An Economic Evaluation of a Storage System for Casks with Burnup Credit

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INTRODUCTION

It is generally recognized that casks designed with burnup credit are more economical than those without burnup credit.
The higher the initial uranium enrichment, the larger the fuel assembly separation is necessary in the cask to satisfy criticality safety criteria when the fresh fuel assumption is adopted.

On the other hand, the consideration of burnup credit in the cask design gives smaller basket channel pitch necessary for sub–criticality requirement.
Accordingly larger number of fuel assemblies can be loaded in a limited size of cask, especially for highly enriched fuels, and considered more economical.

To estimate how much more economical they are, conceptual designs of storage/transport (S/T) casks were made with and without burnup credit for PWR and BWR fuels of various uranium enrichment and total costs were evaluated of cask storage systems incorporating casks with and without burnup credit.

The costs were estimated for the assumed typical BWR cask storage systems in Japan with the capacity of 700 MTU and for the PWR cask storage systems with the capacity of 500 MTU, respectively, assuming that 125ton casks were installed at the storage site.

CONCEPTUAL DESIGN OF S/T CASK

Conceptual designs of S/T casks were made with and without burnup credit for PWR and BWR fuels. The specifications of these fuels and burnup conditions are listed in Tab.1 and Tab.2.

The casks were designed to contain the maximum number of fuel assemblies under the necessary weight and dimensional limitations as well as to the criticality and shielding criteria.

The design procedure was as follows;

(1)WIMS–E code (AEEW R1314) was used for the burnup calculations and the number densities of fissile and FP nuclides were calculated as functions of fuel burnup and uranium enrichment.

(2)Criticality calculations were performed by ANISN code (Engle, 1967) for the infinite basket model basing the parameters for basket channel pitch and number densities calculated in above (1).
Borated aluminum alloy was assumed for the basket material.

According to these calculations, minimum basket channel pitch satisfying the criteria of keff $\leqq 0.95$ and/or keff $\leqq 0.92$, were determined respectively.
The criterion of keff $\leqq 0.95$ is generally used for the criticality design and that of keff $\leqq 0.92$ was chosen to have a margin for the detailed calculation with Monte Carlo code (KENO (West, 1979)) containing standard deviation σ and neutron multiplication factor is judged by keff $+ 3\sigma$.
Tab.3 shows minimum channel pitch obtained from the calculations.

(3)If the channel pitch is known, minimum cavity diameter in a cylindrical cask can be determined as a function of number of fuel assemblies.

(4)Assuming lead for the main gamma shielding material to minimize the cask weight, and water and resin for the main neutron shielding materials covered with stainless steel, shielding thickness that satisfied the required dose–equivalent rate at the cask surface and at 1 meter from the surface was determined using one–dimensional shielding code ANISN. Source terms were calculated by ORIGEN–2 code (Croff, 1980) for the fuels specified in Tab.1 and Tab. 2.

(5)Based on the results obtained in above (3) through (4) and on the lifting weight and diameter limitations, maximum number of fuel assemblies that could be contained in each cask was determined for cask design with and without burnup credit.

(6)The cask designs obtained in this manner both with and without burnup credit were finally confirmed that they satisfied the cask design criteria for criticality by KENO code, shielding by ANISN code.
Thermal analysis was also performed by TRUMP code (Edwards) to confirm the cask surface and fuel temperatures.

Fig.1 shows the flow diagram of the conceptual design procedure.

Fig.2 shows the concept of the cask and Tab.4 and Tab.5 show the main items of the cask.

SCENARIO OF SPENT FUEL CASK STORAGE AND TRANSPORTATION

In the cost evaluation for the cask storage and transportation of spent fuels, following assumptions are made for a typical PWR and a BWR reactor site.

- –all the spent fuels overflowing the storage pool capacity are to be stored in the S/T casks at the reactor site (AR storage site).
- –125 ton class casks are exclusively used
- –those spent fuels are generated equally every year for the first ten years (10%/a), and are transported to the AR storage site.
- –the spent fuels are stored at the AR storage site for next ten years in the S/T cask
- –stored casks are transported next for the ten years equally (10%/a) to the reprocessing plant

Tab.6 and Fig.3 show this basic scenario for the spent fuel AR storage and transportation.

OUTLINE OF CASK STORAGE/TRANSPORT SYSTEM

Cask storage system is to consist of
- a) cask storage building
- b) cask management equipment
- c) cask examination equipment
- d) radioactive disposal storage equipment
- e) radiation monitoring equipment
- f) supplement of storage site building

The storage site building is to be trench type with concrete structure, design anti–earthquake is class C and endurance is to be 30 years.

Outline of the transport system is as follows:

–Reactor site is not specified but typical one in Japan.
Distance between reactor building and AR storage site is assumed 1 km.
–The site of reprocessing plant is located 3–day–voyage from the reactor site.
Land transport distance to the reprocessing plant from the port is assumed 1km.
–Sea transport of the spent fuels is conducted by the same type of ships such as " Pacific Crane" which is used for the shipment to the overseas reprocessing plants from Japanese utilities today .
–135 MT class trailers are to be used for the land transport.

Numbers of S/T casks necessary are listed in Tab.7.
Considering the burnup credit, approximately 5 to 12 casks or 8% to 18% for the BWR and 10 to 19 casks or 24% to 46% for PWR can be reduced depending on the initial uranium enrichment.

COST EVALUATION

Following costs are roughly estimated:
(1)Capital cost of:
- –cask storage building
- –storage site equipment
- –storage/transport cask procurement
- –storage site decomissioning

(2)Operational cost of:
- –maintenance of storage site and equipment
- –transport, including charter of shipping vessels, marine transport, land transport, handling at power stations and storage site, shipment to a reprocessing plant, etc.
- –tax and insurance

Each capital cost was assumed as a function of the number of casks, based on the conceptual design of each item. Cost of transport was estimated on the basis of the required number of transport and equipment. Other items of operational cost and decommissioning cost were also assumed as functions of the capital cost.

Following were shown from the cost evaluation.
(1) The cost of casks shared 50% to 60% of the total storage cost.
(2) 80% to 90% of the total storage cost depends on the number of casks.

Consequently it is indicated that the total cost of cask storage and transportation is considerably proportionate to the number of the casks.

Fig.4 to Fig.7 show the relative number of casks and cost of cask storage installing casks designed with and without burnup credit.

These results showed that the cost of storing casks with burnup credit is approximately 7 to 30% less expensive than storing casks without burnup credit.

In implementing the cask design with burnup credit, a certain amount of additional jobs will arise such as burnup management in the reactor site or the measurement of neutron multiplication factor prior to shipment.
This means that a certain amount of equipment and labors will be required, and cost reduction will be impaired by this requirement.
As the costs for it are not certain at this stage, they are not taken into account in this evaluation.

REFERENCES

A. G. Croff, " A User's Manual for the ORIGEN2 Computer Code" , ORNL/TM 7175 (July 1980)

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J. I. West., et al., " The Combinatorial Geometry Version of the KENO Monte Carlo Criticality Safety Program" , NUREG/CR–0709, ORNL NUREG/CSD–7, Sep. 1979

" A Scheme for Neutronics Calculation" , AEEW R1314

Tab. 1 Specification of fuels

	BWR	PWR
No. of Array	8×8	17×17
UO2 Pellet Diameter (cm)	1.06	0.819
Fuel Cladding Diameter (cm)	1.25	0.950
Thickness(cm)	0.086	0.057
Material	Zircaloy-2	Zircaloy-4
No. of Fuel Pins	63	264
No. of Water Rod	1	25
Fuel Pin Pitch (cm)	1.626	1.26
Fuel Effective Length(cm)	371	366
Weight of Assembly(kg)	280	665
Weight of Uranium (kg)	174	460

Tab. 2 Burnup Condition of Spent Fuel

Type of Fuel	BWR			PWR		
	a	b	c	a	b	c
Initial U Enrichment(%)	3.0	3.4	3.9	3.4	4.1	4.6
Burnup (GWD/MTU)						
Average	33	38	45	32	43	48
Maximum	43	50	60	39	48	55
Specific Power Density (MW/MTU)	24.8	24.8	24.8	38.3	38.3	38.3
Cooling Time (year)	4	5	5	4	5	5

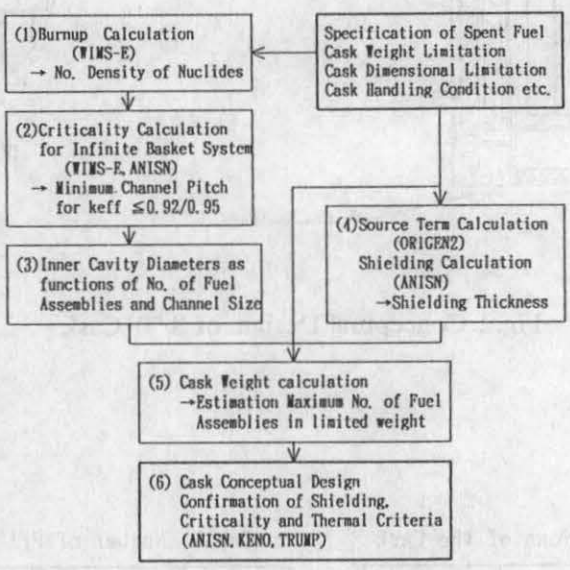

Fig. 1 Flow Diagram of the S/T Cask Conceptual Design

Tab. 3 Minimum Channel Pitch that satisfy Criticality Criteria

Type of Fuel	Initial U Enrich (%)	Minimum Basket Channel Pitch(mm)		
		B/C considered		B/C not considered
		with FP*)	FP neglect	
PWR	3.4	231	239	262
	4.1	231	240	270
	4.6	231	242	276
BWR	3.0	145	145	151
	3.4	145	146	155
	3.9	145	147	162

*) The results with FP considered are calculated only for reference and are not used in the conceptual design.

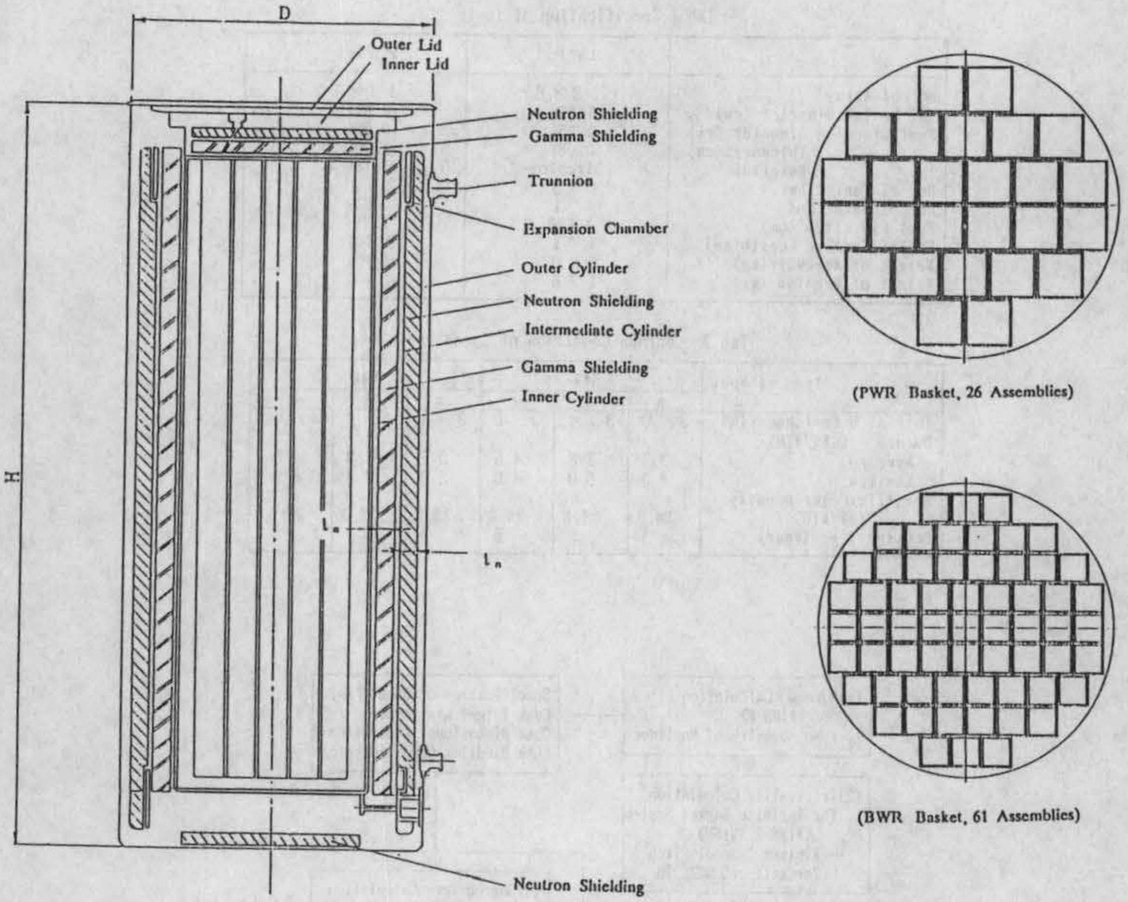

Fig.2 Conceptual Design of S/T Cask

Tab.4 Main Dimensions of the Cask

	PWR	BWR
H (mm)	5000	5350
D*) (mm)	2320 ~2380	2225 ~2281
t n*) (mm)	130 ~148	140 ~160
t a (mm)	120	120
W*) **) (ton)	110 ~115	110 ~115

*) Depend on the specification of fuel

**) Including Cask body, Lid, Basket, Fuel Assembly and Water in Cavity.

Tab.5 Number of F/A in the Cask

Type of Fuel	Initial U Enrich(%)	No. of F/A with B/C	No. of F/A without B/C
PWR	3.4	26	21
	4.1	26	21
	4.6	26	18
BWR	3.0	66	61
	3.4	66	61
	3.9	61	52

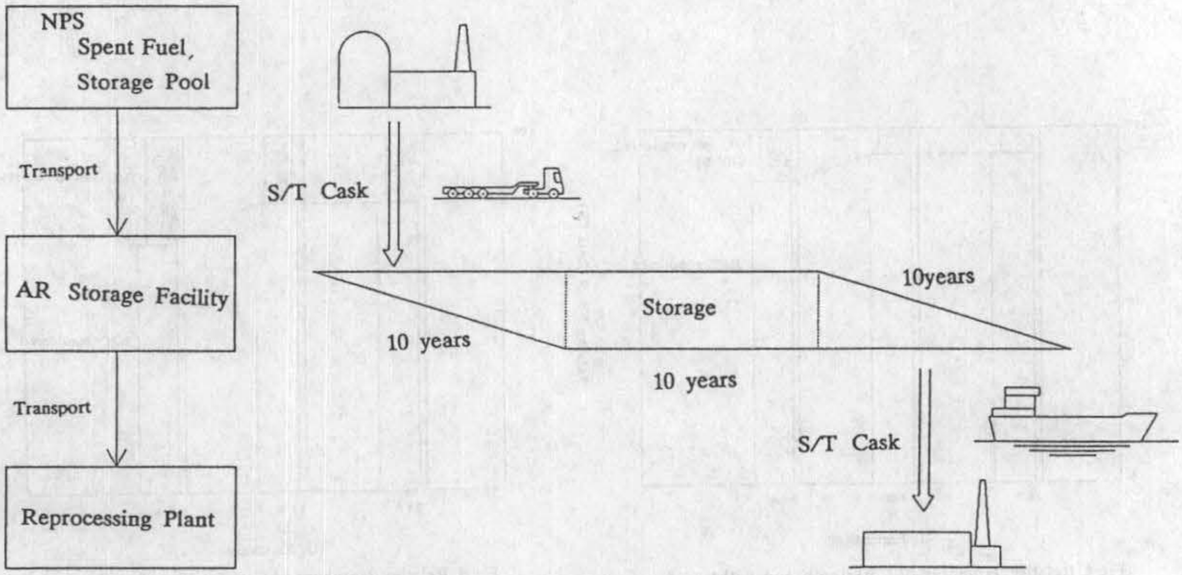

Fig.3 Basic Scenario of Spent Fuel Storage/Transportation

Tab. 6 Required SF Storage Demand at the Supposed Site

Type of Reactor	S/F Storage Demand (MTU)	Storage Capacity(MTU)	Period of Reception(yr)	Reception Rate (MTU/yr)
BWR	665	700	10	70
PWR	435	500	10	50

Tab. 7 Number of required S/T Casks

BWR (665MTU)	U Enrichment	3.0%		3.4%		3.9%	
	Burnup Credit	with/o	with	with/o	with	with/o	with
	No. of Casks	65	60	65	60	77	65
PWR (435MTU)	U Enrichment	3.4%		4.1%		4.6%	
	Burnup Credit	with/o	with	with/o	with	with/o	with
	No. of Casks	51	41	51	41	60	41

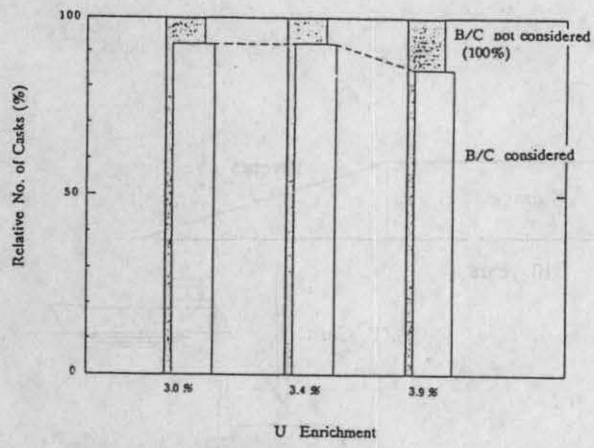

Fig.4 Relative Numbers of Casks with and without Burnup Credit (BWR 125 ton class)

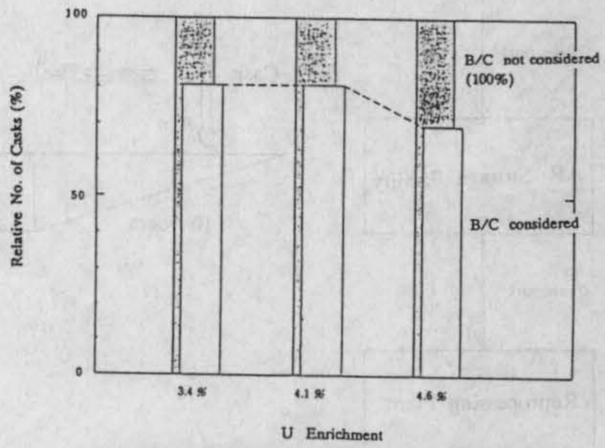

Fig.5 Relative Numbers of Casks with and without Burnup Credit (PWR 125 ton class)

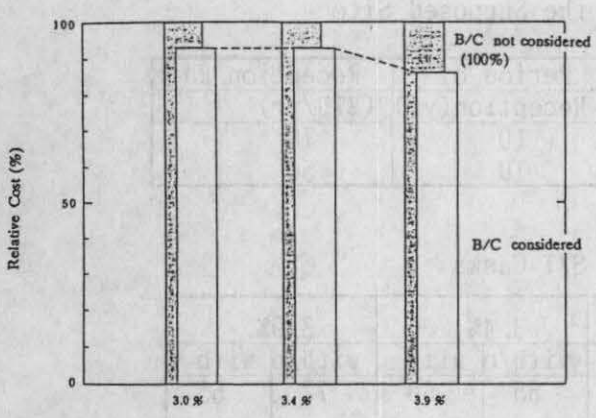

Fig.6 Relative Cost of Casks Storage with and without Burnup Credit (BWR 125 ton class)

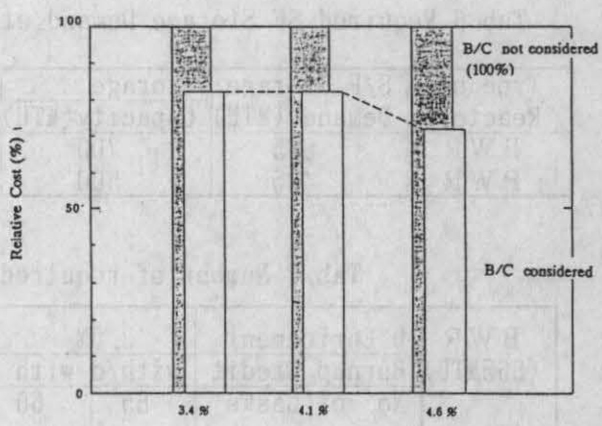

Fig.7 Relative Cost of Casks Storage with and without Burnup Credit (PWR 125 ton class)