KOREAN INTERIM STORAGE ISSUES AND R&D ACTIVITIES ON SPENT FUEL MANAGEMENT

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Abstract

Korea has witnessed over a decade of vicissitudes in the issue of radioactive waste management due mainly to the problem of site acquisition. As the major mission of the nation at radioactive waste management programme was to provide a center for disposal of low-level radwaste and for interim storage of spent nuclear fuel from nuclear power plants, the question of site securing has had a big impact on the implement action of overall programme. The site problem has resulted in, as an aftermath, restructuring of the overall programme for radioactive waste management. Missions of NEMAC (Nuclear Environment Management Center), originally established as a subsidiary of Korea Atomic Energy Research Institute (KAERI), for the national programme was dissolved as of the end of last year. Beginning of this year, a new entity NETEC (Nuclear Environment Technology Center) as a subsidiary of KEPCO (Korea Electric Power Co.) has taken over major tasks of the past NEMAC, while the R&D work associated with the past task of NEMAC is transferred back to KAERI. This paper gives a review on the past background which has driven the radioactive waste management in Korea to the current state of the affairs, with special emphasis on R&D activities associated with spent nuclear fuel transportation, handling, and storage.

1. HISTORICAL INTRODUCTION

1.1. Background of Korean radwaste management programme

Some research activities associated with radioactive waste management in Korea trace back to the seventies when KAERI became a national institute. Systematic R&D on the subject was initiated, however, in the mid-eighties when radioactive waste and spent fuel had begun to accumulate at increasing number at nuclear power plants.

Conscious of the radwaste management in the future, the Korean authority KAEC (Korea Atomic Energy Commission) amended in 1986 the Atomic Energy Law to set forth a programme for long-term management of radioactive waste and of spent fuel. Key projects of the national programme are:

- to provide a repository for disposal of low-and intermediate radioactive wastes from various sources in the nation;
- to provide an interim storage facility for centralized management of spent fuel that are stored temporarily at various reactor sites;
- to provide technical expertise by R&D activities on support of those projects.

Plans to implement the programme had been subsequently developed and approved by the AEC, i.e. major facilities to be built by 1997 on a collocation site to be selected. Until that time, the management of already accumulated wastes or spent fuel at reactor (AR) sites have to be taken care of by the utility itself through appropriate methods.

Institutional arrangements were also made by designating KAERI as the responsible body to implement the programme under government supervision (Ministry of Science & Technology). The necessary fund was provided by collecting a waste fee from KEPCO, the national utility, based on the "Polluters Pay" principle.

The legal arrangements of the programme had been finalized in 1989 when the enactment of the amended law was promulgated by Presidential Decree.

1.2. Public perception problems in search of site

When the Korean programme was set up in the mid-eighties, nobody was much conscious about the social problem that may interfere with the waste management programme, especially in the affairs of site search. The NEMAC team in preparation of the programme implementation began with technical assessment of a suitable site for the waste management center by survey of potential candidate sites all over the country and screened out them to several promising ones on the basis of selection criteria which were mostly technical but little social considerations. This negligence in social factors had to turn out to be a grave mistake as to be witnessed later.

At initial phase of the site survey, the site inspection team did not expect strong protest against the survey activities itself. The naive access to potential candidate sites, without enough prior understanding of the local inhabitants about the assurance of the project, seemed to have spurred them furious oppositions to the survey activities itself. One site after another, the survey team encountered barring oppositions from the local inhabitants instigated by anti-nuclear group of ecologists. These protests had been emphasized by the media which had taken part in promoting the negative aspects of everything about "garbage" disposal as a social issue. It was also a period of Korean society when social oppositions to governmental authority were often confounded with a sort of democratization against political oppression. These series of troubles at several sites was culminated when a serious incident of crash between the protesters and police forces happened in the winter of 1989 in Anmyon Island in west coast of the Peninsula. This mishap was marked as a political fiasco in the governmental measure in radioactive waste management policy confronted with negative perception of the affected public. An extensive revision of the governmental attitude on the problem was inevitable as an aftermath of the Anmyon Incident. The governmental authority of the programme had to be reorganized and a new approach to the problem was looked for a final breakthrough. Financial compensation to the affected inhabitants was one of such approach which was legalized and publicized.

The last coup de grace in the site acquisition problem came in nineties when the newly organized authority designated the Guleop Island, also in the Yellow Sea near Inchon Harbor, as the final resort of the site problem. As the island was not populated with any inhabitant, it was believed that the social protest of NIMBY (not in my back yard) could be avoided or mitigated, at least. This was not the case. By that time, the radwaste disposal had been regarded as something very dangerous not only in the site itself but also in the vicinity around the site. People around the Island, including the Inchon Harbor manifested such concern, in alliance with ecologist group of the country. The polemics was rather technical this time, in comparison with previous ones, because national consensus was more or less converging by that time in such way to approving the necessity of a site and of the justifiable alternative that had to be found on legal ground. The polemics has finally led to a detailed examination of geological structure by a national panel of experts who have finally concluded that the site is not adequate due to active faults found from the study. This conclusion which was announced by the authority in 1995 marked a wrapping up of the decade old project in search of a site for radioactive waste disposal and interim storage of spent fuel.

With the last failure in site acquisition, the government decided a general redirection in the state of the affairs by institutional rearrangements.

2. STATUS

2.1. General

With the last failure with the site acquisition effort, the government decided in 1996 a total redirection in the approach to the national programme for radioactive waste management by institutional rearrangement of the related missions.

First of all, the responsible organ, NEMAC, had to be dissolved and its missions newly rearranged under different scheme:

- The site acquisition task to be taken over by a new entity NETEC (Nuclear Environment Technology Center) by transfer of most of associated personnel of the former NEMAC to work for KEPCO under the policy management of the MOTIE (Ministry of Trade, Industry and Energy Resources). The NETEC inherits also the former NEMAC mission to build and operate the repository for low- and medium-level wastes and the interim storage facility for spent fuel (SF);
- The remaining mission of R&D associated with waste management of the former NEMAC is to be taken back by KAERI as a part of the overall nuclear research programme.

On legal side of the rearrangement, the provisions in the amended Atomic Energy Law is removed to be integrated into the “Electricity Enterprise Act”. "The Act for Promoting the Radwaste Management Project and Financial Support for Local Community" is abolished. Instead, the provisions for the local community support is added to "the Act of Support for Local Communities". The provisions for the securing of a disposal site is inserted in "the Special Act Relating to Development of Electric Power Resources". "The Radwaste Management Fund" founded in 1986 is abolished and "the Nuclear Research and Development Fund" is established to secure nuclear research and development expenses. Radwaste producers such as KEPCO and hospitals are to bear the cost for radwaste management.

The Korean government will re-assess public feeling and the social climate related to radioactive waste, and will redraft the radwaste project plan to safely and efficiently manage radioactive waste from generation, transportation, storage, treatment, to disposal. For this purpose, the government will act as follows : Firstly, it will review the types of disposal methods as well as the size of disposal facilities to find the most suitable ones to actual circumstances. Secondly, it will improve public understanding of the safety of radwaste management by reinforcing public acceptance programmes and maintain transparency in policy-making of radwaste project. Also, it will strengthen the local community support system to induce resident's invitation of the disposal facility. Thirdly, it will minimize the volume of radwaste by developing state-of-art volume reducing technology in addition to current volume contraction technology. Also, Korea will improve the relationships with advanced countries in nuclear technologies and international organizations in order to enhance the exchange of advanced technologies and information, and will elevate the level of radwaste disposal technology by participating in international joint research programmes on radwaste.

Currently, KEPCO is surveying new site for radwaste disposal and SF interim storage. Detailed prospects has not set up yet and any progress can not be found. KEPCO is considering the extension of AR facilities for the LLW and SF rather than construction of centralized storage facility.

2.2. R&D activities related to spent fuel management

While KAERI were conducting the national radwaste management project, it’s research effort was concentrated on developing the technology which is directly applicable to design and construction of the interim spent fuel storage facility (ISFSF). The list of these R&D topics is as follows:

- Study on long-term integrity of SF and development of integrity evaluation code, SIECO (Systematic Integrity Evaluation Code);
- Study on behavior of PWR SF in wet storage conditions;
- Development of SF storage container with oxygen scavenger;
- Development of remote handling and automation technology;
- Structural behavior of base-isolated pool structure;
- Pool water purification technology;
- Development of a large capacity SF transportation cask.

Besides these R&D activities, the SF technology development facility was conceptually designed for the purpose of developing the technology required for long-term dry storage or disposal of SF, and developing the remote handling technology of spent. Functions of this facility are SF cask handling, SF assembly inspection, storage in dry pit, fuel rod consolidation and packaging, integrity test of sample rods, and remote maintenance of equipment.

Since the national radwaste management programme is now reserved for further consideration, the current R&D activities are focused on the technology development related with the dry storage of SF. These are:

- Study on the oxidation behaviors of UO_2 and zircaloy under the air environment;
- Development of rod consolidation technology;
- Development of remote handling and maintenance technology.

Also, the study on direct use of PWR SF into CANDU reactor (DUPIC) project, one of the most challenging topics of KAERI, is on going.

3. INTERIM SPENT FUEL STORAGE FACILITY (ISFSF) CONSTRUCTION PROJECT

3.1. Project overview

The final decision on the ultimate management of SF has not been made in Korea. The 220th AEC held in July 1988 resolved the basic principle that the SF would be managed at the ISFSF in the national radwaste management complex site by government until further decision later. At 221st AEC the specified decision was made on the ISFSF. The decision was to construct the wet storage facility by Dec. 1997 whose capacity is initially 3,000 tU. Due to consecutive delay of site securing project, this decision was canceled at the 237th AEC held in Dec. 1995. Right now NETEC is studying the necessity of construction of interim storage including the future management plan of SF.

3.2. AR storage facility expansion programme

The country's first nuclear power plant (NPP), Kori-1, a 587 MWe pressurized water reactor (PWR), went into commercial operation in 1978, opening a new era of nuclear power generation in the country. The nation's nuclear power programme has continuously expanded since then. Today, Korea has twelve NPPs (10 PWRs and 2 CANDUs) in operation with generating capacity of 10,331 MWe. In addition, sixteen more reactors are planned to be constructed by 2010 as shown in Table I.

With the increase of NPPs, the amount of SF rapidly increases as shown in Table II. In accordance with 220th AEC's decision on spent fuel management that "The KEPCO will store SF at each NPP site until the ISFSF is operated," KEPCO has continuously expanded the storage facilities as shown in Table III [1]. In Uljin site, Uljin unit 2 storage pool was expanded in 1990 by reracking with high density (HD) storage rack before the first cycle SF discharge. In Kori site, Kori unit 3 pool capacity was expanded 1994 by adding the HD storage rack into the reserved space of the existing storage pool. In addition, 156 assemblies of Kori-1 fuel were transshipped to Kori-3 pool in 1991, and another 156 fuel assemblies are being transshipped to the pool of Kori-3 and Kori-4. For CANDU SF in Wolsong site, 60 units of dry concrete canister were installed in 1992 to accommodate 32,400 SF bundles. Currently, the dry storage facility is being designed for KORI NPP and more concrete canisters for CANDU SF are being constructed at Wolsung NPP. After these expansions, as shown in Table III, the storage capacity of AR facility is anticipated to endure until year 2006.

TABLE I. LONG-TERM PLAN OF NPP CONSTRUCTION BY 2010

	Unit	Reactor Type	Capacity (MWe)	Cumulative Capacity (MWe)	Start Operation (year)
In operation	Kori 1	PWR	587	587	78. 4.
	Wolsung 1	CANDU	679	1266	83. 4.
	Kori 2	PWR	659	1916	83. 7.
	Kori 3	PWR	950	2866	85. 9.
	Kori 4	PWR	950	3816	86. 4
	Yonggwang 1	PWR	950	4766	86. 8.
	Yonggwang 2	PWR	950	5716	87. 6.
	Uljin 1	PWR	950	6666	88. 9.
	Uljin 2	PWR	950	7616	89. 9.
	Yonggwang 3	PWR	1000	8616	95. 3.
	Yonggwang 4	PWR	1000	9616	96. 1.
	Wolsung 2	CANDU	715	10331	97. 7.
Under construction	Uljin 3	PWR	1000	11331	98. 8.
	Wolsung 3	CANDU	700	12031	98. 6.
	Uljin 4	PWR	1000	13031	99. 6.
	Wolsung 4	CANDU	700	13731	99. 6.
	Yonggwang 5	PWR	1000	14731	01. 12.
	Yonggwang 6	PWR	1000	15731	02. 12.
Planned	Uljin 5	PWR	1000	16731	03. 6.
	Uljin 6	PWR	1000	17731	04. 6.
	KNU 21	PWR	1000	18731	05. 6.
	KNU 22	PWR	1000	19731	06. 6.
	KNU 23	PWR	1000	20731	06. 6.
	KNU 24	PWR	1000	21731	07.
	KNU 25	PWR	1300	23031	08.
	KNU 26	PWR	1300	23744	09.
	KNU 27	PWR	1300	25044	10.
	KNU 28	PWR	1300	26344	10.

TABLE II. SPENT FUEL INVENTORY

tU

year	PWR		CANDU		Total inventory
	annual arising	cumulative inventory	annual arising	cumulative inventory	
1994	117	1,288	96	1,093	2,381
1997	204	1,843	95	1,378	3,221
2000	242	2,512	380	2,233	4,745
2005	318	3,912	380	4,133	8,045
2010	339	5,645	475	6,413	12,607

TABLE III. STATUS OF AR STORAGE POOL

Unit	Initial Capacity Full (year)	Expansion (Step 1, Finished)	Capacity (FAs)	Inventory (FAs) *as of April 1997	Anticipated Capacity Full after Step 1 (year)	Expansion (Step 2, plan)	Anticipated Capacity Full after Step 2 (year)
Kori 1 Kori 2 Kori 3 Kori 4	1991 2001 1997 1997	Transfer 156 FAs to Kori #3,4 Add HD rack (1994, 455 FAs) Add HD rack (1994, 455 FAs)	3,271	2,042	2002	Construct dry storage facility (2000, 400 FAs)	2006
Yonggwang 1 Yonggwang 2	1997 1998	ADD HD rack (1997, 400 FAs) ADD HD rack (1997, 400 FAs)	2,992	900	2006		2006
Uljin 1 Uljin 2	1994 1995	Reinstall HD rack (1991, 421 FAs)	1,675	573	2007		2007
Wolsung 1	1991	Add concrete canister (1992, 60 canister)	71,616	62,772	1997	Add concrete canister (1997, 80 canister)	2006

FAs = Fuel Assemblies

3.3. Interim spent fuel storage facility design

In 1983, a two-year study with Battelle Pacific Northwest Laboratory of USA concluded that AFR storage option would be suitable for the medium-and long-term spent fuel management in Korea. In 1986, joint studies with Sweden and Federal Republic of Germany were separately carried out to compare two methods of storing SF, wet storage and dry storage. Based on the results of these studies, the Atomic Energy Commission selected wet type for the first AFR interim spent fuel storage facility (ISFSF) to be completed by 1997. Subsequent expansions with a dry storage option will be followed as-needed basis. KAERI has carried out the site independent conceptual design of the ISFSF with Korea Power Engineering Company (KOPEC) as a domestic contractor and SGN in France as a foreign contractor. Also in 1992, KAERI and BNFL in the United Kingdom jointly reviewed the feasibility of Multi Encapsulated Baskets (MEB) for the prospective Korean facility and in 1993, KAERI and Ebasco in the USA have jointly conducted the comparative study between dry and wet storage methods.

3.3.1. Conceptual design of the ISFSF

KAERI has finished the conceptual design of the ISFSF in 1990. For this design, the design base such as storage method, capacity, transportation method and characteristics of SF has been set up (Table IV). Also the design requirements have been determined [2,3].

TABLE IV. DESIGN BASE OF THE ISFSF

Item	Design Base
O Storage type	• Wet unloading and wet storage
O Storage capacity	• 3,000 tU (Modular expansion)
O Reception capacity	• 650 tU/year
O Spent fuel characteristics	• all types of spent fuel generated form Korean NPP minimum 5 years cooling at AR pool • design enrichment and burn up – PWR : 4% enriched uranium, 40,000 MWd/tU burnup – CANDU : natural uranium, 7,500 MWd/tU
O Transportation cask (assumption)	• PWR – TN-17/MK2 (for capacity calculation) – TN-12/2 (for design of handling equipment) • CANDU : KAERI design
O Transportation method	• Sea transportation by ship
O Utility supply	• Centralized utility facility out side main building (only cooling water pump : inside main building)
O Electricity	• Centralized supply
O Secondary radwaste	• Liquid waste : disposal after solidification • Solid waste : disposal after encapsulation
O Layout	• Consider operability, maintainability and safety factor
O Lifetime	• 60 year

3.3.3.1. Design base

3.3.3.1.1. Storage method

Various storage method have been considered including the wet storage, metal cask, concrete silo, air cooled vault and dry well. The safety aspects was emphasized compared with technological and economical aspects. The result was that wet storage method was deemed to be more appropriate in consideration of various factors, especially licensing and schedules, among others.

3.3.1.1.2. Storage capacity

With the usual assumption that the life time of NPPs and the ISFSF are 30 years and 60 years respectively, the following result is obtained. The capacity of receiving area of the ISFSF should be enough to receive maximum anticipated amount of SF in the life time, with the possibility of expanding the storage area in the future. On the basis of this result, the optimum capacity of the ISFSF was decided to be initially 3,000 tU.

3.3.1.1.3. Transportation of spent fuel

Various transportation methods have been analyzed including the land transportation by truck or rail train, and the sea transportation by transportation ship. Since the maximum weight of loaded transportation vehicle is limited up to 40 ton, the truck transportation method is proven to be unacceptable. Also, the railroad transportation has no advantage if the high costs of new railroad construction is taken into account. Finally, the sea transportation is selected as the best option considering that all NPPs in Korea are located along the coast line and that this method can avoid traffic passage through highly populated area.

3.3.1.2. Design requirements

In determining the design requirements, various factors are considered such as NPP construction plan, storage capacity of AR storage facility, future policy of spent fuel management, current available technology, and safety margin etc. As a result the design requirements shown in Table 4 was obtained.

3.3.1.3. Technical features of the ISFSF

Based on the design base and design requirements, the conceptual design of the ISFSF has been conducted and its outlined feature is as follows. As shown in Fig.1 the ISFSF consists of a truck bay, a cooling pit, an unloading pool, a service pool for preparation of storage, and a storage pool. The storage pool is divided into two parts, one for PWR and another CANDU SF, respectively. Pool water is cooled by heat exchanger and cleaned by deep bed ion exchanger both outside the pool. Sea water is used as an ultimate heat sink when the facility is located at seashore. Inside of the pool wall is lined with stainless steel to assure leak tightness. Secondary waste arising from the facility is packaged and/or immobilized by cementation. Achieving high standards of nuclear safety is the major concern in designing this facility. Design goals are to limit the environmental release of radioactivity so that a member of the public in the regional vicinity group receive no more than 0.5msv/y, and to provide adequate biological protection so that the maximum average man-rem dose commitment to operating personnel is less than 0.5 rem/y.

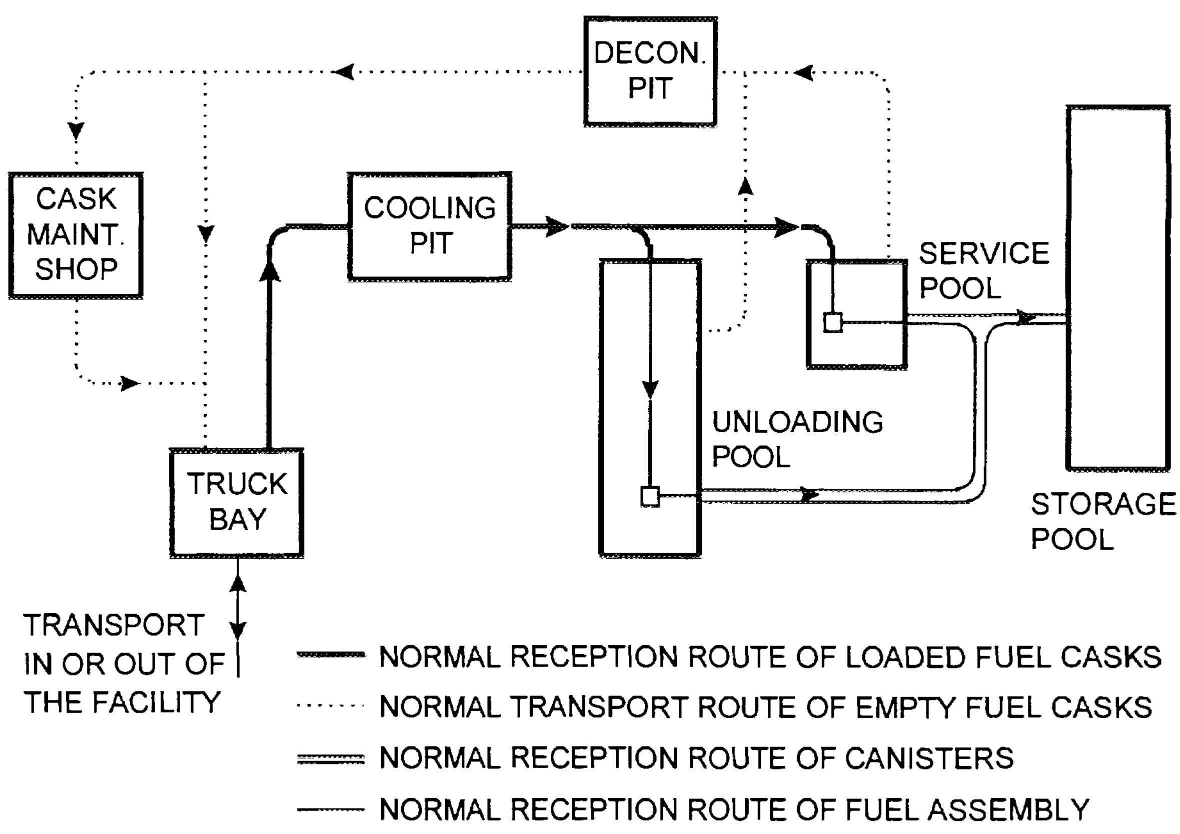

FIG. 1. Handling sequence diagram of spent fuel

3.3.2. Containerized storage option

While the site securing project had been delaying, the optimization study of the conceptual design had been conducted by KAERI with BNFL of UK [4]. In this study, the containerized storage method, developed by BNFL and applied in the THORP reprocessing facility, was examined. This method adopts the multi element bottle (MEB) which contains seven PWR assembly as shown in Fig. 2. The MEB can be used for dual purpose, transportation and storage. The designed lifetime of MEB is 40 years and is made by borate stainless steel. KAERI analyzed the impact on the conceptual design by introducing the MEB and compared the applicability to the ISFSF of containerized storage method with the non-containerized method in terms of technological and economical aspects. The technological comparison result is given in Table V. In economical aspects, the containerized method offers marginal cost savings over non-containerized one.

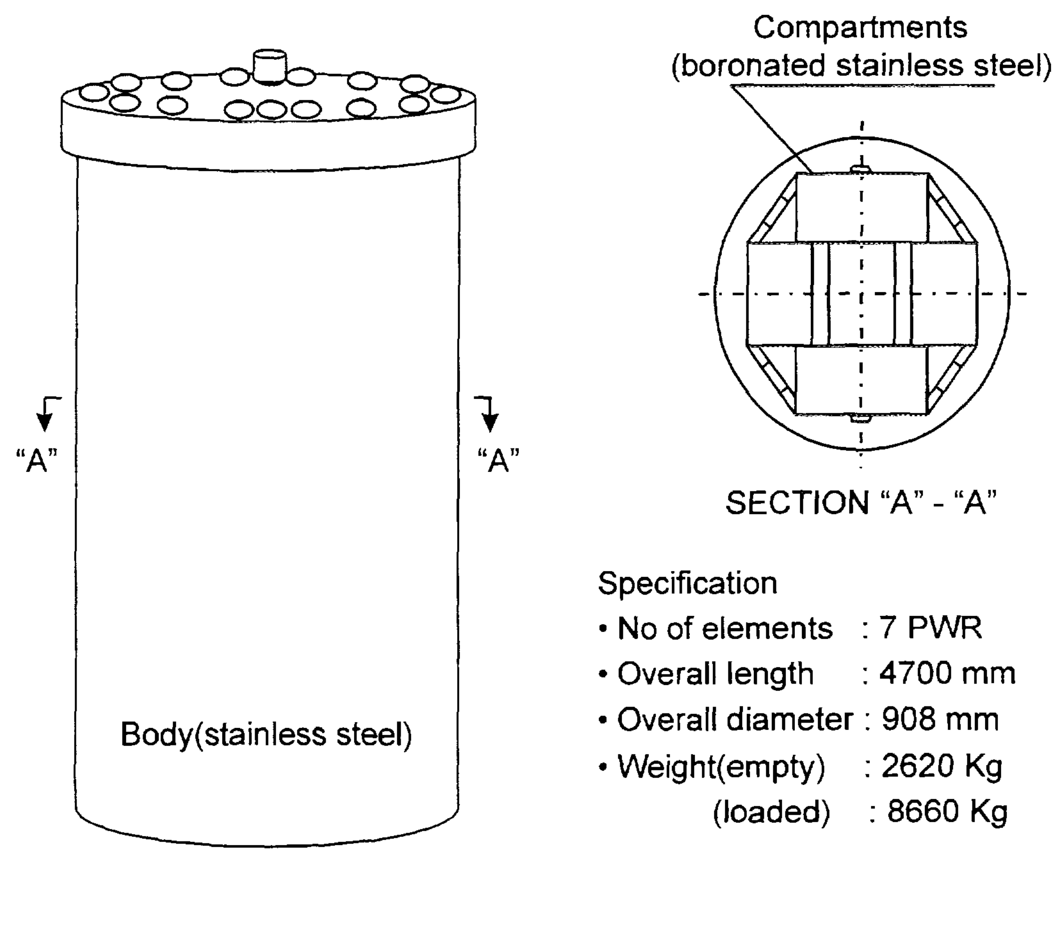

FIG. 2. Schematics of MEB (Multi Element Bottle)

3.3.3. Dry storage option

The dry storage method had been reviewed by KAERI to select the best option for SF storage in 1993. KOPEC and Ebasco in the USA participated in the comparative study on storage method has been conducted for PWR and CANDU SF.

TABLE V. RESULT OF ANALYSIS ON TECHNOLOGICAL ASPECT

Items	Result	
	Non-Containerized	Containerized
Difficulty in process operation	□	Δ
Availability of technology	O	Δ
Required Storage Volume	O	O
Cooling	Δ	O
Secondary waste generation	□	O
Simplicity of supplementary equipment and process	□	O
Construction period	Δ	O
Maintenance	□	O
Applicability at NPP	O	Δ
Possibility of extension	Δ	O
Spent fuel integrity at storage pool	O	Δ
Radiological safety	Δ	O
Nuclear safeguards	O	Δ

O Good Δ Slightly poor □ Poor

3.3.3.1. Comparative study on PWR spent fuel storage option

In this study, several alternatives such as Modular Vault Dry Storage (MVDS), Nutech Horizontal Modular Storage (NUHOMS), and water pool storage types were selected, and each of the alternatives were analyzed by preliminary conceptual design [5] for comparative assessment in terms of technical and economical aspects. The results of this assessment indicated that the water pool type was more favorable in consideration of such factors as safety and licensing, concept maturity, socioeconomic impacts, siting requirement and the flexibility to the future national spent fuel management policy. It also indicated that the dry types were more favorable in such factors as environmental impacts, ease of operation and maintenance, and the construction schedule. A quantitative evaluation was performed by assigning weighting factors and subsequent scoring on each criteria. The results showed that the water pool type had marginal advantage over the dry types in some technical aspects.

The results of the investment costs evaluation have shown that, in case of 4% of discount rate, the unit cost for water pool type and NUHOMS concept were nearly similar, but the unit cost for MVDS concept was the highest as $155-142/kgU for water pool type, $179-162/kgU for MVDS concept and $154-138/kgU for NUHOMS. On the other hand, in case of 8-10% of discount rate, the costs for water pool type and MVDS concept were nearly similar, but the unit cost for NUHOMS concept with high modulability was the smallest as $160-175/kgU for water pool type, $168-175/kgU for MVDS concept and $144-151/kgU for NUHOMS concept.

It has been concluded from these results that the water pool type was preferred in terms of technical aspects while the dry types were marginally preferred for investment point of view.

3.3.3.2. Comparative study on CANDU spent fuel storage option

For spent CANDU fuel, four options were selected as follows:

- storing CANDU SF together with PWR SF in a wet interim storage facility;
- storing CANDU SF separately;
- storing CANDU SF AR and storing PWR SF in the ISFSF;
- storing CANDU SF away from reactor and storing PWR SF in the ISFSF.

These options were assessed in technical and economical aspects. In technical aspects, the option of storing CANDU SF together with PWR SF in a wet interim storage facility requires more complex structure, system configuration and equipment capacity compared with the case of storing only PWR fuel due to the additional design requirements. In economic aspects, assessment was made by the comparison of life cycle costs and levelized unit cost. It was shown that storing CANDU SF and PWR SF separately (PWR fuel in interim wet storage, CANDU fuel in dry storage at reactor or away-form reactor) had advantage over storing both PWR and CANDU SF in the same wet interim storage facility.

It is concluded from these results that CANDU SF may better be stored separately from PWR SF in consideration of long-term management, and that appropriate method be applied for storage of CANDU SF.

4. SPENT FUEL TRANSPORTATION PROGRAMME

4.1. Transportation scenario

As previously described (Section 3.3.1.3), KAERI has analyzed the transportation method of SF from NPPs to the ISFSF [6]. In this study the sea transportation method has been chosen as the best option, since all NPPs are located along the coastline and the land transportation would require passing through highly populated areas.

Also, based on the amount of SF and radwaste, the transportation scenario has been analyzed. In this analysis, the amount of SF and low level waste to be transported was assumed as cumulative amount generated from 23 NPPs counting both the existing NPPs and NPPs to be constructed by 2006. The analytical result shows that transportation ship of 3,000 ton scale should transport 576 PWR assemblies, 18,360 CANDU fuel assemblies and up to 3,196 drums of radioactive waste on annual basis during the first operation stage.

4.2. Transportation cask

Two casks models, i.e. KSC-1 (1986) and KSC-4 (1990), have been designed by KAERI and fabricated by domestic heavy industrial companies [7]. The design parameters have been determined by computer-aided calculations as well as mock-up tests. In the course of design and fabrication stages, licensing procedures have been implemented in compliance with the rules and regulations as ordained by the Atomic Energy Law of Korea.

The wet-type KSC-1, which weighs 28 tons, is capable of loading one PWR SF assembly with a burnup of 40,000 MWd/tU and a cooling time of one year. Major shielding materials used for the cask were lead against gamma-rays and water against neutrons. The transportation system including the KSC-1 cask has been used to transport seven SF assemblies and one basket with 46 failed fuel rods from PWR nuclear power plants (NPPs) to the post-irradiation examination (PIE) facility of KAERI for hot cell examination under strict rules and regulations for nuclear material safeguards.

The KSC-4 weighs 37 tons and is capable of loading four PWR SF assemblies with a burnup of 38,000 MWd/tU and a cooling time of three years [5]. It can be used in both dry and wet conditions. Major shielding material against gamma-rays is lead and that against neutrons is hydrogen-rich resin. The design specifications are summarized in Table VI. Using the KSC-4 casks, a total of 312 PWR SF assemblies has been transshipped to date from Kori-1 to Kori-3 and Kori-4 NPPs.

No technical problems have so far been encountered with the KSC-1 and KSC-4 casks during loading, transportation and unloading of the SF. Design of the KSC-7 cask for PWR SF has recently been completed (1995) and its specification is given on Table VII.

TABLE VI. DESIGN SPECIFICATIONS OF KSC-4 CASK

Items	Specifications
Type of package	• B(U) type, fissile class III
Loaded weight	• 37 ton
Size (m)	
• outside diameter	• 1.35
• height	• 4.82
Materials	
• shells	• SA 240 type 304
• fuel basket	• borax/borate SS
• gamma-rays shield	• lead casting
• neutron shield	• hydrogenous resin
Fuel	
• type	• PWR assembly
• max. burnup	• 38,000 MWd/tU
• cooling time	• 3 years
• radioactive decay heat	• 7 kW
• radioactivity	• 70.3 PBq

TABLE VII. DESIGN SPECIFICATIONS OF KSC-7 CASK

Items	Specifications
Type of package	• B(U) type, fissile class III
Loaded weight	• 70 ton
Size (m)	
• outside diameter	• 1.86
• height	• 5.40
Materials	
• shells	• stainless steel, type 304
• fuel basket	• borax/borate SS
• gamma-rays shield	• lead
• neutron shield	• silicone mixture
Fuel	
• type	• PWR assembly
• max. burnup	• 50,000 MWd/tU
• cooling time	• 1.5 years
• radioactive decay heat	• 32.3 kW
• radiation	• 2.53E+17 photons/sec • 3.12E+09 neutrons/sec

4.3. Cask handling devices

To apply the KSC-1 and KSC-7 to transshipment of SF between NPPs and from NPP to PIEF of KAERI, several devices were designed and fabricated [8]. They are a handling tool of SF, a lifting yoke and a lid handling device. Also, cask maintenance tools such as an internal basket decontamination system, a surface decontamination system, a leak test system and a internal cavity drying system, etc. have been developed. Since these devices are manually operated, there is potential risk of operator exposure to ionizing radiation. However, no severe problem has been encountered during unloading and loading operation. Major devices developed for the cask operation are as follows.

4.3.1. Handling tool of spent fuel assembly

As shown in Fig. 3, a handling tool is used for grappling and transferring one spent FA from storage pool to load into cask or for reverse operation. The handling tool 8.9m long is made of stainless steel. This tool is hooked on the chain of crane and can be manually operated outside the pool.

4.3.2. Lifting yoke

A lifting yoke shown in Fig. 4 is used for grappling the cask when loading or unloading it from transportation truck and the loading pool. This device consists of a main frame, an arm assembly which grapples the cask trunnion, and a guide plate which is used for guide of yoke arm to the trunnion of cask. Two arms are opened by a hydraulic cylinder simultaneously. Two eccentrical holes are provided at the end of each arm, a larger one for insertion and a smaller one for holding and lifting trunnions after the grapples are safely inserted. The lifting yoke weighs one ton and has a maximum lifting capacity over 100 ton which is almost three times that of cask.

4.3.3. Lid handling tool

A cask lid weighs one ton and has an eye bolt at its center. When lifting the lid, the lid handling tool shown in Fig. 5 is employed. This tool has a 3 ton capacity of lifting weight which is three times that of the cask lid. A gripper driven by a hydraulic cylinder is installed at the hook of the lid handling tool and its motion is remotely controlled by manipulating a handle at the other end of the lid handling tool.

4.3.4. Internal basket decontamination system

An internal basket decontamination system has been developed. This system consists of a decontamination brush, a high pressure water pump and filter system as shown in Fig. 6. The decontamination brush with high pressure (180 kg/cm^2) water nozzle, which is attached at the decontamination equipment housing, cleans the internal surface of a basket while rotating and moving into the vertical direction inside basket. This sequence is repeated until four baskets are decontaminated. The contaminated particles are sucked into the water tank through the filter bed and the purified water is recirculated by a high pressure water pump. The flow rate of pump is about 16.7 lpm. The contaminated filter assembly is replaced by using the specially designed filter handling cask. The performance of this system has been investigated by applying the contaminated KSC-4 which has been employed in transshipment operation of 156 spent FAs between NPPs. Table 8 show the amount radioactivity reduction inside the basket as a result of decontamination. As shown in Table 8 the radioactivity is reduced to 0.175 $\mu Ci/100cm^2$ after decontamination. As compared with the level before decontamination (2.38 $\mu Ci/100cm^2$), the performance of this system is proven to be affordable.

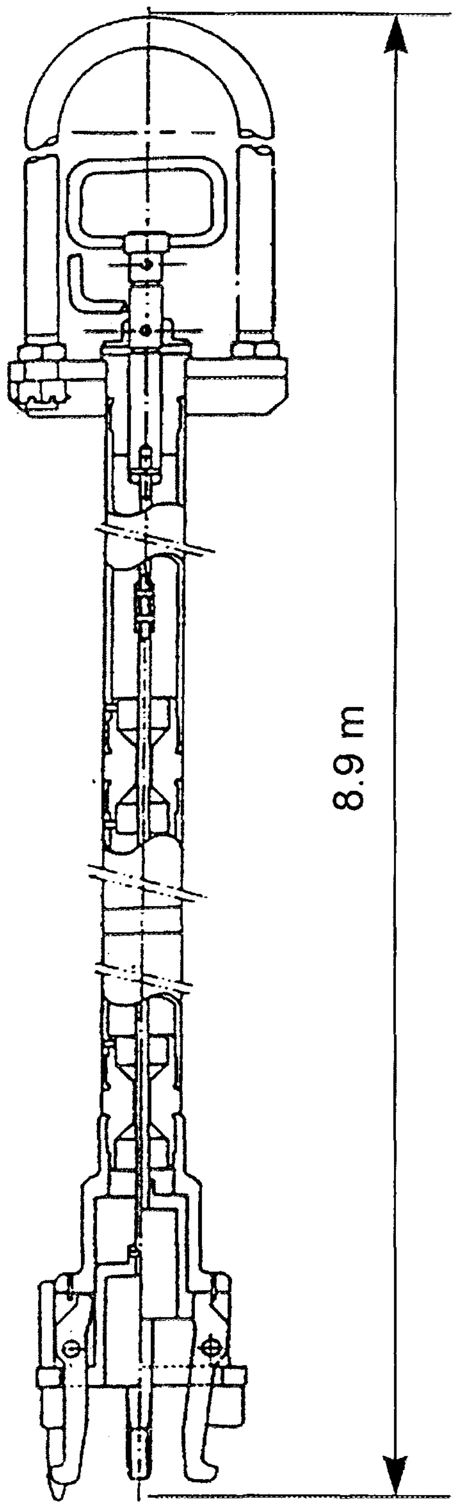

FIG. 3. Spent fuel assembly handling tool

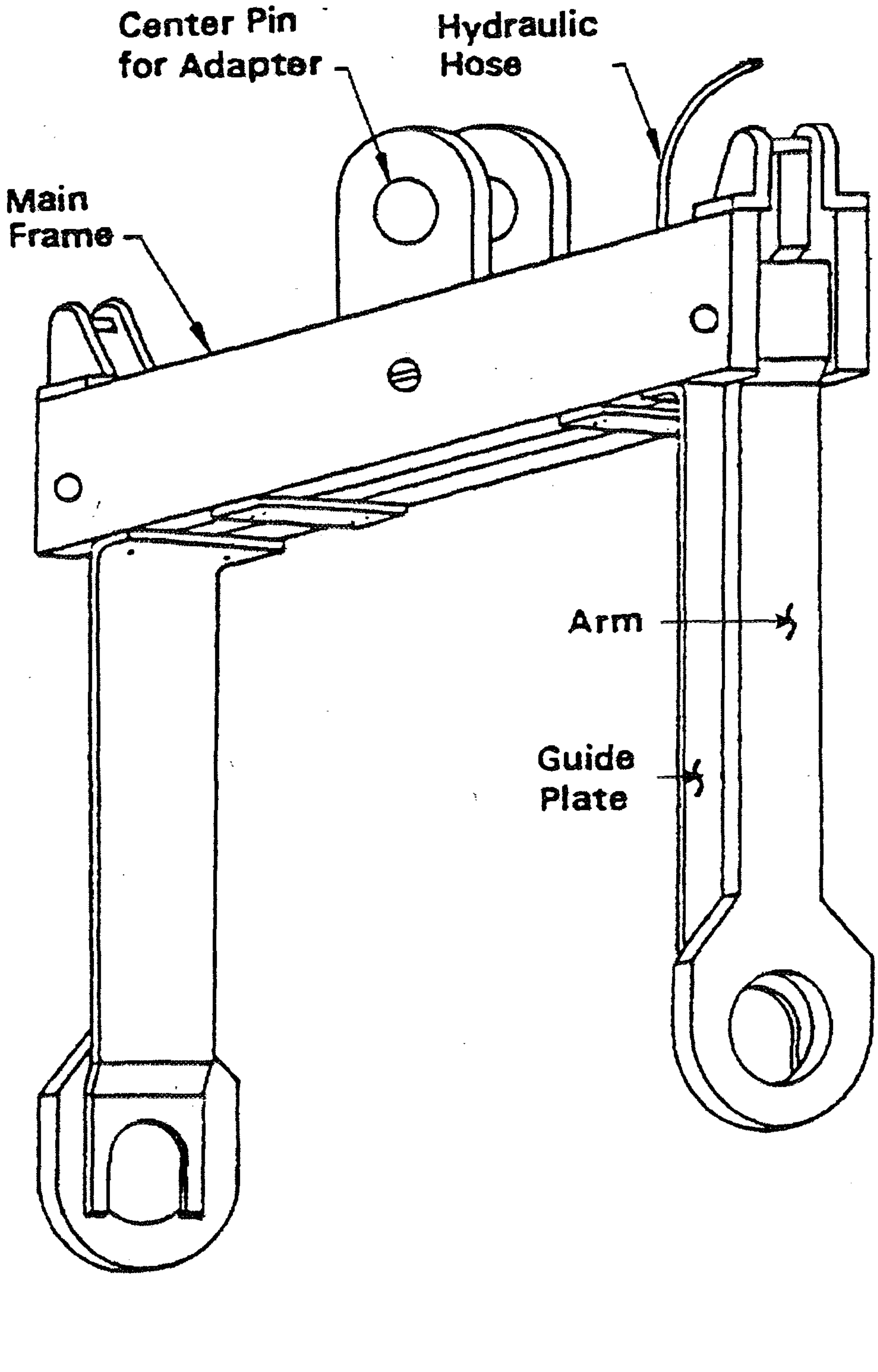

FIG. 4. Cask lifting yoke

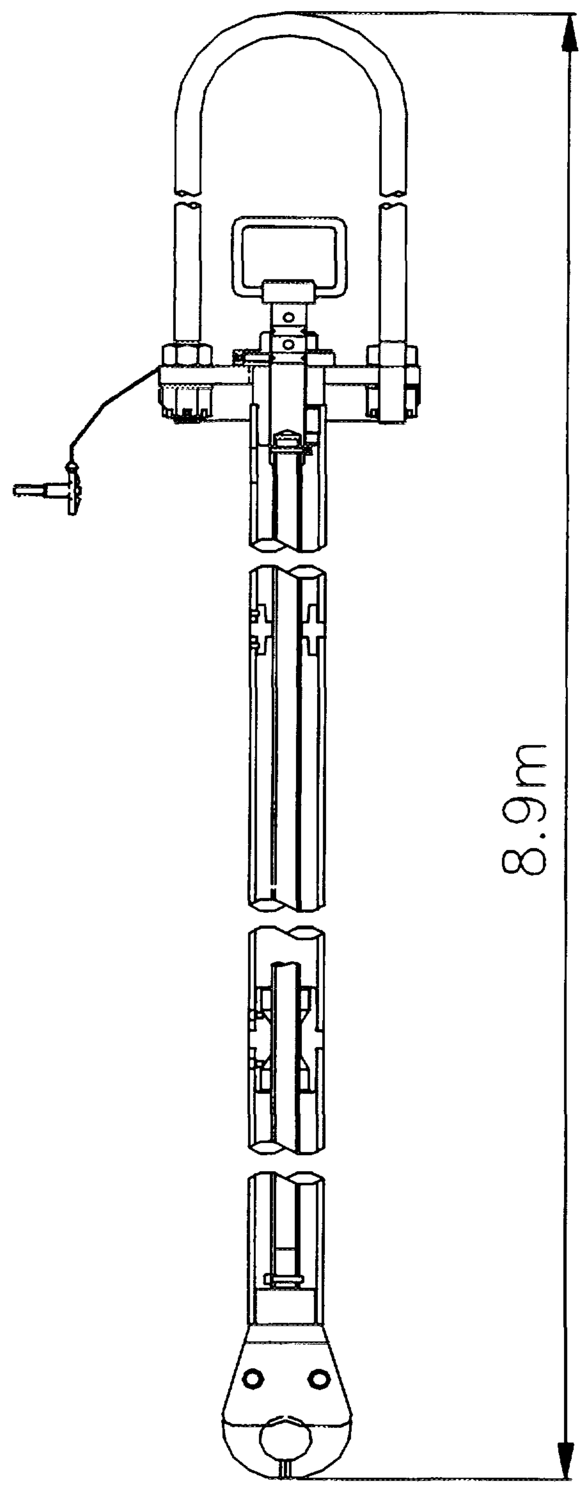

FIG. 5. Cask lid handling tool

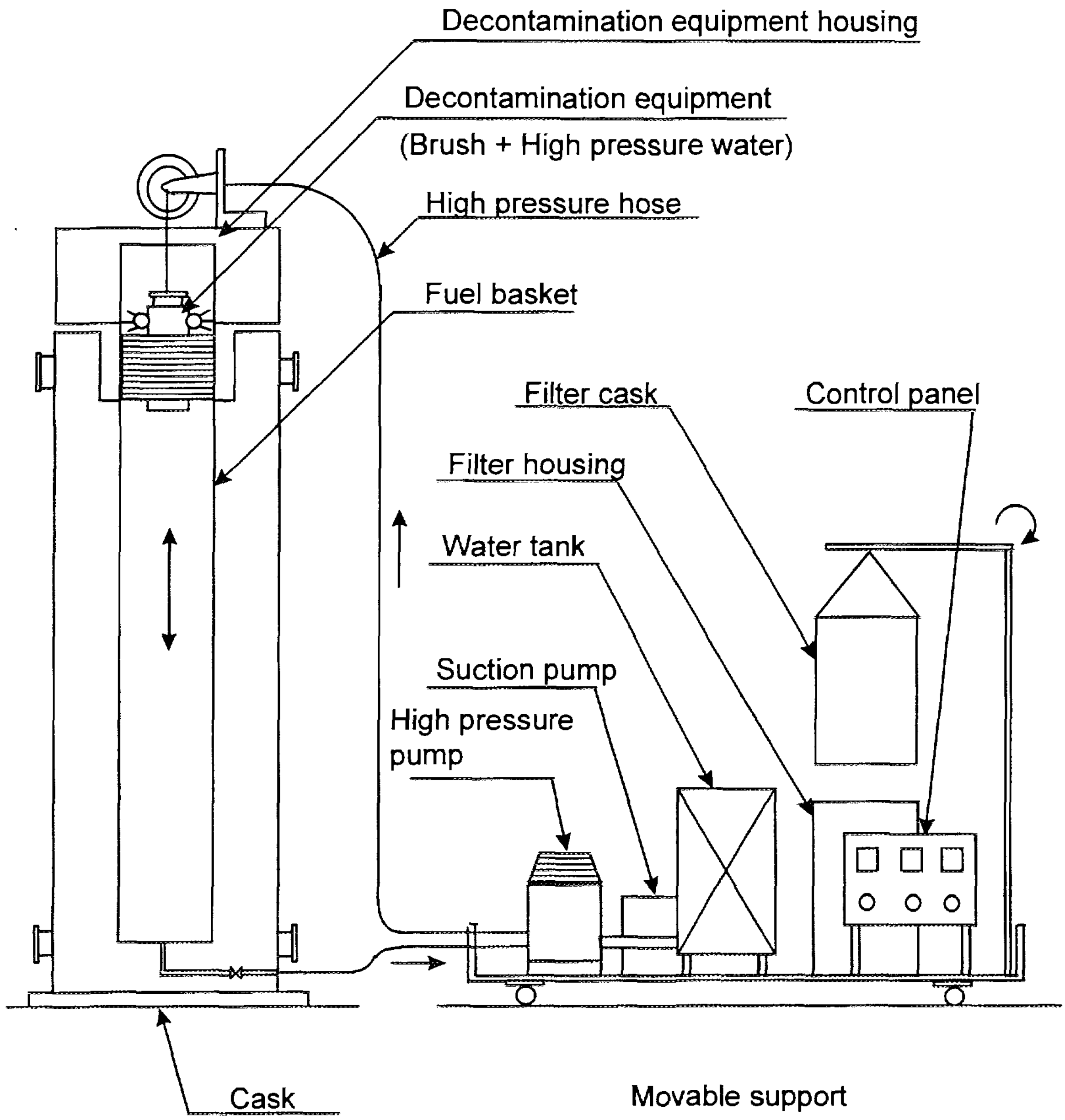

FIG. 6. Internal basket decontamination system

TABLE VIII. COMPARISON OF RADIOACTIVITY OF BASKET BEFORE AND AFTER DECONTAMINATION

Nuclides	Radioactivity ($\mu Ci/100cm^2$)	
	Before Decontamination	Post Decontamination
AM - 241	2.762 E - 03	0
CE - 144	8.667 E - 03	1.094 E - 03
CO - 60	2.303 E - 00	1.718 E - 03
CS - 137	1.313 E - 02	0
MN - 54	7.497 E - 03	0
RU - 106	2.292 E - 02	0
SB - 125	2.089 E - 02	2.177 E - 03
Total	2.381	0.175
D.F. (Decontamination Factor) : 13.6		

4.4. R&D activities for remote cask handling devices

A wide variety of sophisticated handling devices for both spent FAs and casks have been developed for minimizing the radiation exposure to the operators. The devices developed are an anti-swing crane and a Remote Cask Grappling and Lid Unbolting Device (RECGUD). The state of art technology has been adopted and these devices can be employed in NPPs for remote cask handling in near future.

4.4.1. Anti-swing crane

In order to remove the load swinging motion that could hinder operational safety as well as efficiency, an anti-swing crane has been developed. As shown in Fig. 7, the anti-swing crane system consists of a conventional crane, a swing angle measuring device and a control system [9,10]. The swing angle measuring device [11] shown in Fig. 8 works upon two point laser distance sensors attached on the rope and reflection plate attached on the trolley. As the rope swings, the laser sensor also swings in such a way to measure the linear distance changes between laser source and reflection plate. This changes can be translated into the swing angle by the use of geometric calculation. Fig. 9 presents the schematics of control system. Two analog to digital converters are used for capturing the swing angle signal from two laser sensors. Three pulse generators are used for the control commands to each motors and seven digital input device are used for the limit switches signal. Also, three sets of digital counters and frequency to voltage converters are used for the position and velocity input of trolley in each directions. All of these devices were installed in a 386 PC.

Several anti-swing control algorithms using open-loop and closed-loop approaches have been developed and implemented using a one ton scale anti-swing crane system. These algorithms are an acceleration profile planning [12], a pre-programmed velocity feedback controller [12], a fuzzy controller [13], and the hybrid anti-swing/position controller [14,15]. The performance of these control algorithms is verified through a series of simulations and experiments. The results show that the swinging and position errors of load are greatly reduced as compared with those of conventional crane. KAERI has designed a commercialized version of the above-mentioned controllers by integrating various functions of these controllers into a dedicated firmware and has transferred the anti-swing technology to the industrial sectors. Currently, a much large scale anti-swing crane is now being developed for application in the factory automation process.

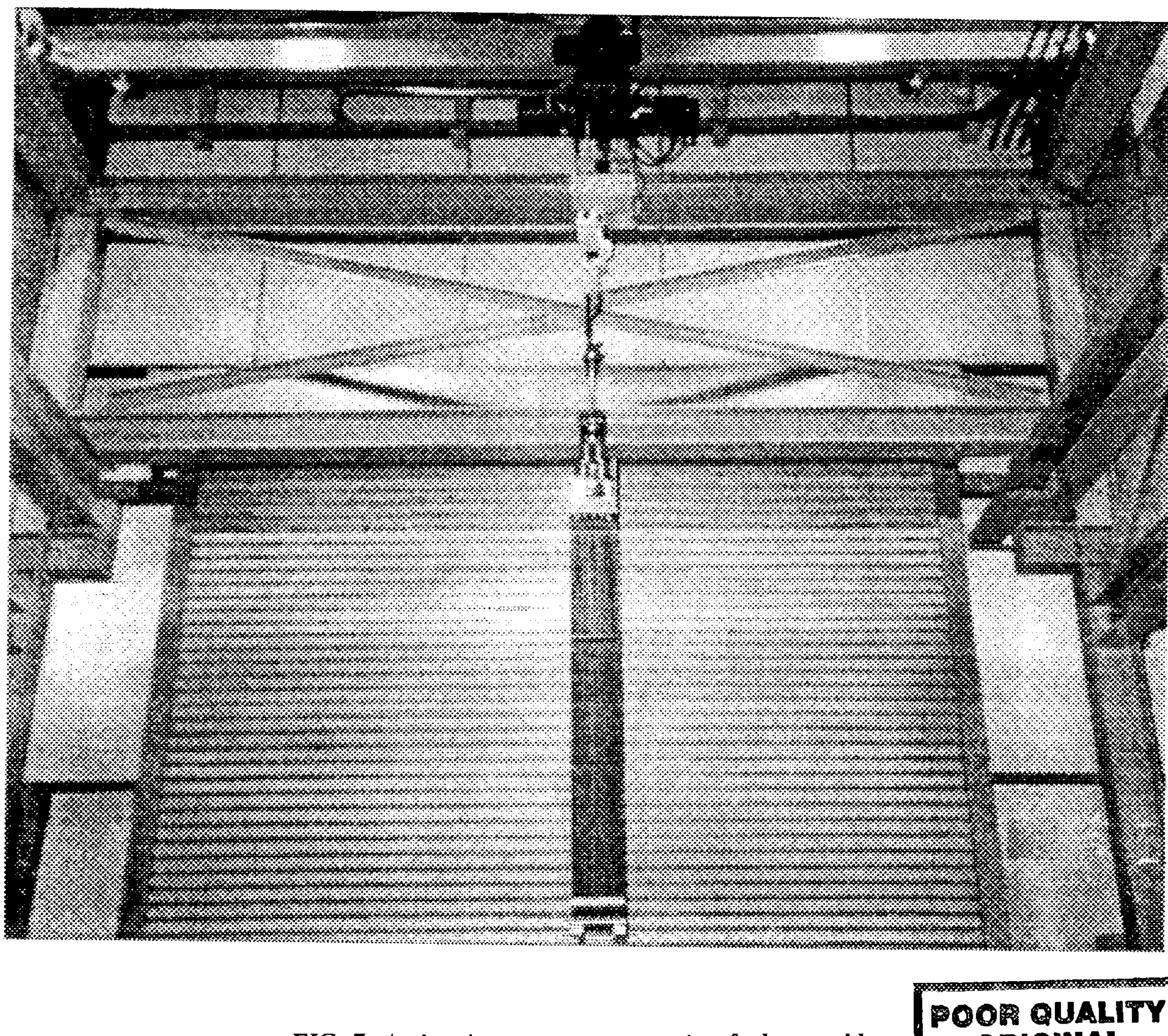

FIG. 7. Anti-swing crane transporting fuel assembly

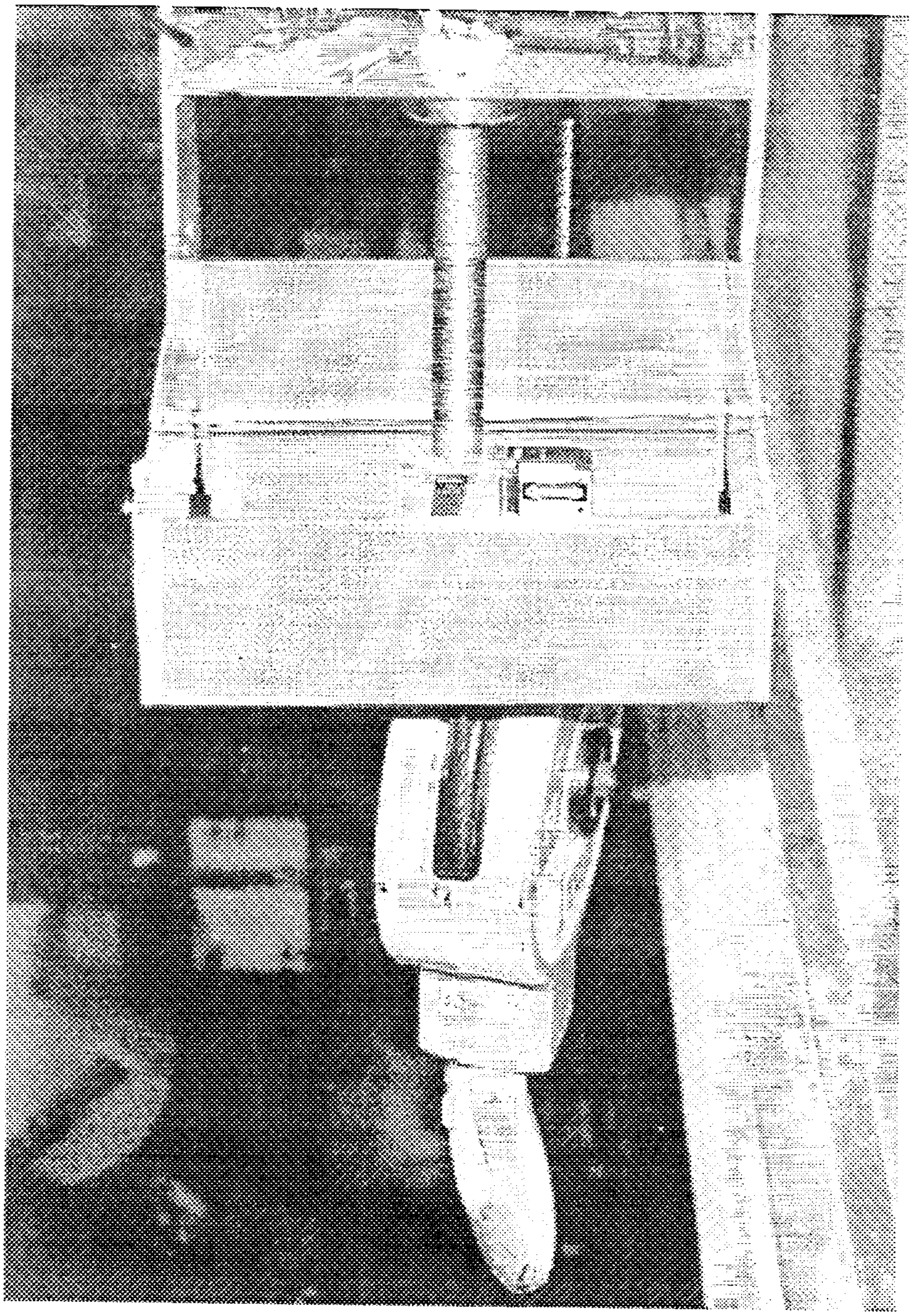

FIG. 8. Swing angle measuring device using laser displacement sensor

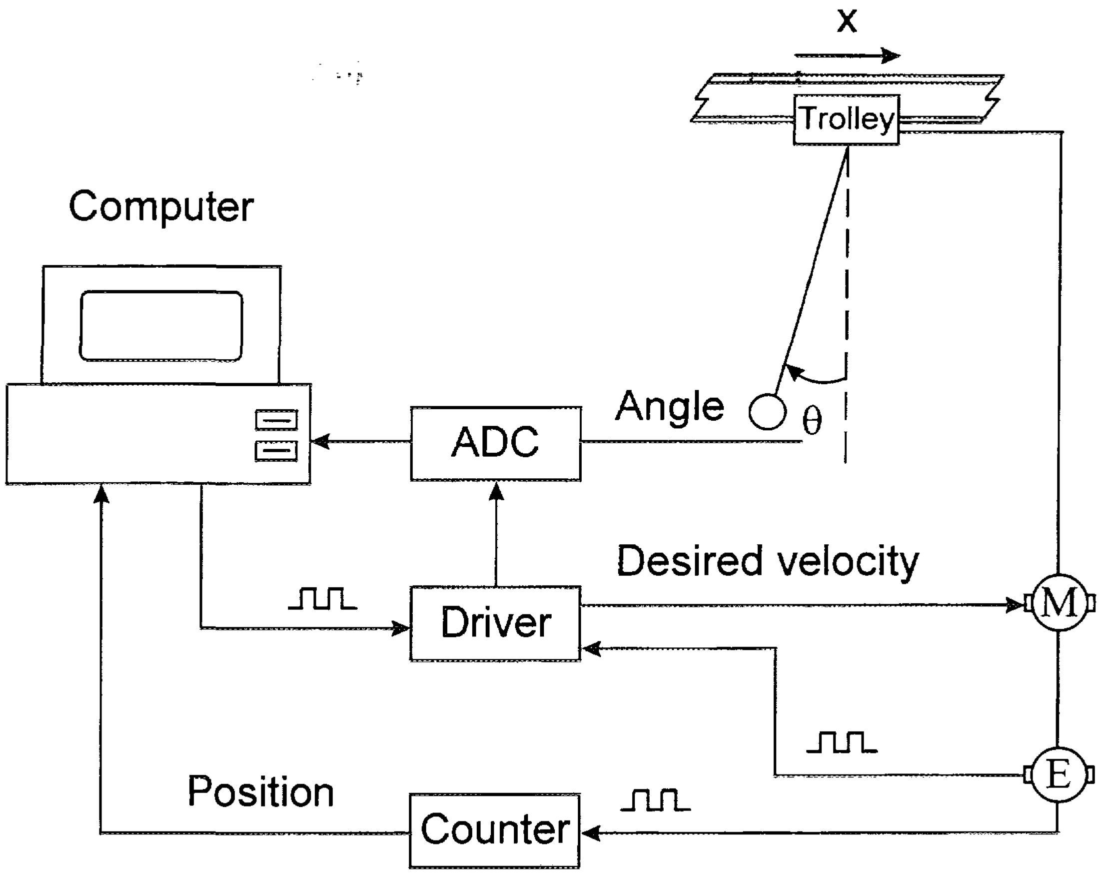

FIG. 9. Schematic diagram of control system

4.4.2. Remote cask grappling and lid unbolting devices

Among various handling tasks associated with cask handling operation, moving the cask and unbolting the cask lid are the most tedious and thereby the most significant contributor to the occupational exposure to the radiation. These tasks were selected as a R&D item to which robotics technologies are applicable. Therefore, along with the anti-swing crane, a Remote Cask Grappling and Lid Unbolting Devices (RECGUD) has been developed as a dedicated device capable of precisely grappling the cask trunnion and unbolting the lid bolt on the cask lid in a fully remote and automatic manner while it is suspended by the anti-swing crane.

4.4.2.1. Design considerations

The RECGUD is designed in such a way that its application requires no special modification on neither the cask nor the cask handling facility. Therefore, the device can be adopted to the current cask handling circumstances without much technological refurbishment. The lid of KSC-4 is bolted by 16 stud bolts with 50 kgf.m torque. The model cask is shorter than the actual one and it's weight is 400 kg. But, the mechanical and geometrical features of its lid are identical to the KSC-4. The prototype of RECGUD is designed to have a 1 ton payload capacity to carry the model cask of KSC-4 and a resolution of 2 mm on all axes for accurate grappling and fine positioning of the end effector. Also it's torque wrench module is designed to have over 50 kgf.m torque.

4.4.2.2. Mechanical structure

As shown in Figures 10 and 11 the RECGUD consists of a main body, two grapples, a wrench guide, a torque wrench module, and a bolt tray. The main body, the frame for the device, is suspended horizontally at the rotation axis to a anti swing crane. At both ends of the body, two grapples are installed vertically. On the same rotation axis, the wrench guide is installed parallel to and below the body. At the end of rotation axis, a CCD vision camera, an ultrasonic sensor, a laser sensor, and a bolt tray are mounted.

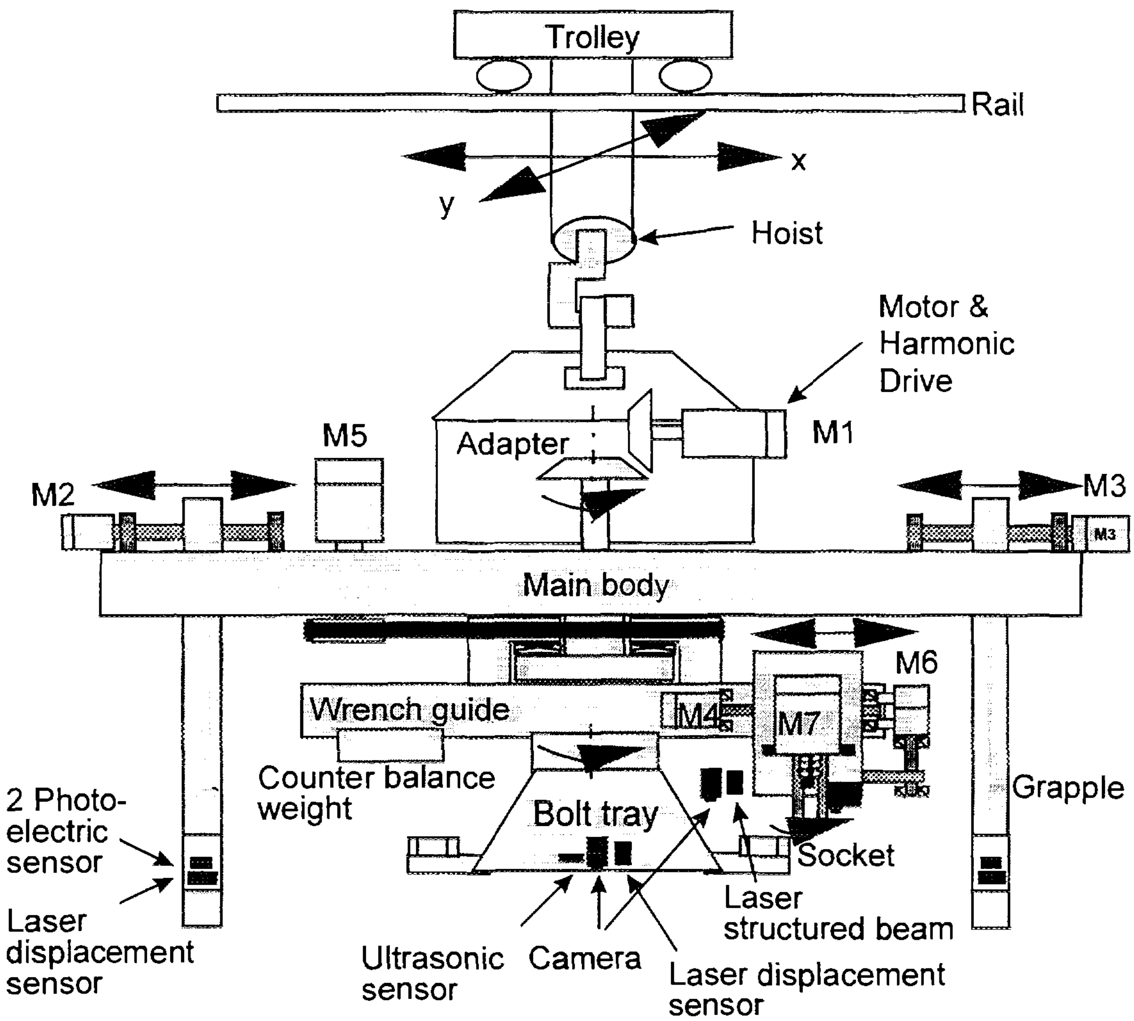

FIG. 10. Structure of RECGUD

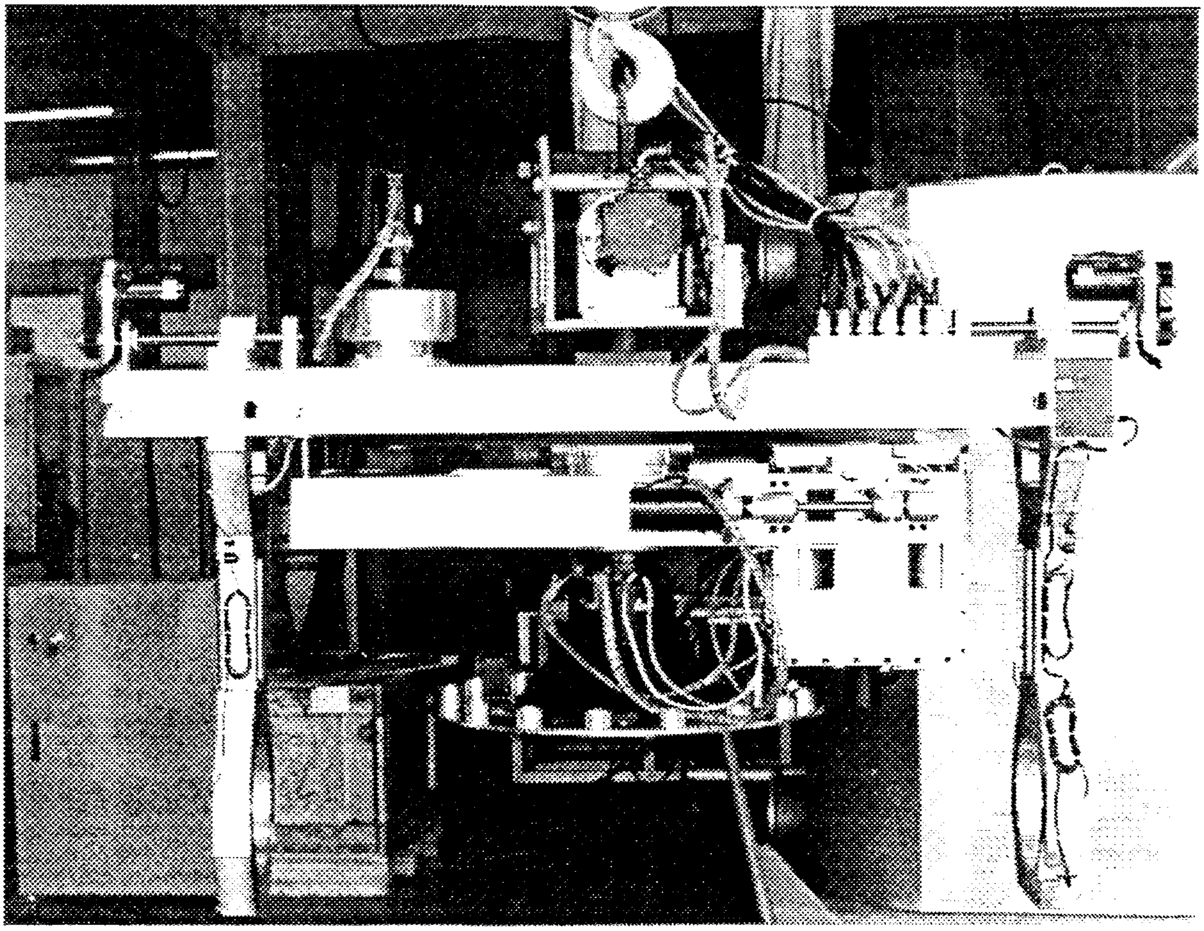

FIG. 11. *Photography of RECGUD*

The grapples have a grapple hole at their lower part. The grapple motors actuate each grapple independently along the longitudinal axis of body until the grapple hole is inserted over the trunnion. At one end of the longitudinal axis of wrench guide, the torque wrench module is installed. The guide is mounted with an ac servo motor for translating the torque wrench module along the longitudinal axis of guide. The wrench guide rotating motor actuates the guide to rotate about the rotation axis of body. The rotation of guide allows the torque wrench module to move along the circumference of cask lid. At the other end of the longitudinal axis of guide, a balancing weight is mounted. The weight plays the role of balancing the device while the device is carried by the crane.

For adopting a socket wrench, an adapter is mounted to the spindle of the motor. The socket is twelve-facet which makes the mating of the socket to the bolts easier. The depth of socket is 90 mm which is deep enough to accommodate both a loosened bolt and a tool for holding the loosened bolt. As shown in Fig. 12, the tool consists of a spring and an electric magnet. The spring is mounted in the socket and the electric magnet for holding the loosened bolt is attached at the end of spring.

The bolt tray with 16 bolt holes where the loosened bolts are collected in order is mounted at the end of rotation axis of body. As the socket approaches the bolt tray, the overall positioning imprecision must be accommodated by the taper of bolt hole.

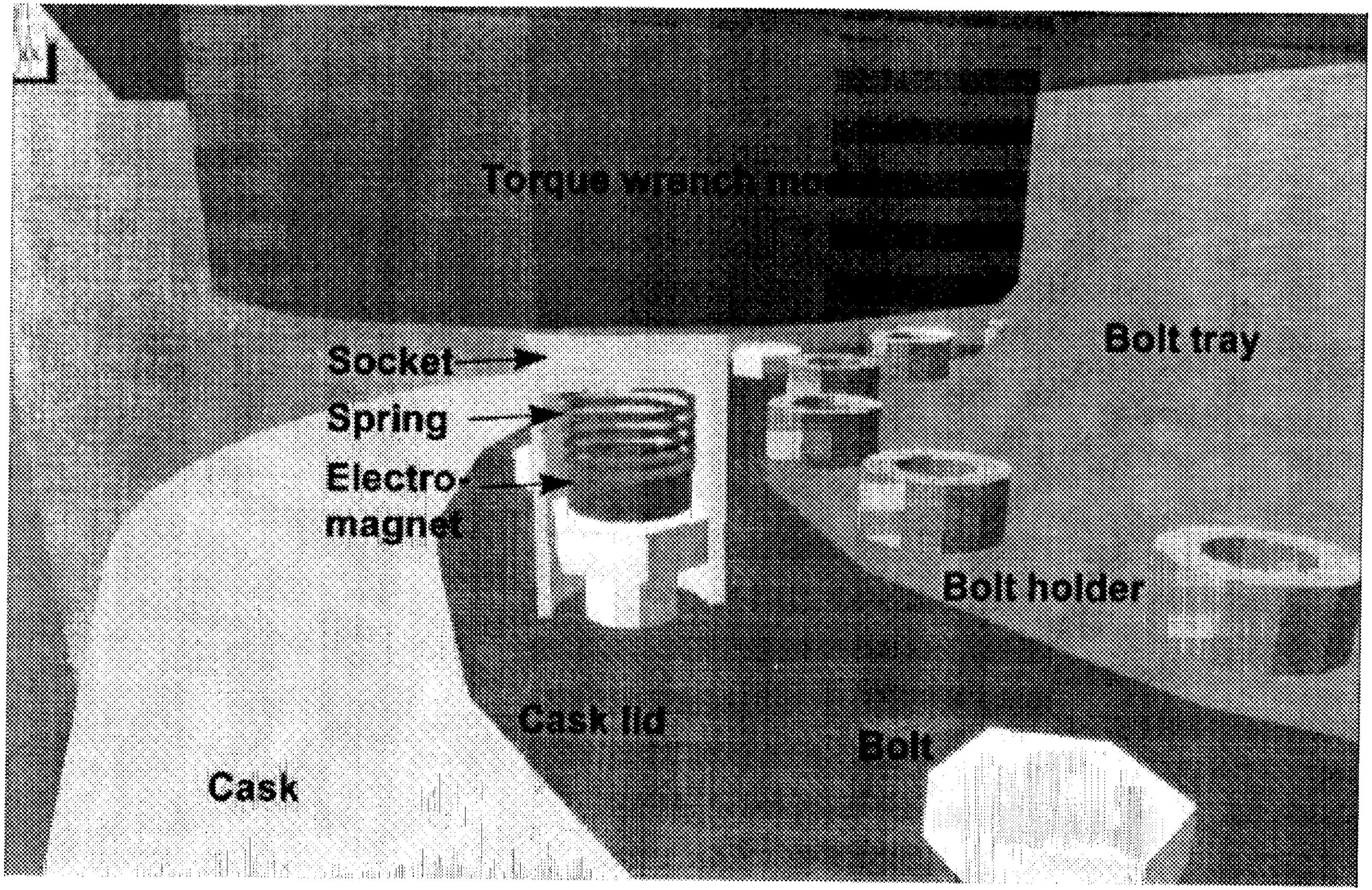

FIG. 12. Electro-magnet and spring inside socket

4.4.2.3. Sensors

The RECGUD is equipped with various sensors for the information about the position of cask and lid bolts and the orientation of cask. The device uses an ultrasonic sensor, five laser displacement sensors, four photoelectric sensors, and two CCD vision cameras.

The ultrasonic sensor in used to calculate the vertical distance between the device and the cask lid until the distance is short enough such that a laser displacement sensor can be used to measure a shorter distance.

Once the RECGUD stops at the exact position, the axis through the centers of two grappling holes and the axis through the centers of two cask trunnions are on the same horizontal plane. Then, the grapples can insert the trunnions, once the orientation of the device is corrected with respect to that of cask. The other laser sensors are for measuring horizontal distance between the grapple and the cask so that the grapple can stop precisely inserting into the cask trunnion.

The photoelectric sensors are for measuring the position and orientation errors of the grapples to the trunnion. The output signals from the sensors which are mounted around the grappling holes toward trunnion are compared to calculate these errors by adopting neural network algorithm.

Two CCD vision cameras are used for the device. The first camera, the device camera, mounted at the end of rotation axis of body, is used to continuously identify the planar location of the cask. Based on this information, the crane is guided to place the device over the cask such that the center of device is aligned with that of cask lid. Then, the orientation of cask is identified. The second camera, the torque wrench camera, mounted on the casing of torque wrench module, is used to identify the location of the bolt and to position the wrench module over the bolt head. For the camera, a strip of laser beam is projected over the top surface and the location of the bolt head is identified by analyzing the distorted pattern perceived by the camera.

4.4.2.4. Control system

As shown in Fig. 13 the control system consists of an actuator subsystem, a sensor subsystem, and a control subsystem. In the actuator subsystem, the rotational axes of device are driven by ac servo motors coupled with speed reducers and the translational axes of device are driven by ac servo motors coupled with ball-screws. The sensor subsystem comprises various sensors and cameras which are used for positioning each part of the device. The control subsystem is designed to be controlled either by a computer keyboard or by a hand controller. The command signals from the hand controller are transmitted through PC-bus to Programmable Mullet-Axes Controller (PMAC). Signals sent by sensors are collected and analyzed in PMAC. Then, the control computer runs on a programme to manipulate the data and output it to the device through PMAC which uses a proportional and integral controller to compensate the control loop. In addition, the desired movement of RECGUD can be performed by entering the absolute coordinate of each axis of device through the keyboard. The communication between the control computer of the device and the crane controller is coordinated via RS-232 serial link.

4.4.2.5. Control algorithms

Various control algorithm have been developed to facilitate the operation of RECGUD such as: the image processing algorithm for the identifying the location of the cask and bolt, the neural network for recognizing the offset position between the hole of grapple and the cask trunnion, and the rotational control algorithms for reducing the operation time of positioning the grapple to the cask trunnion.

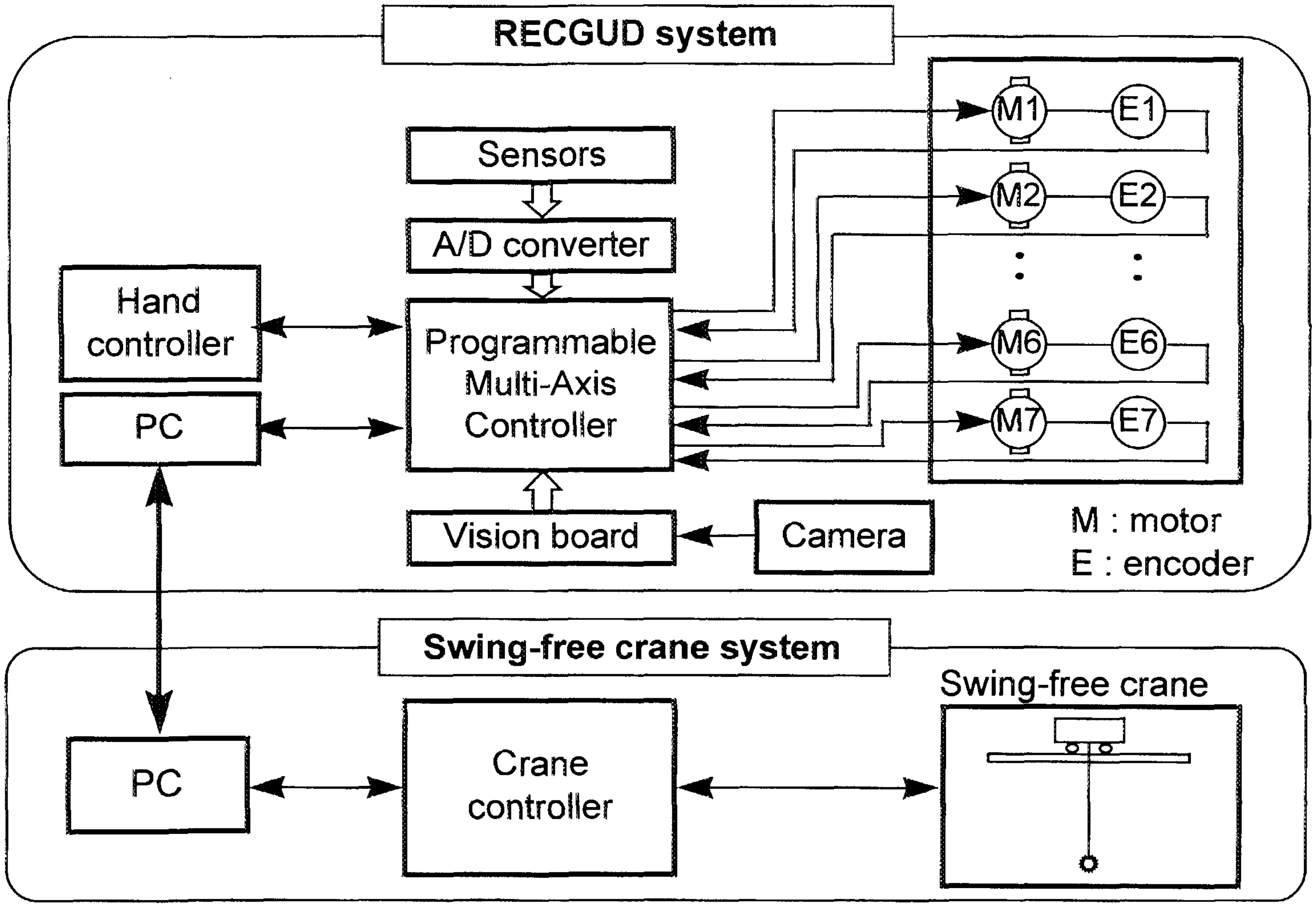

FIG. 13. Schematic diagram of RECGUD control system

The planar location of cask is identified by processing the image from a CCD camera mounted at the end of rotation axis of main body [16]. The conventional image processing technology is modified by introducing the pattern recognition algorithm. This algorithm is used mainly to improve the identification resolution in practical environment where the light is non-uniform. The identification results is affordable such that the accuracy of position error between two centers of RECGUD and the cask is proven to be within 1 cm at a condition that the distance between them is 4 m.

A grapple device, a component of RECGUD, has to be inserted over two trunnions anchored diagonally on the cask wall in order to lift the cask for transportation and unbolting/fastening the cask lid. However, an insertion of a grapple over trunnions is difficult due to position and orientation errors of the center position of the grapple device caused by incongruity with the center of the cask. To deal with this problem, a neural network is used to predict position errors of the grapple device using photoelectric sensors installed on the grapples [17]. Neural network training is performed to infer a mapping between sensor values and position and orientation errors. These estimated errors are to provide control inputs to correct the center position of the grapple device. Data is obtained by using a half scale apparatus that simulates the grapple device of RECGUD and trunnions of a cask. Results show that the trained neural network is able to estimate the position and orientation errors of the grapple device's center with accuracy of below 0.2 cm when presented with untrained sensor inputs, i.e., new locations of the grapple device.

Since RECGUD is suspended to an overhead crane, its body should undergo a prolonged oscillation upon actuation in rotational direction and it becomes difficult to achieve precise grappling of the cask. To suppress the rotational oscillation of the body, an open loop input shaping technique has been developed [18]. This method can rapidly suppress the rotational oscillation within one cycle of oscillation period even though the system dynamics is not precisely modeled.

5. CONCLUDING REMARKS

Korean spent fuel management programme is reviewed including the management policy. KAERI designated to a national radwaste management organization by government has tried to secure the site for LLW disposal facility and the ISFSF. It has finished the conceptual design of the ISFSF and updated the design to make it a lot simpler to operate and cheaper to construct and operate over its full life cycle by conducting the optimization and comparative studies. Also, KAERI developed various technology which are required for the ISFSF design such as transportation and wet storage technology. After the radwaste management programme was transferred from KAERI to KEPCO. KEPCO is reviewing the feasibility of site and the ISFSF.

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