"OPTIONS FOR THE HANDLING AND STORAGE OF NUCLEAR VESSEL SPENT FUEL"

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Options for the Handling and Storage of Nuclear Vessel Spent Fuel

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Abstract:

There are many options for the handling and storage of spent nuclear fuel from naval vessels. This paper summarizes the options that are available and explores the issues that are involved. In many cases choices have been made, not on the basis of which is the best engineering solution or the most cost-effective, but based on the political realities involved. For example, currently it seems that the most prevalent solution for spent fuel interim storage is in dual-purpose (transport-storage) casks. These casks are robust and, politically, they offer the visible evidence that the fuel is 'road-ready' to be moved from the local area where the fuel is being stored in the interim. However, dual-purpose casks are the most expensive of the storage mediums. Drywell storage (storage in below grade or bermed pipes), on the other hand, the least expensive and most flexible storage option, suffers from an image of permanence (not politically acceptable) and from being improperly implemented in the past. Though these issues are easily resolved from a technical perspective, the option is often not seriously considered because of this past history.

It wasn't too many years ago that spent fuel pools were the storage medium of choice. The pools were never intended for long term storage. As the ultimate disposal path for spent nuclear fuel (processing, repository) became bogged down, however, fuel remained stored in the pools for much longer than intended. Strategies (re-racking, consolidation) were employed to lengthen the storage life of the pools. In some cases, inadequate attention was paid to the wet storage and significant fuel degradation occurred. Pools were then unloaded into dual-purpose or storage only casks as required.

It seems that decisions on spent fuel historically have been short sighted. It is time that the spent fuel situation needs to be evaluated for the long term from a systems perspective. Criteria for the evaluation must consider technical acceptability, safety, flexibility (especially in storage times, fuel condition, and fuel types), active monitoring, costs, security, and, of course, political realities. It is the sense of this author that the political issues may be resolved if a reasoned complete approach is demonstrated.

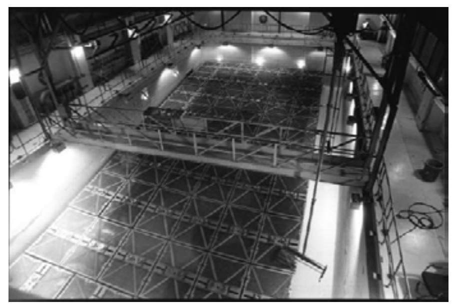
Background

For many years the storage of spent nuclear fuel seemed to be an afterthought. Fuel was typically stored in storage pools that were not designed for long-term storage. In many instances, earlier pools did not maintain adequate water chemistry control and fuel degradation occurred. In other instances fuel was stored in below grade drywells or vaults. These storage mediums also often were inadequately designed and monitored such that fuel degradation occurred. When the time lengthened for the ultimate disposal of fuel (either through delays in reprocessing or decisions on ultimate disposal in a repository), the reality of the magnitude of high level radioactive waste and spent nuclear fuel issue was highlighted. This realization also seemed to occur at the same time as the 'environmental awakening' --- bringing public scrutiny to the issue as well. Conditions became such that utilities (and later governments) needed to show progress on resolving their spent fuel issues. As a minimum from a technical perspective, the fuel had to be moved to a dry environment. It would also be better if the interim spent fuel storage option chosen could be perceived to move the fuel towards it ultimate disposal path.

<u>Options for Spent Fuel Handling and Storage</u>

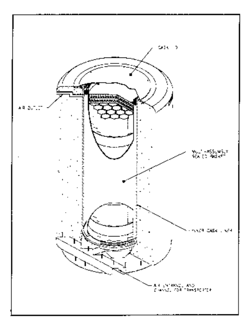
The various types of spent fuel storage that one should consider are summarized below:

1. Pool storage – this type of storage places spent nuclear fuel (SNF) underwater in storage racks. The water provides cooling and shielding, plus allows good visibility for verification. Monitoring the chemistry of the water also provides a good indicator for problems with the fuel. This method is what typically has been used for interim storage at commercial nuclear power plants and the storage of nuclear vessel fuel waiting for processing. Water-cooling is necessary to allow for the short-term removal of decay heat from the SNF after it is removed from a reactor but pool storage was never intended for long term storage (>10 years) of SNF due to corrosion in the water environment. In fact, corrosion and degradation of SNF in water storage pools has been a major issue in the U.S. (and elsewhere), particularly for non-commercial fuels. Consequently, since reprocessing fuel is no longer permitted in the some places or is uneconomic, a final disposal repository is not yet ready, long term storage of SNF is the only option. Consequently, most commercial entities and governments are moving their SNF to dry storage.



Pool Storage in France

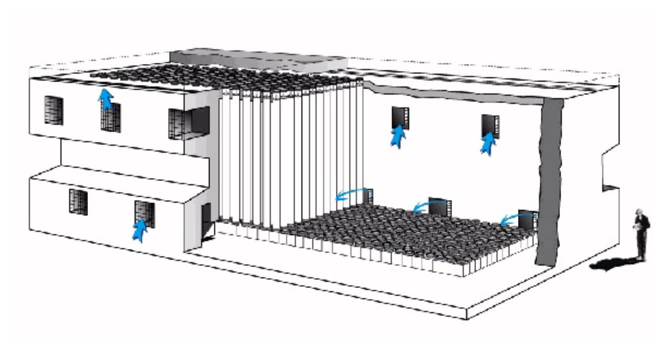
2. Dry storage in casks – this type of storage places SNF in casks designed to serve storage and/or transport requirements. The casks include shielding and passive cooling for the SNF. If designed for transport, exceptional strength and durability to withstand transportation accidents are included in the design. The casks may also include a neutron poison to allow for storage of additional SNF elements. This type of storage has been the predominant storage method chosen by the commercial nuclear power industry in the U.S. Cask vendors have already paid for the initial licensing and incorporated those costs in their cask price. In addition, the USNRC has made it easy to license cask storage as long as the storage is at a licensed nuclear power installation.



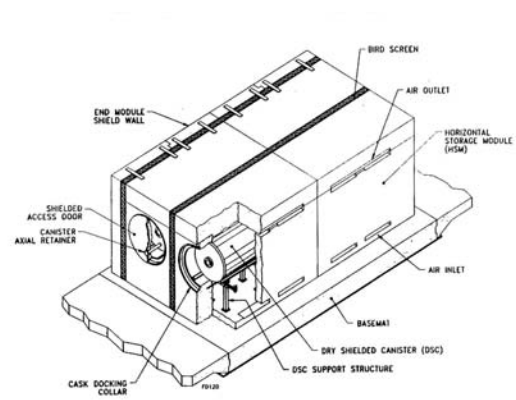
Sirra Pacific Vertical Concrete Cask

3. Dry storage in vaults – this type of storage places SNF in shielded vaults or engineered structures. Typically, individual fuel elements are placed in individual storage pipes. Shielding is typically provided around the entire vault and the movement of fuel elements is done remotely. Passive cooling or active cooling can be provided as part of the design as required. This type of storage was developed in the U.S. particularly to deal with SNF that could not withstand a direct water environment (e.g., graphite fuels). A good example of this type of storage in the U.S. is the Independent Spent Fuel Storage Installation (ISFSI) at the Fort St. Vrain power plant near Ft. Collins, Colorado. Vault storage was also used at DOE's Idaho National Engineering and Environmental Laboratory (INEEL) in Idaho. Internationally a good example is the MACSTOR system in Canada.

It should be noted that the NUHOMS design for horizontal vault storage is a hybrid combination of cask and vault storage.



MACSTOR Vertical Vault System



NUHOMS Storage System

4. Dry storage in drywells – this type of storage places SNF in individual canisters which are then placed in pipes ('drywells') that are buried in the ground or in a berm. The ground provides the heat sink as well as the shielding for the SNF. Typically, the drywell pipes have been made of carbon steel and cathodically protected to minimize corrosion. Alternatively, future designs may be able to make use of advanced coating technology to save money. Similar to storage in vaults, this type of storage was originally designed for SNF that could not be directly stored in water. This type of storage has been used successfully in the U.S. at DOE installations such as Argonne National Laboratory-West, Oak

Drywell storage at Argonne National Laboratory

Ridge National Laboratory, and the Idaho National Engineering Laboratory. Internationally it has been used successfully at Tokai in Japan and the Lucas Heights Storage Facility in Australia.

Table 1gives a relative cost of these storage options[1]:

Storage System	Relative Costs
Cask – dual purpose	1
Storage Cask	.61-.86
Vault	.62-.75
Caisson (silo)	.5 - .6
Drywell	.29 - .6

Historical Perspectives

Through the early 1980s, the spent fuel industry was fairly balanced in its approach to storage options. In the latter 1980s and on, however, this balance shifted towards storage in casks, particularly in the U.S.:

- U.S. Commercial perspective - The U.S. commercial power industry has typically used above ground casks and vaults for dry storage as their spent fuel storage pools have filled up. It is important to understand the driving forces behind these decisions. In a regulated utility environment, costs of spent fuel storage are recovered through regulated rates. Predictability of those costs and stability of the time schedules have a stronger influence on the ability of the utility to recover these costs through the regulatory process than does the magnitude of the cost. The aboveground casks and vaults have a clear advantage because these storage designs have already been issued a Certificate of Compliance (CoC), i.e. they are a tested and proven technology, and local public hearings (with their potential for delays) are not required. Since the above ground storage design has the least interaction with the site, it is less susceptible to court challenges that local site-specific considerations have not been addressed. Storage in dual-purpose (transport-storage) casks also has the advantage of being perceived as 'road-ready' to be moved to the final repository or reprocessing site. This is a naturally positive attribute to the local public.

  Cask designs also provide a unique economic driver for potential manufacturers or vendors of casks. The motivation for a cask vendor to obtain a NRC license is directly related to the patentability and corporate profit potential of the storage system. For example, a company will develop a dry cask design, patent it, and license it when a market niche is identified for the product. That company is willing to incur the substantial cost of the initial NRC cask licensing process because it holds the patent

[1] Based on engineering judgement from 'Cost Comparisons for On-Site Spent-Fuel storage Options', EPRI NP-3380 Project 2062-8, May 1984, and "Storage Technology Options Study for BN-350 Spent Fuel Storage, November 28 2000.

to ensure that it alone can sell the patented design after it is licensed. In contrast, a simple drywell system that has been described in the scientific literature and used in the AEC/DOE complex for approximately 40 years qualifies as a public domain technology that is not legally patentable. In this scenario there is no profit incentive for a commercial company to pursue the licensing of the drywell storage system, because after they license it, anyone can sell or use the technology.

- U.S. DOE perspective - Many DOE sites have spent fuel storage that was built under DOE regulations. Historically, these regulations have allowed much more flexibility in choice of technologies and options. Suffice it to say, just about every type of spent fuel installation has been built in the DOE complex, including six drywell storage facilities. In the last 10 years, DOE has come under increased scrutiny of its nuclear installations – culminating in detailed reviews and upgrades of many of its installations. Currently and in the future, public scrutiny of new installations will rival that of commercial installations under NRC control. Consequently, DOE is dealing with this process by 'privatizing' the design and construction of nuclear facilities, and requiring the contractor to obtain a NRC license as part of the process. Insofar as future spent fuel storage is concerned, this means contractors bidding on DOE contracts for Independent Spent Fuel Storage Installations (ISFSIs) will also tend to opt for above ground casks or vaults that have CoCs. This makes their costs much more predictable. Though the costs may be relatively high, they are readily defendable and 'pass-through' easily for DOE payment under the contract.

  Another aspect of DOE involvement with spent fuel in the U.S. is its mandated obligation to receive and store commercial spent nuclear fuel. The final repository for such fuel is currently a geologic repository being built at Yucca Mountain, Nevada. Concomitant with this obligation is for DOE to receive commercial spent fuel in the interim and store it in a Monitored Retrievable Storage (MRS) Facility.

- Other Countries' Perspective - Dry storage of spent nuclear reactor fuel began in the United Kingdom in 1972 and in Canada in 1975. At least ten countries have experience with dry storage of spent power reactor fuel. The International Atomic Energy Agency (IAEA) has monitored experience with dry storage in these countries since 1980 and it issues periodic reports on the subject. The most current IAEA guidance for safety criteria associated with spent fuel storage is contained in:

  - "Fuel Handling and Storage Systems in Nuclear Power Plants," Safety Standard 50-SG-D10 Rev. 2 (1997),

  - "Design of Spent Fuel Storage Facilities," Safety Series No. 116 (1994), and

  - "Preparation of the Safety Analysis Report for Spent Fuel Storage Facilities: A Safety Practice," Safety Series No. 118 (1994).

  This guidance is compatible with current NRC licensing procedures although the IAEA does not explicitly recognize the "general license" approach. The guidance is also fairly broad, allowing the full array of storage options, including casks, vaults, and drywells.

It should also be noted that the spent fuel storage licensing history in other countries has not skewed itself towards 'pre-licensed' casks or vaults as has occurred in the U.S. since their licensing history is different.

- Former Soviet Union Countries' perspective – As in the U.S., the storage of spent fuel in the countries of the former Soviet Union followed a path using virtually all the various storage options. Similar to the U.S., problems with wet storage have led to degraded and damaged fuel in many circumstances. In addition, the final disposition of spent fuel (typically reprocessing at Mayak) has reached a choke point due to lack of transport, costs, and the lack of a specific need for the reprocessed product. Because of this, it now appears the general storage for naval spent fuel is to have regional storage locations where pads can be constructed for interim storage of spent fuel in either storage or dual use casks. In-country capability to produce casks has long existed and current innovative designs have been developed spurred on by U.S. financial aid (AMEC/CTR). In this regard, the U.S. DOE/DOD preference has been for SNF storage systems that have been previously licensable or are easily licensable in the U.S. As a consequence, the U.S. preference for storage in casks seems to be carrying over to Russia.

<u>Technical Issues</u>

- Long Term storage of SNF Greater than 10 years - Most SNF storage concepts developed around the world did not consider the need for long-term storage of SNF greater than 10 years. This is particularly true for pool type storage. The basic premise had been that the pools were for storage for a very limited amount of time until the fuel could be transported for final disposition (either reprocessing or long-term storage at another location). Consequently, when these intended scenarios did not occur, unplanned for consequences occurred - corrosion set in with the fuel, causing it to degrade and release radioactivity to the fuel pools; and fuel pools leaked, contaminating groundwater. Other types of storage including rudimentary drywell and vault storage also experienced problems such as moisture in-leakage and fuel corrosion. The fact was that the storage simply had not been designed considering long-term storage and what could possibly happen to the fuel in the meantime.

  As a consequence, in the last 10 years, there has been a large dollar investment in order to:

  - characterize SNF that has been in storage to better understand the degradation mechanisms taking place,

  - properly condition fuel for dry storage for the long term based on that knowledge gained,

  - remove fuel from water pools to dry storage for the long term, and

  - upgrade existing dry storage facilities to incorporate features to minimize degradation for the long term.

  Basic design requirements for long-term storage developed because of the above include:

  1. assuring the SNF is properly dried to inhibit corrosion. For fuel coming out of a water pool, this generally means some type of vacuum drying technique.

  2. assuring the SNF is stored in a dry environment – this means that the storage atmosphere is assured to be initially dry and maintained that way through application of leak-tight barriers. If the fuel was degraded or failed, application of an inert cover gas and double canning is necessary.

  3. assuring the capability to periodically monitor the performance of the fuel in dry storage by sampling, inspection, gas space monitoring, or by other indirect methods.

  4. repackaging degraded or damaged fuel in additional leak tight inerted canisters

- Local vs regional vs remote storage – This is a significant issue. As soon as one transports spent fuel beyond the confines of where it is initially offloaded (such as away from the plant or shipyard) into a public access area, one is usually required to meet very strict transport standards. This requires the use of heavy transport casks designed with impact limiters, etc. which is obviously expensive. If one has the transport casks available and can ship to the final repository area, it is an advantage. If one can stay local and avoid this cost, it is an advantage. If one opts for regional storage, one is usually opting for a cost trade-off between the cost savings of a centralized facility (with the increased transport costs) and that of several smaller local ones with the lesser transport costs.

- flexibility – fuel type variability - life extension – Due to the unknowns in the ultimate disposal path of spent fuel (schedules for reprocessing or a repository), storage designs should be made as flexible as possible. For handling of naval vessel spent fuel, this flexibility is extremely important. For example, if a particular storage design can handle various types of spent fuel merely by changing inserts in the casks, vaults, or drywells, significant savings could be accrued. Likewise, ease of retrieval, robustness of the design (for calculation of any life extension) would also be important.

- ease of fabrication/building – some storage designs are amenable to local fabrication and manufacture. For example, many vault and drywell storage designs can be fabricated using the facilities that would typically be available in a shipyard or large industrial facility. On the other hand, storage or dual purpose casks require very sophisticated manufacturing process that must be tailored to the specific product in order to maintain the desired quality. In addition, since many of the cask designs are proprietary, the details of the design are often not available to the end user.

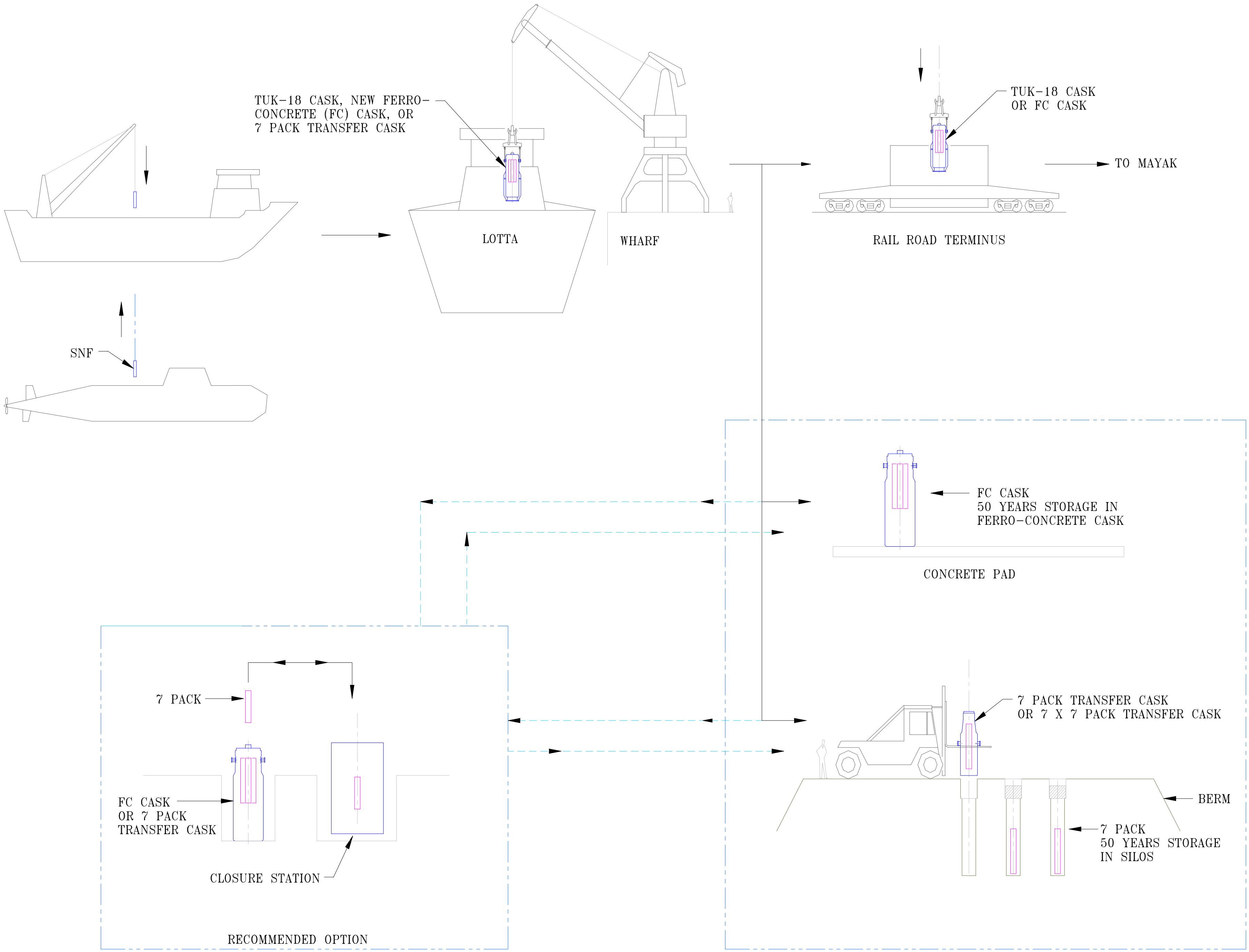
- licensability – A large portion of the cost of dual purpose casks resides in the licensing certification process. This cost is then passed on to the end user who benefits from knowing that he will not have any licensing or regulatory issues if he uses that design. In many instances, this foreknowledge is worth the extra cost. It should be emphasized, however, that there is no technical reason why the in-place storage options (vaults and drywells) are not easily licensable. It is necessary, however, to be proactive with public involvement to ease the process. Being able to construct the facilities with local labor should be a significant advantage in the communication process.

- Security/MPC&A – With increasing concern about terrorism, security of storage facilities is extremely important. All designs should be amenable to active monitoring and have appropriate layers of security to prevent their compromise.

- Political realities – No one wants nuclear fuel stored in their backyard. However, the most satisfactory solution (shipping the fuel to ultimate disposal or reprocessing) is usually not viable for many years into the future. In the U.S., having fuel stored in dual storage – transport casks has seemed to be an acceptable solution at power plants since they appear 'road-ready' to leave the state as soon as possible. Though this solution is expensive, utilities do this because they are likely to get reimbursed fore their work form ratepayers. Where reimbursement is not practical due to the lack of money, harder political work must be done. Full engagement with the public on the nature of the problems, the costs, and trade-offs involved is necessary for success.

Conclusion

In the last decade, the world seems to have focused on the use of storage or dual use casks for the interim storage of spent nuclear fuel. This is not the most cost-effective approach but seems to have been done mostly for political reasons or because the entity desiring to store the fuel can obtain the money. It is well known from an economic perspective that it is much more cost effective if one can postpone a significant capital expenditure until one actually needs it. A good systems analysis of the spent fuel issue for a region is recommended employing the most cost effective storage technologies (using the criteria discussed above). This should include regional or local storage as much as feasible (to minimize the high costs of 'public' transport and minimizing the number of transport casks required). Proactive public outreach is necessary to be successful under any circumstances. In the end, one would hope to have a flexible spent fuel process sheet as is depicted below.



Possible Flexible Process Flow for Interim Storage and Treatment of Russian Naval Spent Fuel