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RADIATION SAFETY RECORDS OF MARITIME TRANSPORT OF NUCLEAR MATERIALS FOR RECENT 10 YEARS IN JAPAN

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ABSTRACT
Radiation safety for sea transport of radioactive material in Japan has been discussed based on records of the exposed dose of sea transport workers and measured data of dose rate equivalents distribution inboard exclusive radioactive material shipping vessels. Recent surveyed records of the exposed doses of workers who engaged in sea transport operation indicate that exposed doses of transport workers are significantly low. This study clearly shows that radiation safety is ensured in cargo operations and onboard ships during the maritime transport of radioactive materials

INTRODUCTION
Presently, most of the nuclear fuel used in Japan is transported by ship from another country, and spent fuel is transported by sea using special-purpose transport ships to reprocessing plants outside of the country. Previously, spent fuel was transported by special-purpose transport ships from each nuclear power station to the Tokai Reprocessing Plant or reprocessing plants in Britain or France. However, in 1998, spent fuel began to be accepted at the spent fuel receiving and storage facility at the Rokkasho Reprocessing Plant. Currently, spent fuel is mainly transported by sea from each nuclear power station to a reprocessing plant in Japan. Low-level radioactive waste is transported to the low-level radioactive waste disposal facility at Rokkasho Village by special-purpose transport ship from each power station. In addition, with the commencement of plutonium thermal reactor power generation, new MOX fuel has been transported to Japan from other countries. In this way, maritime transport of radioactive material plays an extremely important role in the nuclear fuel cycle in Japan. Figure 1 provides a typical diagram of how nuclear fuel is transported in Japan. In addition, prior to the accident at Fukushima Daiichi Nuclear Power Station, the transport of large amounts of low-level radioactive waste was anticipated following reactor decommissioning, and the transport of new MOX fuel within Japan was anticipated after the Rokkasho MOX fuel processing facility went into operation. The accident at Fukushima Daiichi Nuclear Power Station has made the future of such plans uncertain, but it is clear that there are issues which will need to be addressed in the future concerning the transport of large amounts of waste and other materials arising from decommissioning, including debris and other items, as well as the removal of fuel in fuel storage pools and large amounts of debris within the site, which has been contaminated with radioactive material from the accident at Fukushima Daiichi Nuclear Power Station. As such, it is assumed that radioactive packages will become more diverse in Japan in the future. In a global sense, Japan is an advanced nation when it comes to transport of radioactive material, and takes pride in

its very high record of safety in such transport, but an even higher degree of safety will be required to be secured in transport as the cargo to be transported become more diverse, so ensuring safety during maritime transport of radioactive material is one of the important issues which needs to be addressed.

In this paper, we verify safety during maritime transport of radioactive materials from the perspective of radiation protection based on actual radiation exposure data for maritime transport workers in recent years.

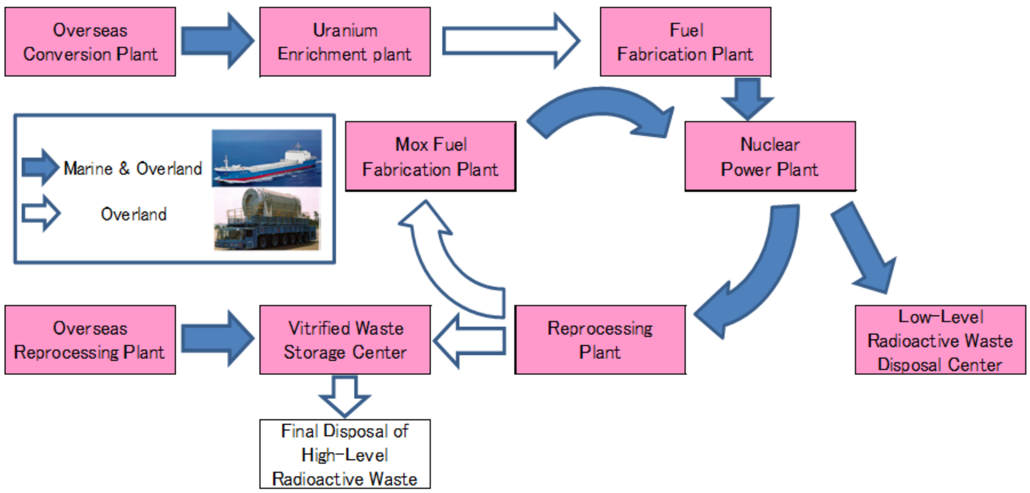

Figure 1. Nuclear materials, spent fuel and LLW transport in current nuclear fuel cycle in Japan.

RADIATION PROTECTION REGULATIONS FOR MARITIME TRANSPORT OF RADIOACTIVE MATERIAL IN JAPAN

Japan has different legal structures for regulations within nuclear facilities where controlled areas are established and managed, and the regulations on transport outside of business establishments. When radioactive materials are transported by sea, regulation is prescribed in accordance with the Ordinance of the Ministry of Land, Infrastructure, Transport and Tourism “Regulations for the Carriage and Storage of Dangerous Goods by Ships” (hereinafter, “Japan Maritime Transport Regulations”) based on the Ship Safety Act and is considered to be transport outside the nuclear site. However, nuclear operators are not totally absent from participating in transport outside the nuclear site. In other words, under the Japan Maritime Transport Regulations, a duty of compliance is placed on the shipper, which is a nuclear operator, in standards pertaining to containers, packaging, regular labeling, secondary labeling and so on, and responsibility for carriage methods and other such requirements is placed on the captain or ship owner. However, as for provisions related to radiation protection, overall radiation management is performed as an employee of a nuclear facility in accordance with the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (“Nuclear Reactor Regulation Act”) in cases where the shipper is a nuclear operator, so such matters are left to the Act and no special provisions are prescribed under transport regulations. Under transport regulations, provisions are prescribed only for mariners and other onboard residents.

Japan’s regulations related to radiation protection in maritime transport are as follows.

- ✓ Not to exceed 2 mSv/h on the surface of the outer shell of the hull (outer plating, hold, compartments, and deck), and not to exceed 100 µSv/h at a distance of 2 m from the surface.

- ✓ Places where there is a risk of exposure exceeding 1.3 mSv over a period of three months are regarded as limited-access areas.
- ✓ The maximum dose equivalent rate is not to exceed 1.8 μSv/h in onboard living quarters or other areas which people regularly use.
- ✓ The dose of radiation which people onboard receive is not to exceed 1 mSv annually (however, in cases deemed appropriate by the Minister of Land, Infrastructure, Transport and Tourism, this may be 5 mSv).
- ✓ The ship owner must draft and provide to the captain a radiation protection plan detailing dose measurement methods, emergency responses, training, education and other aspects so that the captain is able to manage dose appropriately. The captain must make preparations onboard for the radiation protection plan.
- ✓ In cases where it is considerably difficult for the maximum dose equivalent rate in living quarters and other such areas or the dose received by people onboard to be in accord with the aforementioned provisions and the Minister of Land, Infrastructure, Transport and Tourism permits measures to be adopted for dose management in keeping with the dosimetry, special provisions are allowed.

In this manner, the radiation dose limit in transport regulations is prescribed to be 1mSv/year, which is the same as the dose limit for the general public, and is regulated at a sufficiently low level of safety. However, there are special circumstances under which this standard is not able to be followed, and a dose limit higher than this may be set in cases where the Minister of Land, Infrastructure, Transport and Tourism gives special approval after necessary measures have been taken for dose management.

Workers engaged in cargo handling work on land (drivers, stevedores, inspectors) are not covered under the Nuclear Reactor Regulation Act, so such doses are managed in accordance with internal company rules of the company entrusted with such transport so that the annual radiation dose will not exceed 1mSv for persons who are reasonably assumed to be in cargo handling areas (places where there is a risk of exposure exceeding 1.3mSv over a three month period).

DOSE MANAGEMENT OF WORKERS ENGAGED IN MARITIME TRANSPORT

A survey of the actual radiation dose of persons engaged in maritime transport was already been released at PATRAM 2004 regarding the actual radiation doses for the period 1997~2001, detailing the actual exposure data of crew and other such personnel concerned with special-purpose transport ships transporting radioactive material and workers engaged in cargo handling operations at unloading port.

In this paper, we surveyed actual data for the period 2002~2011, focusing on low-level radioactive material transport ships and spent fuel transport ships as concerns transport ships and focusing on low-level radioactive waste, spent fuel, high-level radioactive waste and UF6 as concerns the works involved in cargo handling operations at unloading port.

For radiation dose management of workers engaged in cargo handling operations (stevedores, radiation control personnel, transport company employees), the dose equivalent was assessed using glass badges for monthly periods, and persons entering cargo handling areas (places where there is a risk of exposure exceeding 1.3mSv over a three month period) wore pocket dosimeters when entering such areas with the dose equivalent assessed on each such occasion. For the radiation management of crew on special-purpose transport ships, the dose equivalent was assessed using glass badges for monthly periods, and persons entering limited-access areas (mariners, ship radiation control personnel, stevedores, transport company employees, stowage inspectors) wore pocket dosimeters when entering such areas with the dose equivalent assessed on each such occasion.

RESULTS OF SURVEY OF ACTUAL EXPOSURE

Results for the actual individual radiation doses are shown in Table 1 consolidating the radiation doses for persons entering limited-access areas and crew on transport ships as well as workers engaged in cargo handling operations (transport company employees, stevedores, radiation control workers) in the work related to maritime transport at unloading port. The radioactive packages handled at unloading port, which were subject to data compilation, were spent fuel, low-level waste, vitrified objects and uranium hexafluoride (UF6), but the survey of actual exposure data pertaining to transport ships focused only on ships transporting spent fuel and low-level radioactive waste. Also, in the survey for the period 1996~2001, the number of persons engaged in such work is the actual number, but the figure is for the total number of such persons in the survey of the period 2002~2011.

The following can be indicated based on the results in Table 1.

- ✓ The radiation dose for workers engaged in maritime transport is very low, and 88 % of the workers had a radiation dose of under 1 μSv, which is the detection limit for pocket doses.
- ✓ Over the period from 1996 to 2001, the average for the individual average radiation dose can be assessed, and it is of the order of magnitude of 1 μSv. On the other hand, the average dose for the period from 2002 to 2011 is the total number of persons engaged in such work, so it is believed to be approximately the radiation dose per transport. If the years 2002 and 2003 are excluded, it is a very low dose of 0.2 to 0.5 μSv.
- ✓ The total radiation dose for 2002 is lower than that for other years because it is only data for workers engaged in cargo handling operations of low-level radioactive waste at unloading port. Also, 2003 includes only data for mariners on ships transporting low-level radioactive waste and persons entering limited-access areas as well as data for workers engaged in cargo handling operations for UF_6 at unloading port, so it is necessary to take into consideration that the number of workers is small, and that the transport index in low-level radioactive waste transport is particularly higher than for other years.

In regard to the radiation dose experience by workers engaged in maritime transport, Figures 2 and 3 break down the data in Table 1 into the actual radiation dose for persons entering limited-access areas, mariners on transport ships, and workers at unloading port as pertains to spent fuel and low-level radioactive waste, respectively. From Figures 2 and 3, the following are clear.

- ✓ As for the transport of spent fuel, when the exposure data for workers on transport ships and workers at the unloading port are compared, there is almost no actual exposure for persons on transport ships, but the exposure data for unloading port was higher at an average of approximately 0.4 μSv. The reason is that the time spent in close proximity to transport packages at unloading port, including external inspections, dose inspections and other work pertaining to transport packages before and after cargo handling operations after arrival of the transport ships, is longer than time spent in close proximity to such packages inside a transport ship.
- ✓ In the transport of low-level radioactive waste, actual exposure at unloading port was noticeably lower in comparison to that on the transport ships through 2007. One reason for this is thought to be that the work is able to be completely performed in remote manner with the introduction of gate monitors for radiation dose on trucks carrying transport containers

and remote automation to the extent feasible of cranes for cargo handling operations at unloading port [2]. Most of actual exposure on transport ships occurred during manual dose measurement included in stowage inspection before shipping. On the other hand, the exposure data for unloading port has either increased or has not differed much since 2008. This is related to the facts that visual external inspections after unloading were intensified from 2008 and the transport index for homogeneous vitrified objects per container unit has risen. Since visual external inspections after unloading have been improving to decrease exposure at unloading port, actual exposure at unloading port has fallen recently.(The data in 2011 fall extremely because transport index is particularly low.)

Table 1. Radiation dose of maritime transport workers

Fiscal year	Number of workers	Total dose (man μSv)	Average Dose（μSv）	< 1 μSv	1 - 9 μSv	10 - 19 μSv	20 - 29 μSv	30 μSv >
1996	65	136	2.1	30	34	1	0	0
1997	60	200	3.3	19	35	6	0	0
1998	62	76	1.2	41	21	0	0	0
1999	69	285	4.1	19	38	12	0	0
2000	69	534	7.7	19	28	9	13	0
2001	76	460	6.1	27	30	12	7	0
2002	929	9	0.010	929	9	0	0	0
2003	262	312	1.191	218	121	6	1	2
2004	2555	491	0.192	2258	292	1	3	1
2005	2484	1349	0.543	2213	227	30	8	6
2006	2697	739	0.274	2404	279	14	0	0
2007	1315	231	0.176	1214	98	3	0	0
2008	2216	1203	0.543	1936	259	7	4	10
2009	1682	766	0.455	1476	200	2	3	7
2010	1386	636	0.459	1256	110	13	4	3
2011	1183	409	0.346	994	186	3	0	0

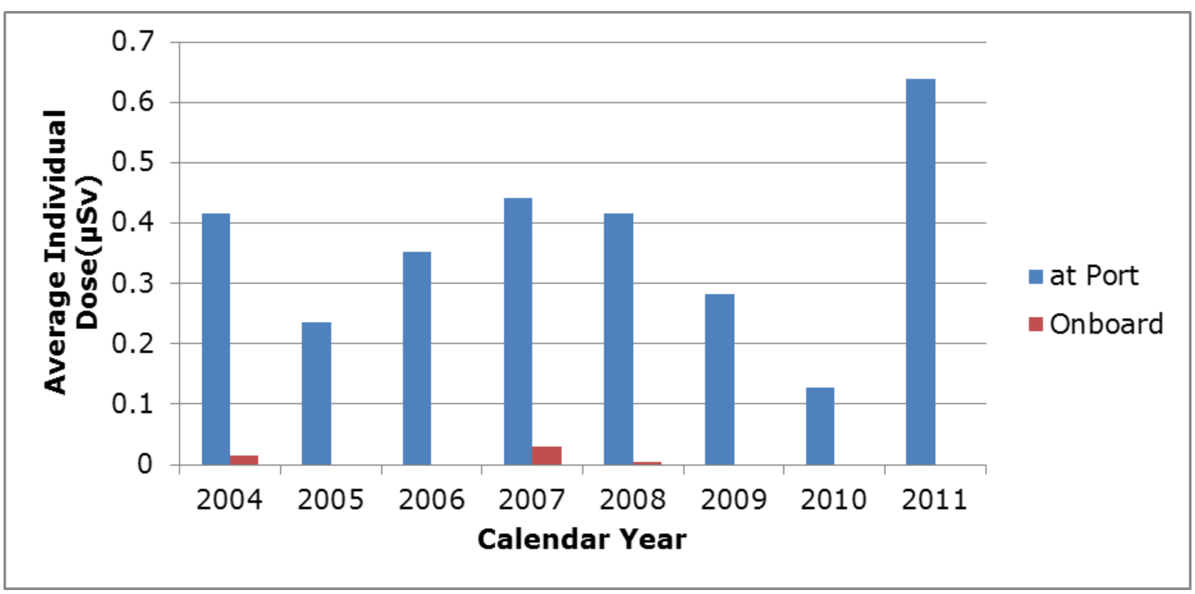

Figure 2. Comparison of onboard work and port work as concerns the radiation dose of maritime transport workers in spent fuel transport

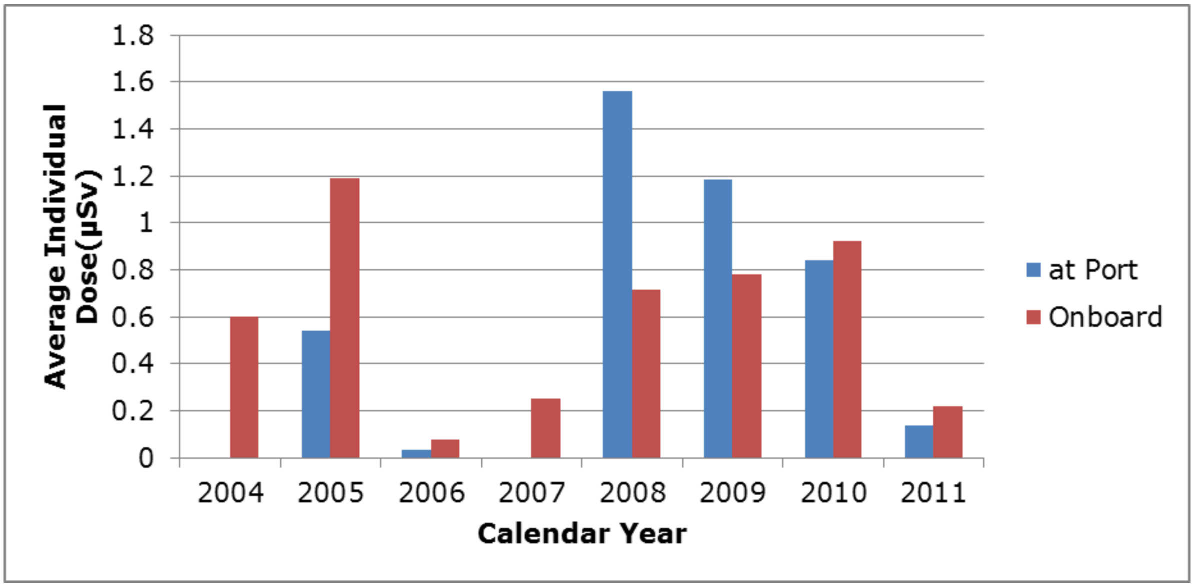

Figure 3. Comparison of onboard work and port work as concerns the radiation dose of maritime transport workers in low-level radioactive waste transport

Table 2 shows the results of radiation dose surveys consolidated according to type of transport package. Table 2 is an assessment of the collective dose per transport index for low-level radioactive waste, spent fuel, high-level radioactive waste and UF_6. For the period from 1996 to 2011, the number of workers is the total number, and includes mariners and persons temporarily onboard in addition to stevedores. With regard to the transport of high-level radioactive waste and UF6, the only data included is that for workers engaging in cargo handling operations at unloading port. Also, the transport index calculated from the results of dose measurements of transport containers prior to shipping is used. The following are clear from Table 2.

- ✓ The maximum dose per transport was 70 µSv for low-level radioactive waste transport, which is below even the 1 mSv for the total annual dose. Even with other types of transport, there was a maximum of 20 µSv for spent fuel transport, a maximum of 27 µSv for high-level radioactive waste transport, and a maximum of 15 µSv for UF_6 transport, which are below 1 mSv even for the total annual doses.
- ✓ In low-level radioactive waste transport, the transport index per container unit for homogeneous vitrified objects has increased since 2008, and the collective dose has risen.
- ✓ The collective dose per transport index when transporting spent fuel is of the order of magnitude of 1 µSv/TI, but the collective dose per transport index when transporting low-level radioactive waste is 1 to 3 digits lower than the former. This effect is due to exposure reduction measures, such as remote automation of cranes and the introduction of radiation inspections at gate monitors.
- ✓ The collective dose per transport index for high-level radioactive waste is of the order of magnitude of 10 µSv, and the primary factor is believed to be that the transport index of such transport packages is higher than for other transport packages, and the radiation dose is higher.

- ✓ In addition, although the transport index is low (0.5 or below) for UF_6 transport, the time spent at work conducted in close proximity to such transport packages is comparatively

Table 2. Change in collective dose by type of transport package

Type of transport		Number of workers	Total dose (man μSv)	Average dose (μSv)	Maximum dose in a single transport (μSv)	Total transport index	Collective dose per transport index (μSv/TI)
LLW	1997	301	119	4.0E-01	20	16320.61	7.3E-03
	1998	333	42	1.3E-01	5	9275.85	4.5E-03
	1999	252	6	2.4E-02	1	3167.1	1.9E-03
	2000	152	10	6.6E-02	2	910.44	1.1E-02
	2001	229	25	1.1E-01	8	599.59	4.2E-02
	2002	403	9	2.2E-02	1	636.36	1.4E-02
	2003*	195	159	8.2E-01	52	3829.56	4.2E-02
	2004*	389	81	2.1E-01	30	314.16	2.6E-01
	2005	477	385	8.1E-01	40	1249.29	3.1E-01
	2006	368	19	5.2E-02	10	408.33	4.7E-02
	2007*	355	30	8.5E-02	10	572.94	5.2E-02
	2008	651	801	1.2E+00	64	3389.1	2.4E-01
	2009	554	580	1.0E+00	70	4144.77	1.4E-01
	2010	680	594	8.7E-01	44	4786.32	1.2E-01
	2011	544	95	1.7E-01	5	939.27	1.0E-01
SF	1998	165	4	2.4E-02	1	2.0	2.0E+00
	1999	271	4	1.5E-02	1	1.0	4.0E+00
	2000	480	39	8.1E-02	2	5.42	7.2E+00
	2001	870	116	1.3E-01	9	19.81	5.9E+00
	2002*	532	0	0.0E+00	0	22.6	0.0E+00
	2004	2094	374	1.8E-01	20	36.8	1.0E+01
	2005	1781	186	1.0E-01	7	25.47	7.3E+00
	2006	2160	347	1.6E-01	11	41.8	8.3E+00
	2007	960	201	2.1E-01	19	23.5	8.6E+00
	2008	1489	295	2.0E-01	6	37.4	7.9E+00
	2009	1078	130	1.2E-01	3	20.3	6.4E+00
	2010	706	42	5.9E-02	2	9.1	4.6E+00
	2011	576	161	2.8E-01	7	8.1	2.0E+01
HLW	2005	153	712	4.7	27	42.4	16.8
	2006	82	271	3.3	16	20.2	13.4
	2009	50	56	1.1	5	5.7	9.8
	2011	63	153	2.4	10	11	13.9
UF_6	2003	67	153	2.3	15	20	7.7
	2004	72	36	0.5	2	10	3.6
	2005	73	66	0.9	8	17.5	3.8
	2006	87	102	1.2	8	20	5.1
	2008	76	107	1.4	9	25	4.3

*) Exposure dose data for workers at port site was not available in these years.

longer, so the radiation dose is higher. Therefore, the collective dose per transport index is 4.9 μSv/TI on an overall average.

- ✓ In transport in Japan, the values for the collective dose per transport index become greater in the order of:

  LLW < UF_6 < SF < HLW

  These results reflect transport indices for transport packages and the mode of cargo handling operations.

COMPARISON WITH OTHER DATA FOR DOSE MEASUREMENT

The National Maritime Research Institute undertook to measure the dose distribution onboard and inboard spent fuel transport ships and low-level radioactive waste transport ships in order to verify radiation safety in the maritime transport of radioactive materials [3-6]. As shown in Table 3, the radiation dose has been measured for transport ships and transport packages. The maximum dose rate in the living quarters of the low-level radioactive waste transport ship Seiei Maru was 0.05μSv/h, and, in the living quarters of the spent fuel transport ship Rokuei Maru, it was the background level. In addition, a British survey reported that the dose rate was 0.07μSv/h in the living quarters of the PNTL ship (special-purpose cargo vessel) [7], which is a result that is the same as these results.

Table 3. Test measuring dose onboard ships carrying radioactive materials as conducted by the National Maritime Research Institute This list includes experiment carried out by former Ship Research Institute.

Shipping Vessel	Packages loaded	Remarks	Reference
Hinoura-maru	2 HZ-75 casks and one NH-25 cask	BWR 19.7GWD/MTU	[3]
Pacific Swan	8 TN-12A casks	PWR 15GWD/MTU	[4]
Seiei-maru	336 LLW containers	Cement solidified LLW	[5]
Rokuei-maru	6 NFT-14P casks	PWR 40GWD/MTU	[6]

As such, the radiation level onboard is sufficiently low compared with the standard stipulated by Japan Maritime Transport Regulations, and this substantiates that the actual exposure to onboard crew, as shown in the previous chapter, is sufficiently low.

At PATRAM 2001, Pope, et al. reported on surveys conducted of actual exposure as relates to transport in the UK and US in relation to radiation protection plans [8]. It was reported that for road transport in the UK, the collective dose per unit transport index was 0.8 to 2.4 μSv/TI, and for the transport of radiopharmaceuticals in the US, the collective dose per unit transport index was 0.6 to 2.3 μSv/TI in road transport and 2.3 μSv/TI in air transport. When compared with the results in Table 2, the collective dose per unit transport index in the UK and US are on the order of the same as the results obtained for collective dose per unit transport index during the transport of spent fuel in Japan.

Also, the UK survey reported that exposures of 10 to 30 μSv occurred during one cargo handling operation because of the manual work necessitated to be performed in close proximity to the transport packages for releasing twist locks and lashings when unloading transport containers carrying uranium concentrate [7]. Even with actual exposure during cargo handling operations in Japan, it is clear that in many cases where there is actual exposure, such exposure results from work performed in close proximity to transport packages.

The Directorate-General for Transport and Energy (DG TREN) surveyed occupational exposure and exposure to the general public occurring as a consequence of transport of radioactive materials [9], and the UK's NRPB, Germany's GRS, Italy's ANPA, Netherlands' NRG, and France's IRSN and CRPN collaborated in preparation of the report. In this survey, the actual exposure data reported is related to spent fuel transport at nuclear power stations in the Netherlands [10]. The collective doses during the preparation of transport packages for the transport of spent fuel from Dodewaard Nuclear Power Plant and Borssele Nuclear Power Plant were 1.46 and 2.26 man-mSv, respectively. When the typical transport index for one transport package is assumed to be 20 which is a conservative estimate to some extent, an assessment of the collective dose per transport index results in 10.4 man-μSv/TI for the Dodewaard Nuclear Power Plant and 18.9 man-μSv/TI for the Borssele Nuclear Power Plant. Exposure to workers engaged in the work of preparing transport packages is not included in the data for actual exposure experienced by transport workers in Japan in this study, but there is data suggesting that a large part of the exposure during transport is due to work in close proximity with transport packages. With transport packages in Japan also, there is a tendency to have high collective radiation doses for transport packages where there is much work in close proximity to the transport packages.

CONCLUSIONS

The results of a survey of actual radiation doses to workers during maritime transport of radioactive materials in recent years showed that the annual radiation dose for workers was much lower than even the annual dose limit of 1mSv, which is prescribed under Japan's transport regulations. When compared with past data, actual exposure data for the past 10 years shows that the cumulative radiation dose has risen as a result of an increase in the transport index of homogeneous vitrified objects per container unit since 2008 in low-level radioactive waste transport, but, even so, this value is sufficiently low when compared to the standard. Based on the aforementioned, it is clear that radiation safety is ensured in cargo operations and onboard ships during the maritime transport of radioactive materials.

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