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PACIFIC SANDPIPER DOSE RATE ASSESSMENT FOR THE CARRIAGE OF SELLAFIELD VITRIFIED RESIDUES

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ABSTRACT
Vitrified Residues produced at the Windscale Vitrification Plant, Sellafield will be transported from Barrow, on board Pacific Sandpiper, to the storage facility in Japan. The vitrified residues will be transported in two different vitrified residues transport (VRT) flasks. This paper describes the radiation dose rate assessment to examine a possible 10 loading locations for such flasks on board Pacific Sandpiper. The ideal scenario is to be able to carry 10 flasks of one type or a combination of the two flask types. All flasks will be carried in Holds 1 to 3.

Dose rates in the accommodation areas and regularly occupied working spaces have been calculated. The most onerous dose rates for centre-line and off centre-line positions have been presented. Additionally, dose rates were calculated on the surface of, and at 2m from, the hatch-covers and the ship's hull plating. The number of flasks capable of being transported without these dose rates exceeding the criteria has been determined to be 9 flasks of one type or a combination of the two flask types.

It has been demonstrated that it would be possible to carry 10 flasks in Holds 1 to 3, if additional shielding were provided for the Hold 3 flasks during the voyage, should this maximum loading plan ever be required.

INTRODUCTION
Sellafield Vitrified Residues will be transported from Barrow, on board Pacific Sandpiper, to storage facilities in Japan. (Earlier studies [1] were for Cogema Vitrified Residues). The Vitrified Residues will be carried in TN28VT flasks (casks) or in BNFL3320 VRT flasks.

This paper describes an assessment to determine the maximum flask loading. The ideal scenario is to be able to carry 10 TN28VT flasks (Figure 1) or 8 TN28VT flasks plus two BNFL3320 VRT flasks (Figure 2). Flasks will be carried in Holds 1 to 3, minimizing dose rates to the aft accommodation and regularly occupied working areas.

Dose rates at points in the accommodation areas and regularly occupied working spaces, immediately aft of the housefront or the shielding tank have been calculated, corresponding to the main measuring positions, identified by JMLIT (Japanese Ministry of Land Infrastructure and Transport) or BNFL health physics dose points. The most onerous dose rates for centre-line and off centre-line dose points have been calculated. Additionally, dose rates were calculated on the surface of, and at 2m from, the hatch-covers and the ship's hull plating.

The number of flasks capable of being transported without these dose rates exceeding the criteria has been determined to be 9 TN28VT flasks in Holds 1 to 3 or 7 TN28VT flasks plus two BNFL 3320 VRT flasks in Hold 1. It has also been demonstrated that it would be possible to carry two BNFL 3320 in Hold 3 and 8 TN28VT flasks in Holds 1 and 2, if wooden shielding ‘blankets’ were provided for the Hold 3 flasks during the voyage, should this full loading plan be required.

There is a requirement to reduce dose uptake in line with ALARP criteria, preferably to the level of earlier calculations for Cogema Vitrified Residues [1] and Japanese Spent Fuel shipments.

DOSE RATE CRITERIA

Dose rates and dose uptake are determined by several Articles of The Japanese 'Regulations for Carriage and Storage of Dangerous Goods on Ship' [2]:

Article 89-1	The maximum dose rate should not exceed 2 mSv/h at the surface and 100 μSv/h at one metre from the surface of the container.
Article 103-1	The dose rate should be no more than 1.8 μSv/h in the living quarters and the spaces normally occupied.
Article 101	The dose rates should be no more than 2 mSv/h at the external surface of the shell plating, cargo hold, compartment and deck plating (except in the cargo holds or inaccessible positions) and 100 μSv/h at 2m from the external surface of the ship.
Article 103-2	The maximum dose uptake should be 1.0 mSv/year. (up to 5.0 mSv/year with JMLIT permission).
Article 102-1	Controlled access areas should be set up around cargo areas, and entry limited for unauthorised persons, unless the dose uptake in such areas does not exceed 1.3 mSv in 3 months.

CALCULATIONAL METHOD

Ship Calculational Model

Figure 1 and Figure 2 show schematic profiles of Pacific Sandpiper with typical flask loading plans. Figure 3 shows a section through the hull, together with hull and hatch-cover dose points.

The main radiation shields are the water tank (750 mm 'thickness' of water within 40 mm steel bulkheads), extending from the Tank Top level to the Upper Deck and laterally 4.5 metres from the ship centre-line, both port and starboard and the concrete deck/hatch-cover shields (Figure 1).

All the structure, materials and equipment on the ship provide shielding but only the main structure of the ship was included in the computer model. This included the shielding tank, the concrete shields, main structural and hatch cover plating and flask support beams. Other items such as machinery, equipment, furnishings, fittings, structural beams, partitions, bulkheads and insulation were neglected for pessimism. The ship model is similar to that used in [1].

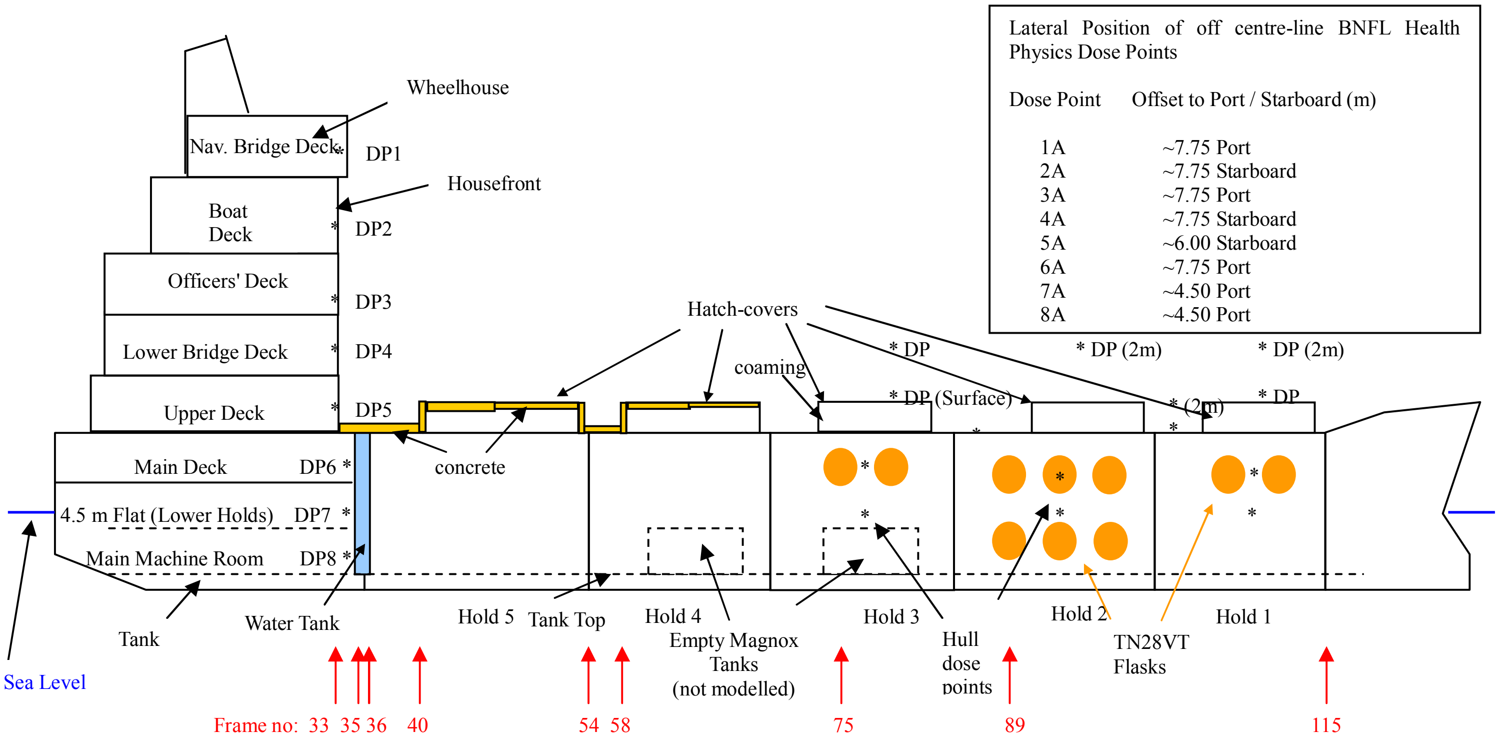

Figure 1. Pacific Sandpiper Desirable Loading with 10 TN28VT Flasks

Calculational Approach

The MCBEND9E RU2 Monte Carlo computer code [3] has been used to determine gamma and neutron dose rates. The code models the transport of individual particles accurately by using a very fine energy group representation of nuclear data using a flexible geometry package. MCBEND simulates what happens in practice, and performs a numerical experiment of the model. For accurate results in reasonable computing time, the code uses acceleration techniques such as internally generated importance maps that define important directions and energies.

Pacific Sandpiper has been assessed for carrying up 10 TN28VT flasks or 8 TN28VT flasks plus two BNFL 3320 VRT flasks containing Sellafield Vitrified Residues, in several different loading options in Holds 1 to 3. The flasks in Holds 1 and 3 are in the upper positions due to space restrictions in the lower tier of Hold 1 and empty Magnox tanks in Hold 3. It is assumed that Holds 4 and 5 will not be used. The individual canisters of vitrified residues were modelled in the flask cavities, 28 in the case of the TN28VT flasks and 21 for the BNFL 3320 VRT flasks.

For reasons of efficiency, MCBEND calculations were carried out for each flask type, with all of the information about particles leaving the flask being stored in an annular leakage file. This information was then used as the source data for a second MCBEND calculation for the whole ship, which included geometric models of the flasks within Holds 1 to 3. The source derived from the TN28VT or BNFL 3320 single flask calculation was input to all the flasks in individual holds, one hold at a time, depending on the loading plan. Thus there were several separate calculations, both for neutrons and gamma rays. The dose rate contributions were then summed.

As neutrons, secondary gammas and primary gammas were calculated on the ship separately, the following approach was used. Two cases were considered; both obeying Article 89-1, one with the primary gamma component of the transport index = 0 and the neutron component = 10 and the second vice versa. If the ship obeyed Article 103-1 in both cases, it would do so for any mix of neutron and gamma components that obey Article 89-1.

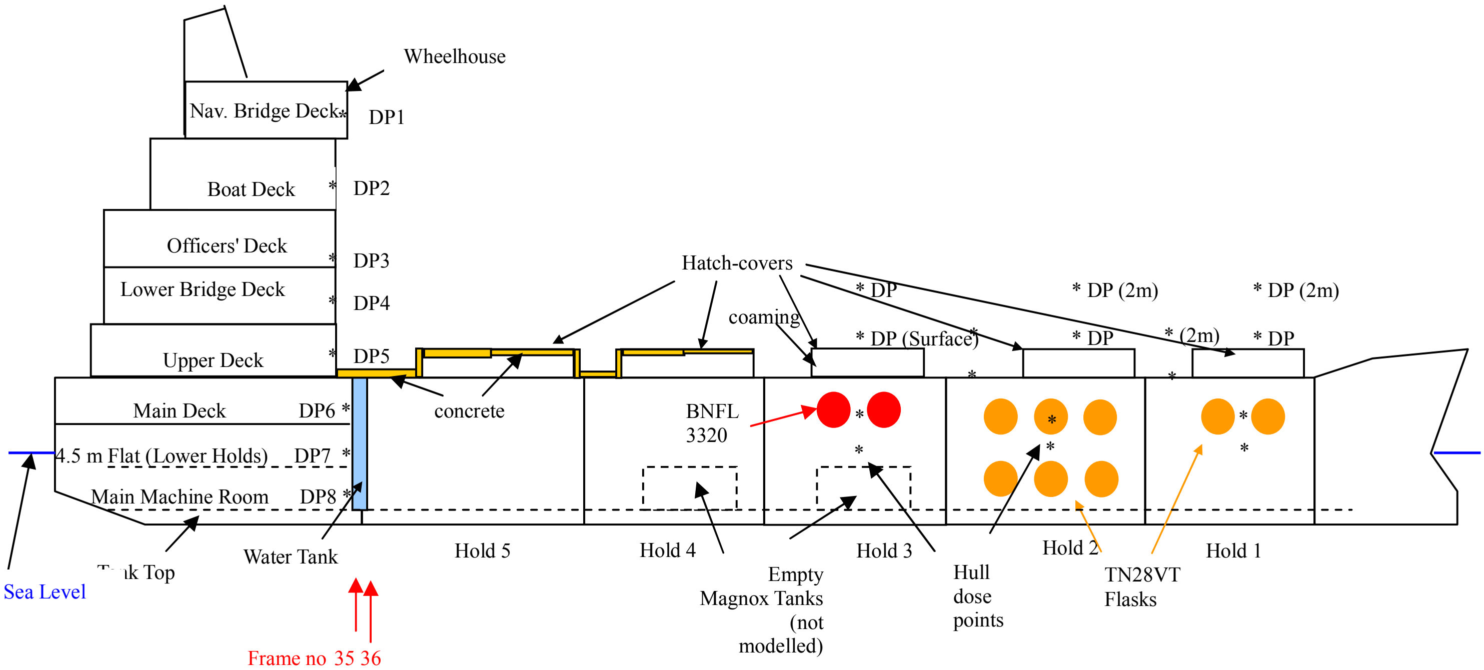

Figure 2. Pacific Sandpiper Desirable Loading 2 BNFL 3320 VRT plus 8 TN28VT Flasks

To calculate secondary gammas, a neutron ship MCBEND calculation is carried out with sources in **all** flasks to create a collision file. The collision file is then used in a subsequent MCBEND to follow secondary gammas. The neutrons **plus** secondary gammas should then satisfy Article 103-1, i.e. give dose rates of less than 1.8 µSv/h, for example, in the accommodation areas.

An experiment to theory comparison, for Pacific Sandpiper, Voyage 40, was used to validate the MCBEND techniques, showing that measured dose rates were over-estimated by MCBEND.

Source Normalisation

In reality, the total dose rate, which must be no more than 100 µSv/h at one metre from the flask, is due to a gamma ray and a neutron component. The neutron and gamma ray sources used in the single flask calculations were individually normalised to achieve a peak radial dose rate of 100 µSv/h at 1 metre from contact (from readily accessible surfaces).

TN28VT Flask Model and Source Activity

The TN28VT flask was modelled cylindrically with a central cavity containing the 28 canisters. The vitrified residues contained in each of the canisters was smeared over the internal volume of 151.2 litres. Some minor regions of the flask were approximated for simplicity but overall the model was pessimistic. The model included the shock (impact) absorbers.

The neutron and gamma activity of the vitrified residues were derived from blending THORP and Magnox derived highly active liquor. The production Blend Q9 represents the worst of nine blends considered. The Q7 blend which is less onerous is more likely to be transported to Japan. Normalising other Q blend sources would give similar results. In order to normalise the source strengths, dose rates were calculated at one metre around the flask periphery. The peak neutron and gamma dose rates occurred approximately opposite the axial centre of the 28 canisters. The dose rates were approximately 19.7 and 50.5 μSv/h. The source strengths were then scaled in MCBEND to give 100 μSv/h at one metre from the flask external surface, separately for neutrons (by a factor of 5.07) and gamma rays (by 1.98).

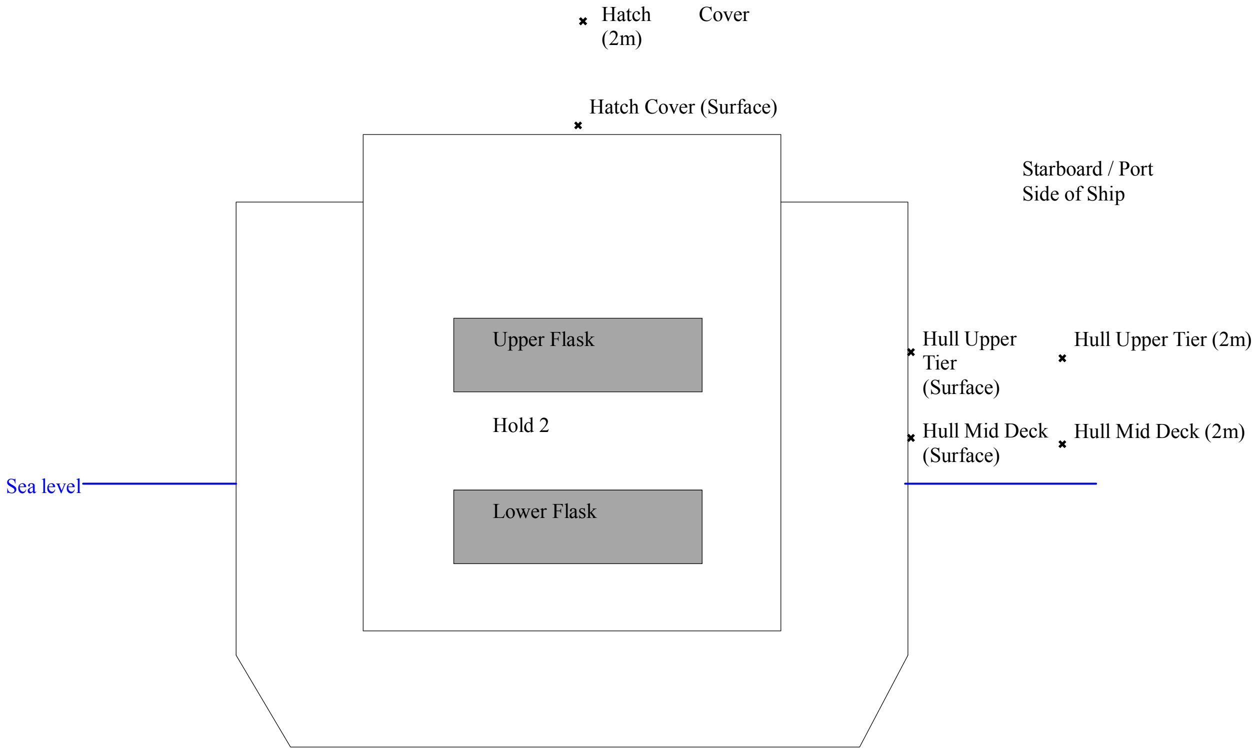

Figure 3. Pacific Sandpiper Hull and Hatch Cover Dose Points

BNFL 3320 VRT Flask

The BNFL 3320 VRT flask was modelled with a cylindrical cavity containing 21 vitrified residues canisters. The vitrified residues contained in each of the canisters was smeared over 151.2 litres. Again, some minor regions were approximated pessimistically. For example, the fins were modelled as two smeared regions: fins/resin and fins/air. The shock absorbers were included. Again, the Q9 neutron and gamma source terms were assumed.

Dose rates were calculated around the flask periphery. The peak one metre neutron and gamma dose rates of 31.8 and 5.26 μSv/h, respectively, occurred opposite the axial source region centre. Source strengths were scaled in MCBEND, neutrons by a factor of 3.15 and gamma rays by 19.0.

Flask Numbers and Loading Positions

Dose rates were calculated for a range of dose point locations throughout Pacific Sandpiper. It was necessary to show that none of the dose rates in accommodation areas and regularly occupied working spaces exceeded 1.8 μSv/h (Article 103-1). It was found that dose rates were much lower for primary gammas than for neutrons. From a primary gamma ray viewpoint, ten TN28VT flasks or eight TN28VT flasks plus 2 BNFL 3320 VRT flasks were acceptable so it was clear that neutron dose rates would limit the flask loading.

Acceptable Loading Options

Four basic loading **Options** (1 to 4) were shown to be within dose rate limits for neutrons:

1. The maximum acceptable number of TN28VT flasks was found to be nine, with the flask in the Hold 3 upper forward (3UF) position omitted. It was found that dose rates exceeded 1.8 μSv/h with 10 flasks (2 flasks in Hold 3) or with nine flasks with the Hold 3 flask in the upper forward (3UF) position. The 3UA flask provides better shielding for the more forward flasks in Holds 1 and 2 and is probably shielded more than 3UF by the Hold 3 hatch cover.

2. Eight TN28VT flasks with one BNFL 3320 VRT flask in the 3UA position.

3. Eight TN28VT flasks with one BNFL 3320 VRT flask in the 2UA position, the 2UA expected to be the most onerous position for the BNFL 3320 VRT flask.

4. Seven TN28VT flasks with two BNFL 3320 VRT flasks (in 1UA and 1UF positions).

Separate MCBEND calculations were carried out for each hold and for each option, with the correct total number of flasks on board in Holds 1 to 3, so that the self-shielding provided by flasks aft of those in a particular hold was properly taken into account. Although there may be less than 10 flasks available for transport, all 10 positions were considered initially, so that the more onerous loadings could be identified. Flasks were progressively removed to reduce dose rates. This was done to license the transport of as many flasks as possible.

Acceptable Loading Options – Gamma Dose Rates

Gamma dose rates were calculated for the most limiting loading plans for neutrons. Primary gamma ray dose rates were calculated for acceptable loading Options 1, 2 and 4. Secondary gamma dose rates that need to be added to neutron dose rates were calculated for Options 1 and 2. It was judged that there was ample margin between the neutron dose rates of loading Options 3 and 4 and the limit of 1.8 μSv/h to make the secondary gamma ray calculations unnecessary.

Loading Positions for Hull and Hatch Cover Dose Rates

Dose rates were also calculated above the hatch covers, cross decks and to the side of the hull, on the surface and two metres away. Dose point locations are shown in Figures 1, 2 and 3. For neutrons, the most onerous acceptable loading Options 2 and 4 were chosen. Primary and secondary gamma dose rates were determined for Option 4 that was slightly worse for neutrons.

Skyshine and Sea Level Modelling

The effect of skyshine was considered by running MCBEND calculations with air surrounding the ship out to a distance of 50, 100 and 1000m and comparing against a calculation with air modelled as void. Further increases produced no significant difference. Thus, 1000 m of air was included and the sea was modelled as 40 cm of water followed by a black absorber.

BNFL 3320 VRT Flasks with Wooden Neutron Shielding Blankets (Option 5)

To demonstrate that 10 flasks could be carried, if necessary, densified wooden neutron shielding blankets were placed around the two Hold 3 BNFL flasks in an extra MCBEND run (these only to be used during the voyage). It was assumed the wood was 60mm thick with a 6% hydrogen content and 1.8 g/cc density. Similar designs have been used on BNFL Excellox flasks.

RESULTS – DOSE RATES

Dose rates are given in Tables 1 to 3. Dose points are shown in Figures 1 to 3. An 'A' after the BNFL dose point number signifies it is at the off centre-line dose point (see Figure 1). (Not all peak dose rates off centre-line occur at the labelled positions). Note that the neutron and gamma dose rates are each for a Transport Index (TI) = 10.0 representing extreme cases for neutrons and primary gammas. In reality, the TI comprises neutron and gamma components summing to ten. Thus the total dose rate for a total TI of ten lies between the neutron (plus secondary gamma) and primary gamma dose rates given (not the sum of the two). As secondary gamma dose rates are relatively small, they have only been calculated for the most onerous conditions. Peak dose rates for the acceptable loading Options 1 and 2 are given in Table 1, hold contributions in Table 2.

Table 1. Dose Rates at Dose Points shown on Figure 1 for 9 Flasks (Options 1 and 2)

Dose Point	Option	Dose Rate (μSv/h)			
		Neutron	Secondary Gamma	Total [1]	Pr. Gamma
1, C/L	1	1.47	0.04	**1.51**	**0.19**
1, Off C/L	1	1.64	0.03	**1.67**	**0.29**
2, C/L	1	1.29	0.04	**1.33**	**0.18**
2, Off C/L	1	1.68	0.04	**1.72**	**0.31**
1, C/L	2	1.52	0.04	**1.55**	**0.19**
1, Off C/L	2	1.55	0.05	**1.60**	**0.31**
1, C/L	5	1.16	0.06	**1.22**	**-**
1, Off C/L	5	1.34	0.11	**1.45**	**-**

[1] The peak neutron plus secondary gamma dose rates are:
Option 1: 1.68 (± 4.35%) + 0.04 (± 8.47%) = 1.72 (± 4.25%) μSv/h
Option 2: 1.55 (± 1.67%) + 0.048 (± 5.29%) = 1.60 (± 1.63%) μSv/h
These are less than 1.8 μSv/h (even with the addition of one standard deviation). This is considered to be satisfactory taking into account the pessimism in the approach.

Table 1 also shows dose rates for Loading Option 5 with two BNFL 3320 VRT flasks having neutron shielding blankets covering them during the voyage. This demonstrates that ten flasks could be carried if required. However, blankets are unlikely to be required, as source terms are likely to be such that neutron dose rates at one metre would be much less than 100 μSv/h (not all canisters in all flasks would contain Q9 source). The use of blankets could be avoided based on specific neutron dose rate measurement or prediction made prior to the voyage.

Table 2. Dose Rates Contributions from Each Hold for Dose Points 1 and 2

Dose Point	Option	Component	Percentage Contribution to Dose Rate		
			1 Flask Hold 3	6 Flasks Hold 2	2 Flasks Hold 1
1, C/L	1	Neutron	28	57	15
		P. Gamma	25	57	18
2, Off C/L	1	Neutron	20	66	14
		P. Gamma	10	78	12

Neutron dose rates on the surface of and at two metres from the hatch covers and the hull are shown in Table 3 for Loading Option 4. This is the most onerous loading. Secondary gamma and primary gamma dose rates are also given. Dose points described as ‘Mid deck’ are midway between the upper and lower tier flasks. Dose points described as ‘Upper Tier’ are opposite the upper tier flask centres. Dose points on hatch covers are on the centre-line of the ship.

Table 3. Peak Dose Rates for the Hatch Covers and the Hull Plating

Dose Point	Dose Rate (µSv/h)			
	Neutron	**Sec. Gamma**	**Total**	**Pr. Gamma**
Surface of Hatch Cover 2 (centre)	141.0	4.63	**145.6**	**72.3**
2 metres above Hatch Cover 1 (aft)	81.3	0.79	**82.1**	**35.7**
Hull Surface Upper Tier centre Flask Hold 2	35.5	1.53	**37.0**	**7.79**
2 metres - Hull Mid Deck f'w'd Flasks Hold 2	22.8	0.79	**23.6**	**4.77**

Dose Uptake

Dose uptake to the crew has been estimated for Loading Option 2 based on expected occupancy data. To obtain realistic estimates, neutron and gamma dose rates were used based on un-normalised source strengths. This analysis indicates that crew members should attain a dose uptake less than 1 mSv for a 65 day voyage. However, monitoring of health physics dose points, analyzing film badges and controlling access to high dose rates areas has allowed the dose uptake of the crew to be controlled to well below 1 mSv per annum. Experience has shown that this is so, even during the time when several annual spent fuel shipments were carried out.

Uncontrolled Areas

Article 102 – 1 defines 1.3 mSv per 3 months as the limit of dose uptake for the uncontrolled area on ship. Areas for which greater dose uptake would occur are defined as controlled areas. The value 1.3 mSv per 3 months is equivalent to 0.6 µSv/h. On this basis, some areas, for example dose points 1 to 6 (see for example Table 1) exceed this limiting hourly dose rate. Dose rates at such points may be 'discounted' by the occupational time in the area and by the fraction of 3 months the voyage lasts. Thus for Wheelhouse dose point 1, Table 1, discounting the neutron dose rate could result in a dose rate = 1.47 x (65/90) x (6.5/24) = 0.3 µSv/h for the Chief Officer (assuming he were to spend 6.5 hours a day there during a 65 day voyage). Thus with careful monitoring, the dose uptake limit may be achieved with up to 9 flasks on board.

CONCLUSIONS

MCBEND calculations confirm that nine vitrified residues transport flasks may be carried on Pacific Sandpiper. For a combined TI of ten, total dose rates in accommodation and regularly occupied working areas are below the 1.8 µSv/h limit for Loading Options 1 to 4. Ten flasks could be carried, by using shielding blankets on Hold 3 flasks. Total dose rates on the ship's hatch-covers and hull are also well within the appropriate limits. The peak is above or alongside the central flasks of Hold 2. Crew dose uptake, based on realistic dose rates, is within the limits.

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