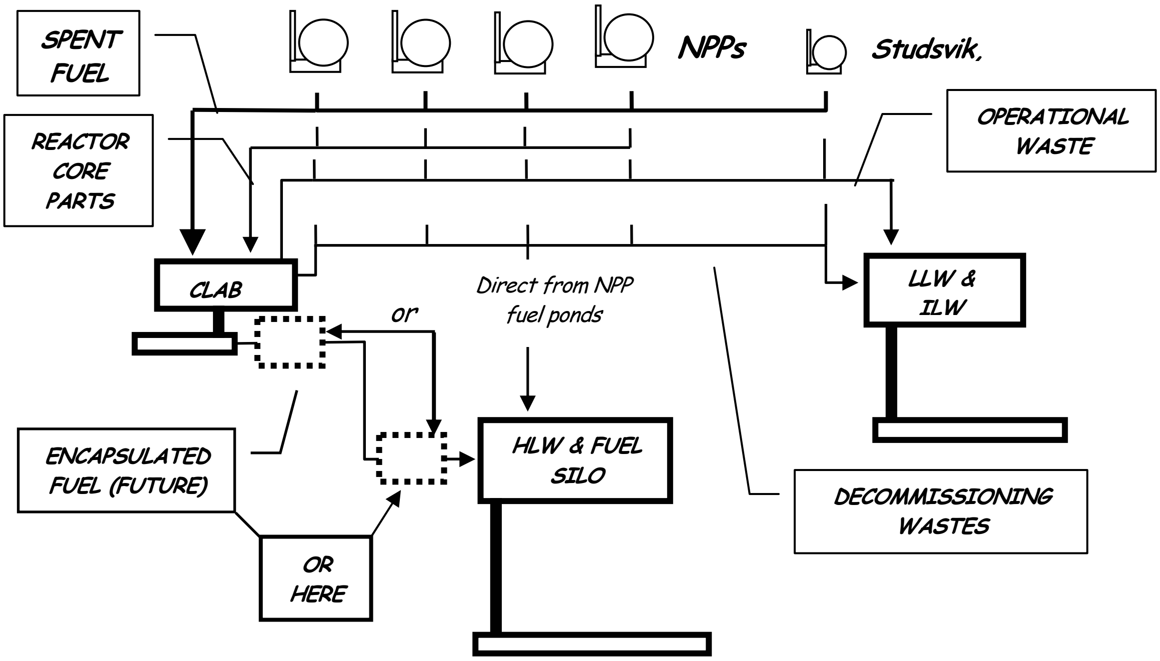


FIGURE 6a – ALL RADIOACTIVE WASTES

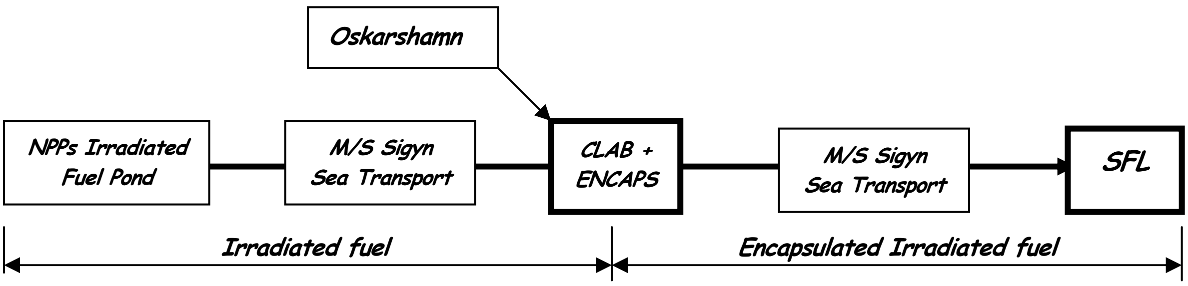


FIGURE 6b – IRRADIATED FUEL WASTES

In terms of final volumes of waste, the predicted[k] total flask movements, for the 25 and 40 year NPP operation scenarios are:

k Here the final numbers are very dependent upon the type of packaging and encapsulation treatment chosen for the wastes, particularly the wastes being ultimately disposed to the final SFL rock vaults, although the number of flask movements for fuel from the NPPs to CLAB is reasonably reliable because virtually no treatment or encapsulation is undertaken at this early stage of the waste management process. Throughout this text, it is assumed that the fuel encapsulation plant will be sited at CLAB and that the encapsulated fuel flasks will have the capacity as described by Knopp (8).

TABLE 3 PREDICTED TOTAL FLASK MOVEMENTS

WASTE TYPE	ROUTE	FLASK MOVEMENTS		COMMENTS
		25 YEARS	40 YEARS	
CURRENT & ONGOING MOVEMENTS:				
Spent Fuel	**NNP to CLAB**	**3,020**	**4,530**	Assumes 12/4 BWR/PWR assemblies per Flask
Core internals	NNP to CLAB	1,370	2,630	Thimbles, RPV shield rebuilds, control rods, etc
Other Fuel	Studsvik, etc	35	35	Destination unknown
LLW/ILW	NPPs to SFR	2,200	3,550	Operational and Includes ISO containers
LLW/ILW	CLAB to SFR	100	160	Operational waste
LLW/ILW	Studs to SFR	520	520	Operational wastes
POST YEAR 2008 MOVEMENTS (SFL COMMISSIONED):				
Spent Fuel	**CLAB to SFL**	**3,020**	**4,530**	Assumes encapsulation Plant at CLAB prior to SFL disposal and that 12/4 flask capacity is maintained for disposal copper cylinder – also assumes 15% of total fuel stockpile will PWR and that, on average, flask capacities are evenly utilised for both cases.
Core internals	CLAB to SFL	1,370	2,630	Core components for repackaging and SFL disposal
ILW/HLW	CLAB to SFL	425	600	Operational waste
ILW/HLW	Studs to SFL	280	280	Operational waste
ILW/HLW	Encap to SFL	60	100	Probably same site
POST YEAR 2030 MOVEMENTS (DECOMMISSIONING):				
ILW/HLW	CLAB to SFL	350	470	Decommissioning CLAB/Encapsulation Plant
ILW/LLW	NPPs to SFR	6,000	6,000	NPP Decommissioning and all ISO containers
ILW/LLW	Studs to SFR	100	100	Studsvik Decommissioning and all ISO containers
LLW/HLW	various to SFL	37	37	Redundant transportation flasks and containers

Source: Abbreviated Appendix 1 of Ref (9).

At year-end of 1995, 2,300 tonnes of fuel had been delivered from the NPPs to CLAB and this would have involved about 1,100 flask movements. Up to year-end 1995, 3,213 tonnes of fuel had been discharged from the NPP reactors, leaving about 913 tonnes of fuel held in the fuel storage ponds of the NPPs.

It is of interest to note that from year 2008 M/S Sigyn, or its successor, will be fully occupied for about 10 years just transferring the encapsulated fuel (25 year scenario) from CLAB to the repository.

Thus, to clear the NPP reactors and ponds completely of fuel at the end of the working lives for the 25 and 40 year life scenarios will involve: -

TABLE 4 FUTURE FUEL FLASK AND SHIP MOVEMENTS FOR THE NPP PROGRAMME[1] (ASSUMES ENCAPSULATION PLANT AT SFL AND NOT AT CLAB)

OPERATION	FUEL TONNES	FLASK MOVEMENTS		SHIP VOYAGES		COMMENTS
BWR FUEL DISCHARGED <96	2,487					
PWR FUEL DISCHARGED <96	727					Accounts for fuel at Oskarshamn NPP
BWR FUEL TO CLAB BY 96	1,780	810		135		Assumes BWR/PWR = core discharges
PWR FUEL TO CLAB BY 96	520	281		47		Assumes Sigyn loaded to 60% capacity
BWR FUEL IN PONDS AT 96	707					
PWR FUEL IN PONDS AT 96	206					
		25 YEAR	40 YEAR	25 YEAR	40 YEAR	
BWR TO BE DELIVERED TO CLAB		1,415	2,475	236	412	Accounts for fuel at Oskarshamn and
PWR TO BE DELIVERED TO CLAB		517	967	86	161	assumes Sigyn loaded to 60% capacity
BWR/PWR CLAB TO SFL		3,020	4,530	503	755	Assumes SFL not at Oskarshamn
TOTAL OVERALL[A]		**6,040**	**9,060**	**1,006**	**1,510**	
TOTAL AWAITED		**4,949**	**7,969**	**825**	**1,328**	

[1] TABLE 4 relates only to irradiated fuel movements and excludes core components, wastes and the other transfers featured in TABLE 3. If the NPP decommissioning programme is assumed to take 10 years following a dwell of 20 years after close down of the last NPP, and if all of the radioactive wastes are dispatched by ship to both the SFL and SFR disposal facilities then, on average, about 40 voyages per year (at 80% capacity) will have to be made over the 41 and 57 years NPP closure period for the 25 and 40 total service life scenarios identified by SKB.

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8 *Feasibility Study of a Transport Cask for the Transport of Canisters for Encapsulated Spent Fuel to Final Disposal*, Knopp U, GNB SKB 96-07, 1996

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