INTEGRATED CASK STORAGE SYSTEMS FOR STORAGE, TRANSPORTATION, AND DISPOSAL OF SPENT NUCLEAR FUEL

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The Tennessee Valley Authority (TVA) has been active in exploring alternatives for spent nuclear fuel management since the mid-1970s when it became apparent that there would be substantial delays in reprocessing. In 1979 TVA completed a comprehensive study of storage alternatives from which we concluded that (1) it was desirable to utilize existing plant storage pools to the extent practical and provide any additional storage that may be required at the power plant site, (2) we should be prepared to store spent fuel onsite indefinitely, and (3) it was desirable to develop passive dry storage systems as alternatives to building new pool storage facilities. TVA has sponsored or participated in conceptual design studies of various forms of dry storage vaults, silos, casks, and caissons and has undertaken limited demonstrations of rod consolidation and cask dry storage at TVA's Browns Ferry Nuclear Plant in Alabama in cooperation with DOE and others.

Early in our work we realized the importance of considering the back end of the nuclear fuel cycle as a system that must be effectively integrated rather than several fragmented and unrelated problems that can be addressed separately. Therefore, in choosing a future course for our spent fuel management activities, we undertook to evaluate the information we had obtained by taking an overall integrated systems approach that included onsite storage, transportation, offsite storage if necessary, and disposal in a geologic repository. This, of course, involved trying to deal with a great many uncertainties with regard to how much spent fuel will be produced, when will the Government actually accept the fuel, as well as performance, licensing, and cost uncertainties related to the various technologies. Since the preferred technology choice can depend on the outcomes of these uncertainties, we adopted probabilistic evaluation methods where we quantitatively describe the uncertainties. Use of these methods permits making choices that have a high probability of success, as well as incorporating credit for flexibility to respond to changing conditions as the unknown future unfolds.

The Nuclear Waste Policy Act of 1982 (NWPA) has established procedural requirements for resolving institutional issues and provides an open-ended means of financing the Government's waste management activities. It, however, has done little in constructively getting this work done. I think it is fair to say that the perceptions are that we are further away from demonstrating onsite dry storage and getting a repository in place now than we were in 1982 when the NWPA was passed. Even based on DOE's success-oriented mission plan, it appears very unlikely that DOE can begin disposal by 1998 as prescribed by the NWPA. Yet DOE assures utilities that DOE will accept their spent fuel by then and there will be no need for additional onsite storage facilities. This representation is presumably based on DOE's contractual obligations and hopes that Congress will authorize a monitored retrievable storage (MRS) facility. This is by no means ensured, and siting an MRS could prove to be at least as difficult as getting a State to accept a repository. We are particularly concerned that DOE and NRC are not diligently pursuing research, development, and demonstration work in support of new onsite storage technologies and DOE is becoming committed to orchestrating its programs around a mission plan that is not achievable. We are also concerned about the apparent complacency of many utilities and public utilities commissions that DOE will somehow accomplish the objectives of the NWPA simply because they are the law. A careful reading of the NWPA and the DOE contract indicates that the only remedy available if DOE fails to perform is to revise the schedules and increase the fee paid by the utilities which is to be passed on to their ratepayers to cover whatever it may eventually cost.

From the spent fuel management systems studies that we have done, we have come to believe that it is essential that DOE take an integrated systems approach, with realistic consideration of uncertainties, in developing and carrying out a progressive program. Our studies indicate that a major departure from previous directions may be appropriate. The development of integrated cask systems for onsite storage, transportation, offsite storage if necessary, and perhaps use as a disposal container could completely revolutionize high-level waste management. Our analysis indicates that such systems potentially have:

- Greater flexibility to deal with uncertainties
- The lowest overall cost to ratepayers for managing nuclear waste
- The lowest occupational and public radiological dose commitments
- Several other desirable social and environmental attributes

I would like to share with you the study we did which illustrates the potential value of an integrated systems approach to spent fuel management and has been very helpful in developing our views on this subject.

In preparing to analyze a large number of diverse alternatives, we decided to base our analysis on full life cycle cost, including decommissioning of storage facilities, spent fuel shipment, and disposal. This permits tradeoffs between these sectors to reduce overall costs to TVA's ratepayers. When we started developing this procedure, we assumed TVA would be responsible for all aspects of spent fuel management through delivery to the DOE repository. With passage of the NWPA, the scope of our direct responsibility was limited to onsite storage; however, it continues to be appropriate to consider the overall cost to our ratepayers.

How much spent fuel a plant will produce over its lifetime and when DOE will actually accept spent fuel at a rate greater than the rate at which it is being produced are the major factors which will determine how much spent fuel storage capacity a utility will need. These are subject to considerable uncertainty. A subjective assessment of these factors is shown in Table I. From this assessment we see that there is very little possibility that DOE will be accepting fuel on a large scale before the turn of the century, there is a 50/50 chance that they will by 2008, and there is a 10-percent chance it may be after 2017. This assessment was made in 1982 before passage of the NWPA and appears to continue to be appropriate today. The useful service life of a nuclear plant is the principal indicator of how much spent fuel it will produce. From this table, it is seen that the expected life falls well within the 30 to 40 years generally used for financial purposes.

TABLE I

Subjective Assessment of Major Uncertainties that Affect Utility Spent Fuel Storage Needs

Cumulative Probability (%)	DOE Acceptance (Date)	Nuclear Plant Nominal Life (Years)
0.1	1998	9
10.0	2001	21
25.0	2004	27
50.0	2008	33
80.0	2013	42
90.0	2017	47
99.9	2030	70

However, this distribution recognizes the possibility that it may be significantly shorter or substantially longer which would make a large difference in the amount of spent fuel storage that will be needed. At this time we do not and cannot definitely know the outcome. We can only take these uncertainties into account by planning to provide the flexibility necessary to deal with them as the future is revealed.

The effects of these uncertainties on the spent fuel storage needs of TVA's Sequoyah Nuclear Plant are illustrated in Fig. 1. While there are plants that have earlier needs and plants that have later needs, Sequoyah is probably about representative of the typical industry situation.

The cumulative spent fuel discharges versus time are plotted for the 10-, 50-, and 90-percent cumulative probability level that the actual discharges will be equal to or less than the indicated amount. It is seen that beyond the year 2000 there is great uncertainty in spent fuel discharges.

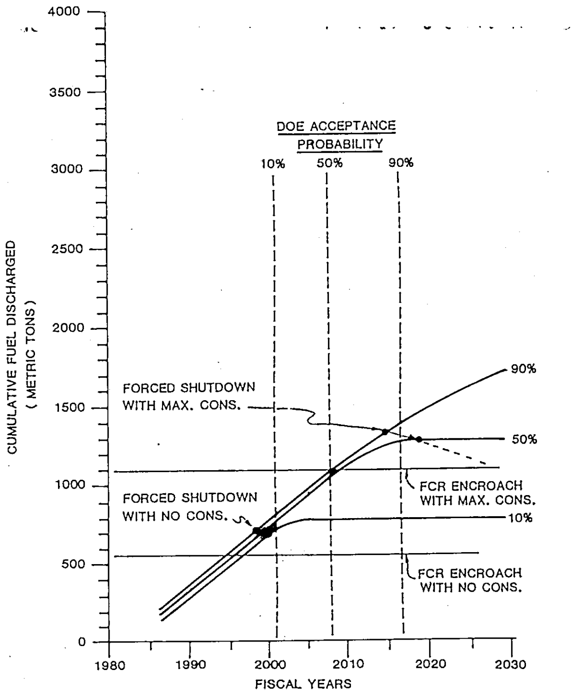

Fig. 1. Reference Nuclear Plant Probabilistic Spent Fuel Storage Requirements Forecast.

Superimposed over these are two horizontal lines that indicate plant storage capacity with and without expanding in-plant storage capacity through rod consolidation or other means. Uncertainty in when DOE will begin receiving the fuel is also shown as vertical lines. This figure illustrates the bounds for planning spent fuel management for TVA's Sequoyah plant.

For Sequoyah, we see there is a 10-percent chance that we will encroach on full core reserve by mid-1994. If we do nothing, there is a 10-percent chance that the plant will be forced to shut down by 1997. Considering the uncertainty of when DOE will actually take TVA's fuel, as well as the uncertainty in how much spent fuel we will produce, we expect to need additional onsite storage of about 532 metric tons. There is, however, about a 10-percent chance that our storage needs could be as little as 240 or as much as 725 tons. If we increase the effective storage capacity through rod consolidation or other means by a factor of 2, then the expected additional onsite storage requirements are reduced to 33 tons.

Similar results for all of TVA's nuclear plants are shown in Table II. I would like to call your attention in particular to the column indicating the Expected Additional Storage Duration. This includes the time it will take DOE to work off the backlog of fuel once they are able to start shipping fuel at the nominal production rate. It is seen that we expect to have this fuel in auxiliary storage for some time. Like most other utilities, TVA does not have a particularly pressing spent fuel storage problem and we can afford to take a long-term view of developing the most effective means for dealing with the large-scale spent fuel management problems of the 1990s when our and most other utility needs will materialize.

TABLE II

TVA Spent Fuel Storage Needs

	10% Prob. Full Core Reserve Encroachment (Fiscal Yr.)	Additional Spent Fuel Storage Needs (Metric Tons)			Expected Additional Storage Duration (Years)
		10% Prob. Less Than	Expected Value	10% Prob. Greater Than	
With No Consolidation					
Sequoyah	1994.5	230	532	725	25
Watts Bar	1997.5	160	333	640	19
Browns Ferry	1999.0	0	371	650	12
Bellefonte	2009.0	0	35	200	2
With Full (2.0) Consolidation					
Sequoyah	2008.5	0	33	175	3
Watts Bar	2010.5	0	19	130	1
Browns Ferry	Never	0	0	0	0
Bellefonte	Never	0	0	0	0

These probabilistic methods provide some valuable insights into economic and technological risks, as well as placing a value on flexibility, when it is necessary to make decisions under uncertainty. Perhaps the greatest value of this methodology is that it requires a systematic examination of the problem and permits a quantitative measure of relative risk.

By taking an overall systems approach, it appears possible and desirable to develop an integrated cask system suitable for storage, transportation, and disposal with no compromise in safety. In such a system, once the fuel is placed in the cask at the reactor, it would never be removed unless a decision is made to reprocess the fuel (then the container could be reused for the reprocessing plant waste disposal). Fuel is consolidated, placed in cask for onsite storage, and is eventually shipped to the repository. The economics of shipment are completely different than traditional considerations when fuel is dedicated to a particular cask. Preliminary engineering studies indicate that self-shielding repository waste packages appear to be an attractive option for repository design. These self-shielding waste packages are very similar to dry storage casks.

Figure 2 illustrates the reference case for managing spent fuel using auxiliary pools for onsite storage, shipment to an MRS or geologic repository, use of drywell storage at an MRS if one should be required, and disposal of canned consolidated fuel in a repository bore hole. This concept would require several special facilities and would involve repackaging or handling the spent fuel several times. We understand that DOE recently selected the concrete silo as the preferred technology for an MRS and the drywell as the backup alternative. For comparison, Fig. 3 depicts the use of metal casks with unconsolidated fuel for onsite storage, transportation, and storage at an MRS. Facilities and handling requirements onsite and at an MRS would be greatly reduced. Operations at a repository, however, would not be affected since the fuel would still need to be consolidated, canned, and placed in a bore hole in the repository. Fig. 4 depicts the so called "universal cask" concept in conjunction with an MRS. The apparent simplicity of this concept is very appealing.

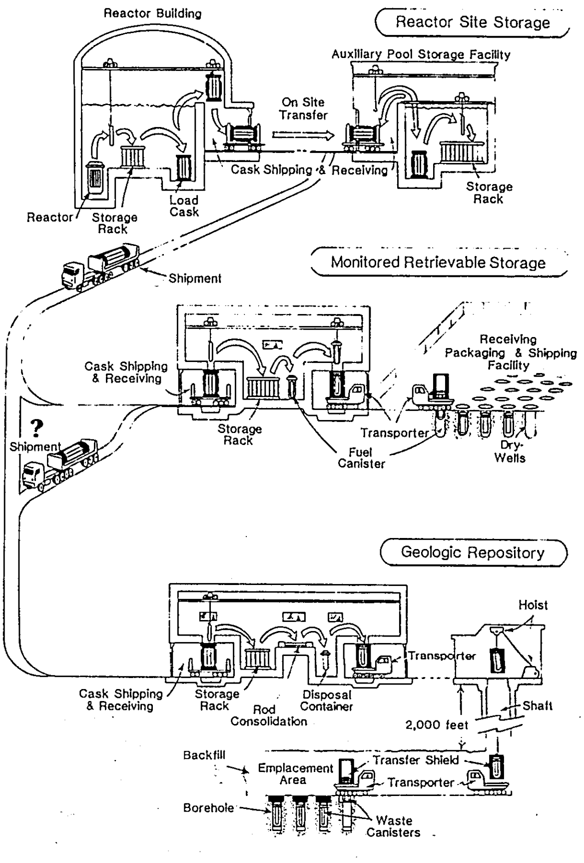

Fig. 2. Spent Nuclear Fuel Management Reference Case.

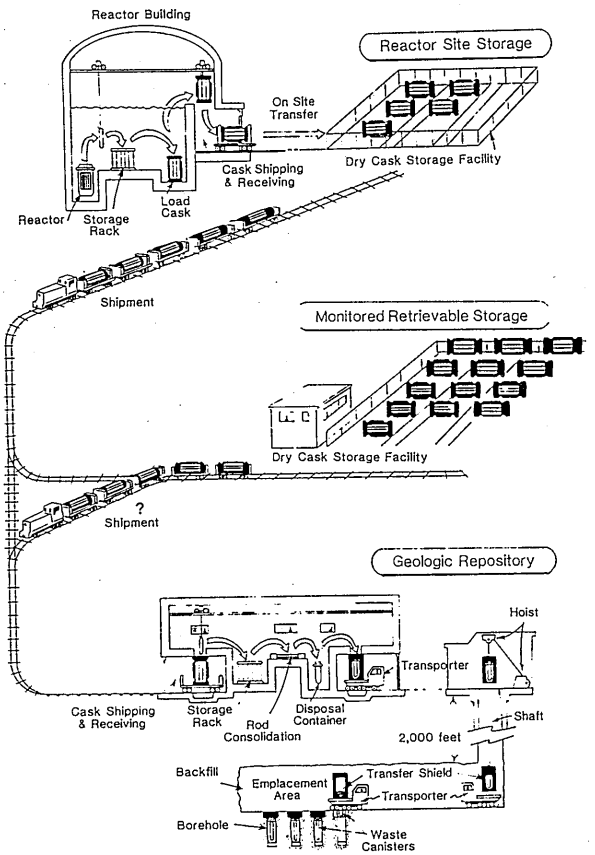

Fig. 3. Spent Nuclear Fuel Management Integrated Storage/Transport Cask Design.

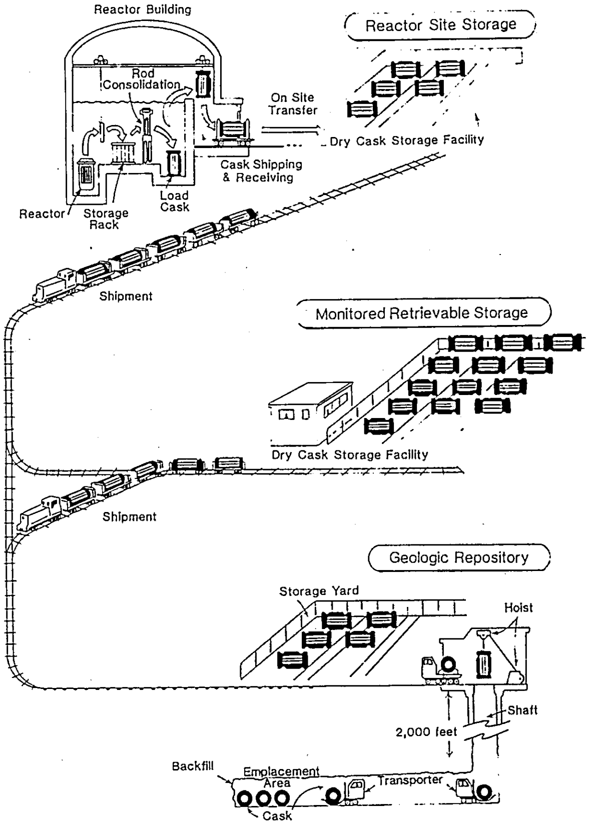

Fig. 4. Spent Nuclear Fuel Management Universal - Storage/Transport/Disposal/Cask-Design.

In order to examine the potential benefits of developing integrated cask storage systems, we have carried out a preliminary study of alternative cask designs based on the needs of our Sequoyah plant. The decision flow network used for comparing conventional pool storage and various cask design alternatives is shown in Fig. 5. While there are many other possibilities, these 11 cases serve to examine the range of interest. In the decision tree, the first choice is whether or not to consolidate fuel. If we choose not to consolidate then our choices are to provide additional pool storage or use dry cask with unconsolidated fuel for which we have several choices of cask size and use. The 3-ton unconsolidated cask represents the GNS Castor 1C technology, and the 10-ton cask would correspond to the REA cask technology both of which we hope to have successfully demonstrated in a few years. Both of these casks can potentially be licensed for shipment. Ten tons of unconsolidated fuel is about the practical handling limit of dry cask capacity which would have a hook weight of about 100 tons, loaded. However, with consolidated fuel that is 10 years old, it appears feasible to get about 20 tons of fuel in a cask weighing about 100 tons, loaded. Therefore, for simplicity we only consider the larger cask in examining the potential for the three use options with consolidated fuel. The principal difference in the two consolidation branches is whether the fuel is consolidated and placed directly in a cask which is then stored onsite or whether the fuel is consolidated and placed back in the pool storage racks until it is necessary to make room for more discharged fuel.

The results of an economic analysis of these alternatives for the expected conditions previously described for TVA's Sequoyah Nuclear Plant are shown in Table III. The pool storage option, case 1, is used as a base. Results are presented in terms of present worth of saving in 1983 dollars over this option. The total cost of spent fuel management is considered and is divided into onsite cost which will be paid directly by utilities and offsite cost which is within DOE's scope of responsibility but will be paid by utilities through the waste fund fee. The total cost will of course be paid by the ratepayers and is the appropriate overall objective.

The smallest capacity storage cask technology will save about $25 to $30 million over pool storage. While investment costs are higher for these casks, this disadvantage is more than overcome by the large operating cost saving for passive cask storage systems. Except for some modest transportation savings in the transportable cask case, DOE's costs are not affected.

With the larger unconsolidated cask, utility savings are more than doubled, and DOE's transportation savings are of increasing importance in the transportable cask. Potential savings to the ratepayer are quite significant for development of large casks, especially casks that are transportable.

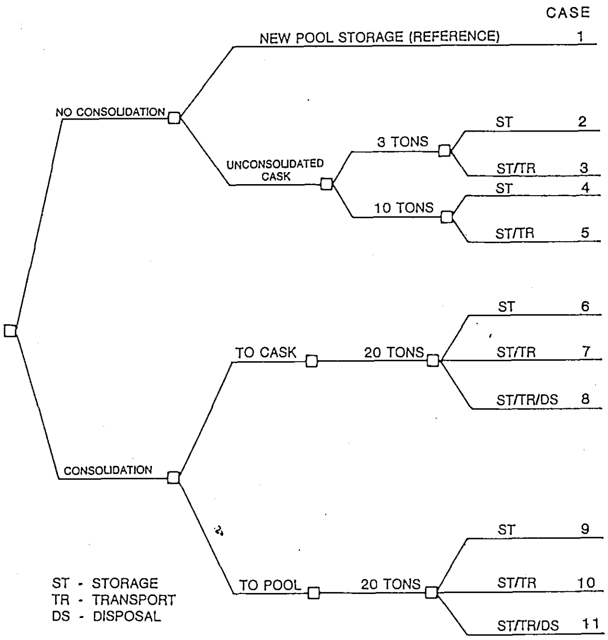

Fig. 5. Decision Flow Network of Integrated Cask Storage System.

The potential total savings resulting from further expanding cask capacity to 20 tons by consolidation is not large if use of such casks is limited to storage. However, if the cask can also be used for transportation, the total savings are increased to the range of $75 to $87 million which justifies development of this level of technology. This additional saving is, however, in DOE's scope and would require some form of credits to utilities if the saving is to be realized.

The largest overall saving is for the universal cask cases which ranges from about $91 million for consolidation directly to cask to about $96 million for consolidation to the pools. In the former case, the savings are about equally shared by the utility and DOE. The case with the greatest saving is for consolidation to the pool, most of which would be realized by the utility since they would not need to buy any casks. DOE's cost would be increased since they must buy all the casks in this case, but somewhat later.

With a potential saving to our ratepayers in the order of $100 million for Sequoyah, TVA's overall savings on all our nuclear plants could be one-quarter to one-half billion dollars. On a national basis, potential savings could be 10 times greater than TVA's savings.

Economic cost and technical feasibility, however, are not the only considerations that should be taken into account in choosing the future course of spent fuel management. We have undertaken to extend the analysis to include environmental, health and safety, and socioeconomic impacts, as well as public perceptions. Our analyses of the usual environmental considerations such as land use, air

TABLE III

Potential Savings Related to Development of Integrated Cask Dry Storage Systems for TVA's Sequoyah Nuclear Plant (Millions of Present Worth 1983 Dollars)[a]

Case	Additional Storage Alternative	Onsite Cost: Facilities	Onsite Cost: Operations	Onsite Cost: Total	Offsite Cost: Shipment	Offsite Cost: Disposal	Offsite Cost: Total	Grand Total
1	New Pool	Base[b]	Base	Base	Base	Base	Base	Base
	Unconsolidated to Cask							
2	3-Ton ST	-6.5	32.0	25.5	0.0	0.0	0.0	25.5
3	3-Ton ST/TR	-6.5	32.2	25.7	2.8	0.0	2.8	28.5
4	10-Ton ST	17.7	38.3	56.0	0.0	0.0	0.0	56.0
5	10-Ton ST/TR	17.7	38.4	56.1	11.6	0.7	12.3	68.4
	Consolidated to Cask[b]							
6	20-Ton ST	26.5	25.5	52.0	3.0	0.0	3.0	55.0
7	20-Ton ST/TR	26.5	25.7	52.2	13.4	9.0	22.4	74.6
8	20-Ton ST/TR/DS	21.1	25.7	46.8	13.4	31.1	44.5	91.3
	Consolidate to Pool							
9	20-Ton ST	38.5	27.8	66.3	2.8	0.0	2.8	69.1
10	20-Ton ST/TR	38.5	27.9	66.4	12.2	9.0	21.2	87.6
11	20-Ton ST/TR/DS[c]	38.5	27.9	66.4	12.2	17.1	29.3	95.7

a. Based on a 3.5 point differental between inflation and discount rates.
b. Fuel is consolidated and placed in the cask rather than back in the pool storage racks.
c. In this case DOE pays for all of the casks since more are needed for onsite storage.

and water quality, endangered species, etc., show no significant difference. The attributes for which we could identify potentially meaningful differences are summarized on a normalized basis in Table IV. A magnitude of one is assigned the lowest quantity for a particular attribute, and the others are shown in relative magnitudes. When weighted with the appropriate values placed on each attribute, the alternative with the lowest overall score would in theory be the best. The weight placed on the various attributes may depend on your point of view.

From an economic cost standpoint, the preference is clearly toward large casks with consolidated fuel. There is not much difference in total cost whether consolidated to casks or consolidated to pools. However, radiological dose commitments favor consolidation to casks, particularly from an occupational standpoint which is strongly related to active storage and fuel-handling operations. Public radiological dose commitment is almost directly related to the number of shipments. The number of shipments required is directly related to cask capacity. The new pool and the consolidated-to-pool cases delay the time until fuel is secured in some passive storage or disposal mode. It appears that, regardless of the weight placed on the different attributes, a high degree of integration is preferable. In fact, it appears quite possible to agree on the best solution while disagreeing on the reasons.

We believe that the work we have done clearly points to the desirability of giving a high priority to development of integrated cask storage systems. We believe the next step should be a thorough systems study to analyze the trade-off between sectors and design features. Since transportation, MRS, and disposal activities are clearly in DOE's scope of responsibility, DOE should take the lead in actively pursuing system integration studies. We are encouraged that DOE is beginning to undertake some studies in this area. However, we are disappointed that DOE did not specifically include the integrated cask storage concept in the MRS alternatives that they will study. We believe this is very unfortunate since dispersed storage of the cask at power plant sites would serve the same purpose as an MRS at a lower cost to ratepayers and avoid the problems related to siting an MRS. This concept is illustrated in Fig. 6 in conjunction with a universal cask. In this concept DOE would simply provide the cask to the utility which would be loaded with fuel and kept on the power plant site until DOE is ready for disposal. We think this concept is very attractive from any standpoint and would like to see DOE include it in their program as a siting alternative to a central MRS.

TABLE IV

Comparison of Normalized Attributes of the Alternatives Considered in Dry Cask Systems Study for the Sequoyah Nuclear Plant

Case	Additional Storage Alternatives[b]	Economic Costs: Utility Onsite	Economic Costs: Total Ratepayer[c]	Radiological Dose Commitments[a]: Occupational	Radiological Dose Commitments[a]: Public	Time to Passive Management	Number of Shipments
1	New Pool	6.1	1.6	5.9	6.4	2.1	6.6
	Unconsolidated to Cask						
2	3-Ton ST	4.2	1.4	2.2	6.4	1	6.6
3	3-Ton ST/TR	4.2	1.4	1.8	6.4	1	6.6
4	10-Ton ST	1.8	1.2	1.8	6.4	1	6.6
5	10-Ton ST/TR	1.8	1.2	1	1.9	1	2.0
	Consolidated to Cask						
6	20-Ton ST	2.1	1.2	1.7	3.3	1	3.3
7	20-Ton ST/TR	2.1	1.1	1.5	1	1	1
8	20-Ton ST/TR/DS	2.5	1	1.4	1	1	1
	Consolidated to Pool						
9	20-Ton ST	1	1.2	5.3	3.3	2.1	3.3
10	20-Ton ST/TR	1	1	5.1	1	2.1	1
11	20-Ton ST/TR/DS	1	1	5.0	1	2.1	1

a. Actual total occupational doses are one to two orders of magnitude higher than total public doses.
b. Cases 1, 2, 4, 6, and 9 assume a 3-ton cask is used for transport.
c. Actual total costs are in order of magnitude higher than utility costs.

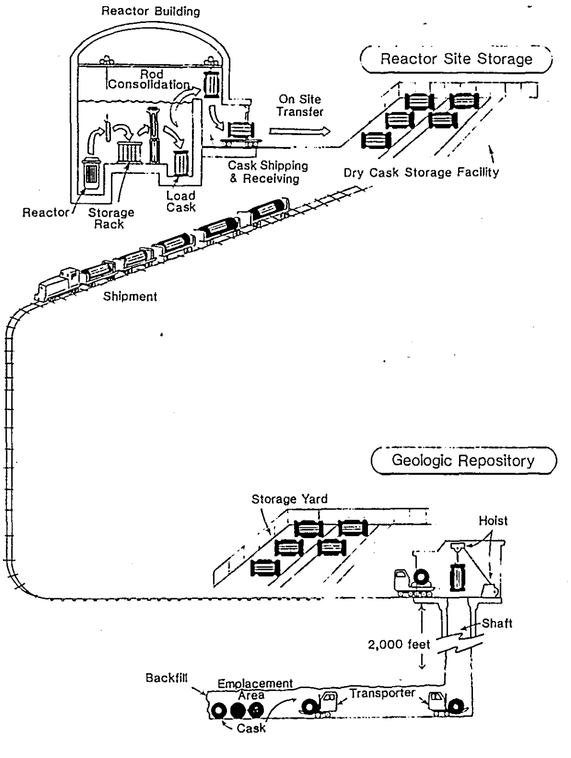

Fig. 6. Spent Nuclear Fuel Management Universal Cask/ Dispersed MRS Concept.