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Radiological Protection in Transporting Fissile Material within Refrigerated ISOs

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Abstract

The UK government has a strategic objective to consolidate fissile materials onto a single site. Our customer's site inventory included unused, spent Fast Reactor fuel and an assortment of fissile material from other mainly UK/USA nuclear establishments originally received for reprocessing, and stranded by the closure of specialist facility in the 1990s.

To enable the transport of significant quantities of material with a high risk of thermal degradation to packing materials, the material was transported in a temperature controlled environment to prevent material from degrading.

The impact of degradation of an internal polyvinyl chloride (PVC) bag would not compromise safety or product quality during transport; however should the material degrade there would be a significant human impact due to additional reprocessing work requirements before final storage.

The material was transported in a temperature controlled environment, maintaining a set temperature off -23ºC from packing at the consignor's site until unpacking at the consignee's site. To ensure the temperature controls were met during transport, strict controls were put in place, such that if PVC degradation was suspected, the consignee could plan mitigating actions.

This was the first time International Nuclear Services (INS) had transported radioactive material within temperature controlled ISO containers, this presented new challenges and requirements to be met. Studies were undertaken proving that the increased requirements of the temperature controlled container systems resulted in the potential for employee dose limits to be breached.

Ultimately, a hierarchy of controls were implemented to mitigate the risk of increased dose uptake during different stages of multimodal transport.

This paper will detail the challenges faced with this novel method of transporting fissile material and how INS worked closely with stakeholders to complete the transport whilst ensuring dose uptake for employees was kept as low as reasonable practicable (ALARP) and compliant with regulations.

Introduction

The UK government has a strategic objective to consolidate fissile materials onto a single site. Our customer's site inventory included unused, spent Fast Reactor fuel and an assortment of fissile material from other mainly UK/USA nuclear establishments originally received for reprocessing, and stranded by the closure of specialist facility in the 1990s.

To achieve a strategy UK government objective to consolidate all CAT I fissile material onto a single site, stakeholders were encouraged to think of innovative solutions outside of previous experience, and consider solutions which could bring the programme completion date forward, saving the taxpayer £m's in costs.

One major outstanding issue was legacy material which has been stored for decades, with containment condition unknown. This material also posed the additional hazard of higher thermal output (>8W) which was above the criteria of the Package Design License for the package used throughout the programme to date.

Some options to mitigate the higher thermal output would be to design a new package with a better ability to dissipate heat more effectively that the 2816J Package, however considerations to effectively cool the package suggested there would be an adverse effect on the radiation shielding effect of the package, specifically removing Vitrite material which although provides effective Neutron radiation shielding effect, does not aid cooling.

Ultimately the consignor, with technical support from INS, developed a solution to provide cooling to the external surface of the packages by transporting the packages in a temperature controlled Refrigerated ISO container (which is an intermodal shipping container used in intermodal freight transport that is refrigerated for the transportation of temperature sensitive cargo). This approach required INS to work closely with the UK Competent Authority to gain approval to transport the material.

The use of Refrigerated ISO containers to transport fissile material is a first within the UK, and as such there were a number of associated challenges which needed to be resolved to enable the programme of multi-modal transports to commence.

This presentation/paper will focus primarily on the transport by sea, and multimodal cargo handling operations.

Acronyms

ALARP	As Low As Reasonably Practicable
CfA	Conditions for Acceptance
MCAS	Machinery Control & Alarm System
PNTL	Pacific Nuclear Transport Limited
INS	International Nuclear Services Limited
NDA	Nuclear Decommissioning Authority
EPD	Electronic Personal Dosimeter
TLD	Thermoluminescent Dosimeter
Reefer	Refrigerated ISO Freight Container

Background

Numerous shipments have been previously completed using the SAFKEG 2816J, however the thermal properties of the material was relatively low. As the programme progressed, a strategic change to the programme was made and thermal power output of the material to be shipped became higher.

Many of the higher heat load cans contain PVCs and other organic materials[1] which may degrade from exposure to high temperatures that could occur during transfer. As such the Conditions for Acceptance (CfA) from the receipt facility, the consignor had a requirement to ensure that the “Internal PVC material did not exceed 100 degrees Celsius”, which would be justified by maintaining an ambient temperature at a set point of (-23 degrees) within the inside of the ISO container.

With such a variation to the method of transporting the material, a new Shipment Approval was required for this material and subsequently was granted by the UK Competent Authority for the 2816J Package on 15th May 2018. *Reference Number GB/2816J/B(M)-96T (Rev.7*).

During the programme a new Type B (M) Package for transporting radioactive material was developed, with better heat dissipation properties such that radioactive material with a thermal power output greater than 8W could be transported. A Certificate of Approval of Package Design for the Carriage of Radioactive Material for this package was granted on 1st February 2019.
Subsequently a Shipment Approval was granted by the UK Competent Authority for the 4085A Package on 8th March 2019.

The shipment approval contained a number of specific stipulations which INS had to prove were being met at all stages during the transports. These requirements included setting a range of temperature controls and ensuring the maximum internal thermal load (decay heat) per refrigerated ISO shall be limited to 648W, calculated to the latest date of delivery of the consignment.

To undertake the transports, INS has to satisfy the legal provisions laid down in the following transport legislation, [1] [2] [3] and [4]. The first shipment using this new package was successfully completed in March 2019.

Refrigerated ISO Container

To ensure PVC temperatures remain below 100°C during transport, refrigerated ISO containers were used as the solution to provide cooling to the external surface of the package during transport.
The ISO container model specific was the KLINGE NMR 262-50 Refrigerated ISO container (also known as a “Reefer”) which is specially designed for the handling of organic goods in ambient temperatures found throughout the world.
These units are designed to maintain temperatures from -29°C (-20°F) to +29°C (+84°F) automatically, using cooling and defrost cycles during its operation. Main power is 400/480 volts 3 phase, 50/60 Hz electrical power. Control circuit voltage is reduced to 20/24V AC.

The KLINGE NMR-262 units have two independent systems; each system is solely capable of maintaining temperature. Only one system will operate at any one time, and will automatically changeover when required. To ensure runtime is divided across both systems, the primary system will change over to the other system periodically, with a maximum period of 24 hours.

The electrical section consists of two complete electrical systems for each unit. The electronic microprocessor thermostats control the temperature of the cargo space and each system has its own thermostat, compressor, evaporator motor and condenser motor. Each electrical system has a built in alarm system which will trigger in a breakdown scenario with the associated cooling plant, and if required will automatically start the secondary cooling plant.

[1] PVCs and other organic materials are referred to collectively as PVCs in this document.

Power Supply
The Refrigerated ISO containers use a dual duty power supply, with the refrigeration units able to be supplied by a direct 410V fixed power supply from an external source, or using a built in diesel generator unit.

As the ISO containers were to be transported in an enclosed vessel hold space, the diesel generators could not be used due to the exhaust fumes. The vessel required fixed electrical power supply points to be installed in a number of designated positions, which were identified for transporting containers. To reduce costs, a number of loading scenarios were assessed against the segregation requirements for mixed cargo to identify a suitable number of designated positions to install a power supply, instead of fitting 20 power points, some of which realistically would never be used.

The ISO containers have a fuel tank containing up to 190 litres of fuel (which will last approximately 50 hours at full load) therefore the electrical supply must be intrinsically safe as to reduce the risk of ignition of the fuel.

Operational Controls - Documentation
To support the justification with the CfA that the PVC material had not degraded during transport, the consignor required specific additional information to be recorded in a log book for each Refrigerated ISO container during the transport cycle as evidence that cooling was maintained at the desired temperature. The log books were a key document in providing the evidence which would be audited by the UK Regulator, containing records such as transfer of responsibility between carriers, temperature records, and maintenance, repair and alarm records.

Proving Temperature Control

To provide this evidence the ISOs are fitted with a data logger which continually monitored inlet supply and outlet temperatures from the refrigeration units, however as there is only a single data logger, to reduce the list of data loss or not maintaining temperature at the set point, a physical check of ISO temperature readings was required to be carried out periodically from departing the consignors site until arrival at the consignee facility.

The frequency of these physical checks was set at 6 hours, due to a thermal calculation (insert reference) which specified a maximum time period between loss of cooling at the defined set point until it the PVC material inside the package could breach the 100 degrees Celsius criteria.

At Sea, the holds of the INS vessels are designated as controlled areas and as such entry is limited to only emergency requirements routinely, unless the package transport has specific operational requirements such as period venting.

This 6 hourly monitoring required a person to be in close proximity to the ISO container to take the required readings, and as such committing to a dose uptake.

Radiation Dose Uptake

INS is directly responsible for its subsidiary company PNTL, and as such has an obligation under the Ionising Radiation Regulations (IRR17) [5] to ensure dose uptake is kept as low as reasonable practicable (ALARP) and carry out a risk assessment of any new work involving ionising radiation.

Regulation 8 of IRR17 states:

(1) *An employer, before commencing a new activity involving work with ionising radiation in respect of which no risk assessment has been made by that employer, must make a suitable and sufficient assessment of the risk to any employee and other person for the purpose of identifying the measures the employer needs to take to restrict the exposure of that employee or other person to ionising radiation.*

PNTL employees have a Dose Investigation Limit of 1 mSv/year and have never previously exceeded this level in their 40 year history, and are not designated as classified radiation workers under IRR17.

Prior Dose Assessment

INS therefore undertook a study to consider the dose uptake implications for its employees and contractors involved in the work to be conducted. This involved engaging a specialist shielding calculation expert to model a number of scenarios and report the expected dose uptake [6]:

Step 1 - the loaded package external dose rate based on the radionuclide data to be transported.
Step 2 - The loaded ISO container containing numerous packages (up to 24) in different loading configurations and material heat loads.
Step 3 - The committed dose uptake to personnel involved in working in close proximity with the ISO container, based on their individual role on the vessel, occupancy times in specific areas, and time taken to undertake activities (including the 6 hourly monitoring of the ISO containers).

The outcomes of the scenarios gave the following results:

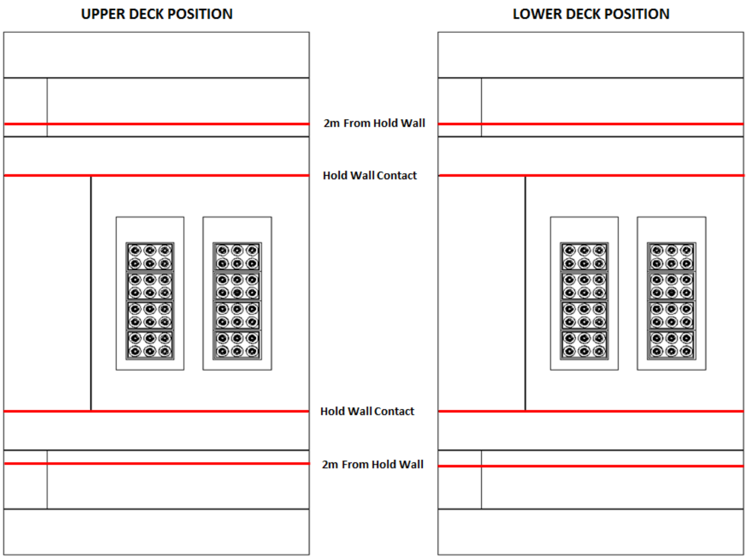

Figure 1 - Dose Target Locations from the Hold

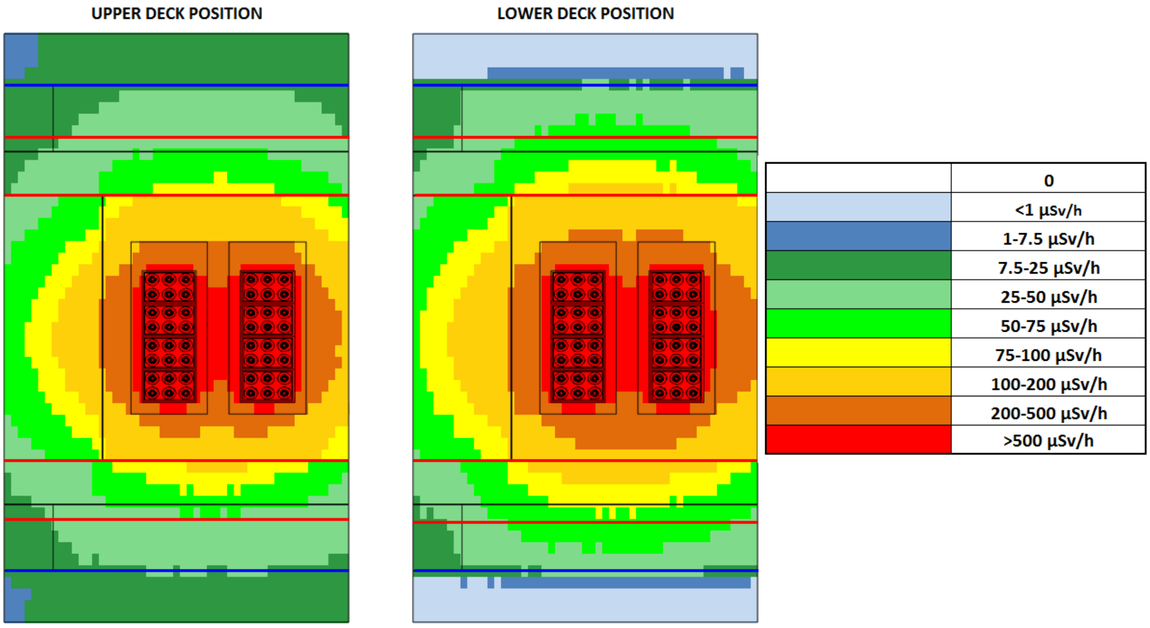

Figure 2 – Dose profile of Hold containing 4 Refrigerated ISO Containers with SBK Source

The initial outcome of the calculation suggested that for the (>8W material) there was potential for PNTL employees to receive a dose uptake above their investigation limits for the calendar year. The calculated dose uptake for 4 ISOs was 0.69 mSv, and shipments containing 7 or more ISOs are planned.

Table 1 - Dose Uptake for 4 ISOs in 1 Hold (based on 6 hourly hold entry monitoring)

Activity	Dose At Location (mSv)			
	3.5W-8W	8W-12W	>12W	SBK
Total Dose Activity 1	0.03	0.05	0.07	0.07
Total Dose Activity 2	0.24	0.36	0.54	0.58
Total Dose Activity 3	0.02	0.02	0.03	0.04
Total Dose Activity 4	0.02	0.03	0.05	0.05
Total Dose Activity 5	0.02	0.03	0.05	0.05
Total Dose Activity 6	0.04	0.06	0.10	0.10
Total Dose	0.37	0.56	0.83	0.89
Total PNTL	0.29	0.43	0.63	0.69
Total INS	0.08	0.13	0.20	0.20

This was based on scenarios where one individual was responsible for the 6 hourly monitoring of the ISO containers, over the full duration of the voyage. At this stage the easy solution would have been to share the activities between more employees, however due to recent changes to IRR17 regulations this was not possible.

Regulation 9(1) ACOP of IRR17 states that:

> "Dose-sharing should not be used as a primary means of keeping exposures below the dose limits. Employers should take particular steps to restrict the exposure of any employees who would not normally be exposed to ionising radiation in the course of their work. The dose control measures should make it unlikely that such people would receive an effective dose greater than 1 mSv per year…."

Hierarchy of Controls

The hierarchy of controls should be considered when undertaking any new work involving ionising radiation. Regulation 9(2) of IRR17 states that:

"An employer in relation to any work with ionising radiation that it undertakes must –

(a) So far as is reasonably practicable achieve the restriction of exposure to ionising radiation required under paragraph (1) by means of engineering controls , design features and by the provision and use of safety features

(b) Provide such systems of work as will, so far as is reasonably practicable , restrict the exposure to ionising radiation of employees and other persons: and

(c) Where it is reasonably practicable to further restrict exposure to ionising radiation by means of personal protective equipment, provide employees or other persons with adequate and suitable personal protective equipment (including respiratory protective equipment) unless the use of personal protective equipment of a particular kind is not appropriate having regard to the nature of the work or the circumstances of the particular case."

This regulation effectively sets out the order of the hierarchy of controls to be considered when assessing any activities involving work where a person is exposed to ionising radiation. When considering the working requirements during a transport to be in close proximity to the source of radiation (the ISO container), following the outcome of the shielding assessment the hierarchy of controls was used to implement methods to restrict the exposure to an acceptable level.

Engineered Controls

CCTV System

After challenging the requirement for hold entry, INS investigated whether any engineered controls could be put in place to reduce the dose uptake for the PNTL employees. The outcome of this was to implement a bespoke CCTV system which was used to monitor the ISO container, and could be accessed from a location outside of the cargo holds (at a safe distance from the ISO) where the dose rate was closer to background levels.

The primary function of the CCTV system was to allow an operator to conduct all temperature monitoring requirements for the Refrigerated ISO containers remotely. As such, this would minimise the need for employees to enter the holds routinely, and as such reduce the time spent in close proximity to the ISOs.

Another consideration was the time required to set-up the CCTV system prior to or during cargo operations at a port. Due to this being required for a Security CAT I transport on an INF3 vessel it brought additional considerations such as access to restricted information or SNI to be compromised on a non-secure system.

A bespoke CCTV system was developed with the functionality required, which underwent inactive commissioning trials followed by an active commissioning trial in July 2018.

Alarm Indication & Response

In the event of a Refrigerated ISO container triggering an alarm, the CCTV system installed onto the vessel will allow an engineer to evaluate the risk of the situation and act accordingly without committing to any potential dose uptake from entering the cargo holds.

The CCTV system was set-up such that both the data logger display and the alarm panel are visible and sufficiently lit, with all active cameras recording simultaneously. The CCTV monitor can be manually controlled by a user to focus on a specific camera, or show numerous ISO container temperatures simultaneously.

One significant challenge was the ability to quickly respond to an audible alarm in a vessel cargo space which is not regularly occupied. However each Refrigerated ISO container has an alarm relay cable, for which a bespoke alarm linking system was designed such that if an alarm is triggered on any ISO container, the alarm will be relayed to the CCTV monitor which will change automatically to this specific ISO.

At the same time an alarm signal will be sent to the Ships MCAS which will alert the on-watch Engineer at his work station. Should a further alarm trigger on another Refrigerated ISO container, this will also be triggered and sent to the Ships MCAS. Figure 3 shows the alarm system wiring diagram.

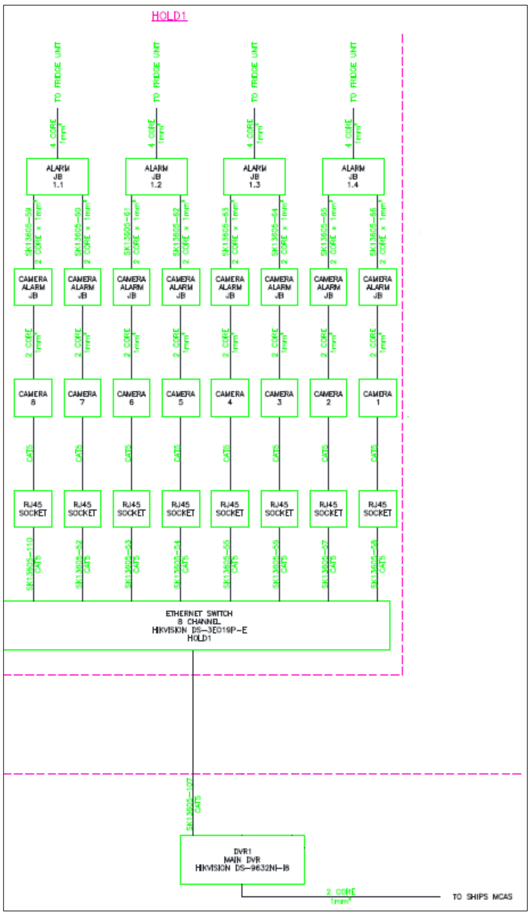

Figure 3 - Vessel Alarm Wiring Diagram

ISO Container Repair

The PNTL crew contain a team of skilled engineers and electricians, who are capable of complex maintenance and repair activities while at sea. Whilst the Refrigerated ISO containers have extremely high reliability statistics, it is not unforeseeable that if an alarm is triggered a repair could be required whilst transporting radioactive material by sea.

The Refrigerated ISO container manufacturer, KLINGE, provide a list of alarm codes, along with recommended courses of action to rectify the fault. These alarm codes have varying level of severity, with the majority not resulting in any loss of cooling, however a specific Emergency Plan was developed put in place when shipping Refrigerated ISO containers. This Emergency Plan allows repairs to be assessed and the dose implications considered prior to commencing with any repair work.

As well as this, all responsible engineering staff across the PNTL fleet have undergone specialist training on how to operate the ISO, identify any fault conditions, and carry out a number of repairs. Simultaneously, an external Refrigeration plant specialist is available 24/7 to provide additional advice on repairs should they be required.

Prior Dose Assessment - Revised

The results of a dose uptake assessment were then revisited, based on the agreement to reduce the frequency of the physical hold entry from 6 hourly to 12 hourly.

The calculated dose was reduced further by assessing whether estimated times for each activity were realistic, by carrying out inactive trials on board the ship. The time spent in the hold reduced by approx. 10% from 87 minutes to 78 minutes, and this was included in the results in Table 2. The activity times were reviewed further during the first shipment and proven to take marginally longer than the revised estimates.

Table 2 – Dose Uptake for 4 ISOs in 1 Hold (based on 12 hourly hold entry monitoring)

Activity	Dose At Location (mSv)			
	3.5W-8W	8W-12W	>12W	SBK
Total Dose Activity 1	0.03	0.05	0.07	0.07
Total Dose Activity 2	0.09	0.13	0.20	0.21
Total Dose Activity 3	0.02	0.02	0.03	0.04
Total Dose Activity 4	0.02	0.03	0.05	0.05
Total Dose Activity 5	0.01	0.02	0.03	0.03
Total Dose Activity 6	0.04	0.06	0.10	0.10
Total Dose	0.21	0.31	0.47	0.50
Total PNTL	0.13	0.20	0.29	0.32
Total INS	0.08	0.11	0.18	0.18

Dose Monitoring & EPDs

The existing approach to monitoring personal dose records is contained with our RPP (INS/RPP/302/001 Issue 10). In summary, there is no UK legal requirement to keep personal dose records for non-radiation workers (due to the DIL being set at 1 mSv/year equivalent to the general public limits).
As best practise, INS will routinely monitor individual dose records for each of the PNTL crew members, and apply the same retention period, solely for re-assurance purposes of the individuals.

Dose monitoring within PNTL is recorded using passive Thermoluminescent Dosimeters (TLDs). These are useful for lifetime record keeping, but they cannot be used when the work activities requires the doses to be controlled on a real-time basis due to a number of factors such as high radiation levels or short work time periods.

As such, for the higher heat load material (>8W), when human intervention is required, Electronic Personal Dosimeters (EPDs) were available and specific guidance placed into Emergency Response procedures regarding activity based dose uptake limits. EPDs were chosen as the best option following discussions between INS and the consignor's RPA, due to doubts regarding sensitivity of the passive Neutron PADC dosimeter and the ability to provide a method of control for employees.

The loaded packages were found during calculations (and initial trials at DSRL) to emit a higher neutron proportion (>50%). With the existing Gamma EPD Mk2+ models measuring only Beta/Gamma radiation, and the dose proportion being less than 50% Gamma, to ensure suitable instruments were chosen for the task, INS identified and procured the EPD-N2 model be used during this work.

Implementation of the new EPD-N2 was overseen by the RPA, which included specific practical training on the use of EPDs and understanding the alarm levels, however the users were already familiar with operating similar instruments. Specific guidance notes were developed and issued to support the practical training given.

Individual Doses within PNTL and INS are reviewed on a shipment by shipment basis to ensure Dose Investigation Limits are not breached. INS staff who work closely with the Refrigerated ISO (such as the Health Physics Team) are designated as Classified Radiation Workers and have undergone suitable training to support the higher dose uptake limit should it be required.

Conclusions

INS has successfully carried out numerous complex sea transports using Refrigerated ISO containers, including the first within the UK. These transports have been conducted safely and securely, to date the reliability of the ISO containers is exceptional as there have been zero high level alarms which have required a repair to be made.

This new cargo required bespoke solutions to both the operational challenges and radiological challenges to be implemented under significant time constraints to meet UK government requirements.

Computer-based modelling techniques were developed and supported by physical measurements where possible to provide a realistic dose uptake assessment for employees involved in the transport of radioactive material by sea. The hierarchy of controls enabled engineered solutions to remotely access the cargo to be implemented to reduce the expected dose uptake significantly.

New Radiation Monitoring Equipment was implemented, improving the capability to make informed assessments of non-routine repair work if required, whilst also enabling INS to review a dose assessment for each individual transport of Refrigerated ISOs, primarily to predict the expected dose uptake, whilst simultaneously specifying acceptable dose uptake time constraints for responding to potential emergency repairs whilst transporting radioactive materials by sea.

References

[1] "The Carriage of Dangerous Goods and use of Transportable Pressure Equipment Regulations 2009, SI 2009 No 1348 as amended by the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment (Amendment) Regulations 2011, SI 2011 No 1885.".

[2] "United Nations Economic Commission for Europe (UNECE). European agreement concerning the International Carriage of Dangerous Goods by Road (ADR) 2017.".

[3] "Intergovernmental Organisation for International Carriage by Rail. Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) 2017 Edition.".

[4] "International Maritime Organisation. International Maritime Dangerous Goods (IMDG) 2016 Edition (Amdt. 38-16).".

[5] C.Hughes, DESF/SH22 INS Dose Uptake aboard the REDACTED for movements of SAFKEGs REDACTED, 2018.

[6] HSE, Ionising Radiation Regulations 2017.