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THE IMPACT OF THE FUKUSHIMA DISASTER ON INTERNATIONAL NUCLEAR TRANSPORT SAFETY - A UK PERSPECTIVE

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ABSTRACT

On 11 March 2011, Japan was struck by an earthquake measuring over 9.0 on the Richter magnitude scale, the strongest known to hit Japan and one of the top five largest earthquakes ever recorded in the world. The epicentre was 175km (110 miles) east-north-east from the Fukushima Daiichi nuclear power plant, and within an hour a massive tsunami had inundated the site. This caused a serious nuclear accident, with an International Nuclear and Radiological Event Scale (INES) rating of Level 7 (the highest).

Following the events at Fukushima, the nuclear industry in the UK responded quickly to review UK nuclear installations against seismic and flooding hazards. On 14 March 2011 the UK Secretary of State for Energy and Climate Change requested that Dr. Mike Weightman, HM Chief Inspector of Nuclear Installations, examine the circumstances of the Fukushima accident to see what lessons could be learnt to enhance the safety of the UK nuclear industry. An Interim Report was published in the middle of May 2011, with a Final Report six months later. A further report was published in October 2012 that provided an update on progress in implementing the lessons for the UK's nuclear industry.

In addition to the Weightman Reports, the UK Office for Nuclear Regulation (ONR) produced two national reports on the European Council 'Stress Tests' focussing on licensed nuclear sites. The first covered all civil nuclear power plants with the second, on the instructions of the Chief Inspector, covering all of the remaining UK nuclear installations. In both of these reports, areas for potential improvement (known as 'considerations') were identified by licensees and these were augmented by Stress Test Findings identified by ONR.

This paper reviews the key findings of these reports with the objective of extracting and drawing out key learning which could translate to and impact nuclear transport safety. It summarises the potential impact on INS and its nuclear transport operations, and the progress made to date.

INTRODUCTION

On 11 March 2011 Japan suffered its worst recorded earthquake. The epicentre was 110 miles east north east from the Fukushima Dai-ichi (Fukushima-1) nuclear power site which has 6 Boiling Water Reactors. Reactor Units 1, 2 and 3 on this site were operating at power before the event and on detection of the earthquake shut down safely. Initially 12 on-site back-up diesel generators were used to provide the alternating current (AC) electrical supplies to power essential post-trip cooling. Within an hour a massive tsunami from the earthquake inundated the site. This resulted in the loss of all but one diesel generator, some direct current (DC) supplies and essential instrumentation, and created massive damage around the site. Despite the efforts of the operators, eventually back-up cooling was lost. With the loss of cooling systems, Reactor Units 1, 2 and 3 overheated. As a result of the fuel overheating, the fuel suffered damage and an increased production of hydrogen. This resulted in several explosions, leading to major releases of radioactivity, initially to air but later by leakage of contaminated water to sea.

There were no deaths caused by radiation exposure, while approximately 18,500 people died due to the earthquake and tsunami. Future cancer deaths from accumulated radiation exposures in the population living near Fukushima are predicted to be extremely low to none. [Ref 1,2].

This was a serious nuclear accident, with an International Nuclear and Radiological Event Scale (INES) rating of Level 7 (the highest level). Tens of thousands of people were evacuated from a zone extending 20km from the site and remain so today.

Within days of the event the UK Secretary of State (SoS) for Energy and Climate Change requested that the ONR examine the circumstances of the Fukushima accident to see what lessons could be learnt to enhance the safety of the UK nuclear industry.

This paper considers any extracts any identified learning which may also translate across to radioactive transport. Security issues are considered 'out of scope' of this paper due to the different level of institutional responsibility and transparency vis-à-vis the public.

SUMMARISED WEIGHTMAN REVIEW FINDINGS

The aim of the Weightman series of reports is to identify any implications for the UK nuclear industry, and in doing so co-operate and co-ordinate with international colleagues.

This paper seeks to analyse recommendations from a number of UK ONR reports produced in response to Fukushima [Ref 3, 4, 5, 6] and extract any transport related learning. The reference reports are highlighted in the table below. The latest ONR report ‘National Action Plan’ is a summary of the current status of, and future activities that are planned for, implementation of the lessons learnt.

Date	Report	No of recommendations
May 2011	Interim Report by HM Chief Inspector to UK Govt	26
Sept 2011	Final Report by HM Chief Inspector to UK Govt	38
Dec 2011	UK National stress test report	19
Oct 2012	Implementation Report on the progress in the implementation of all the above recommendations through applying specific findings to UK facilities	75
Dec 2012	UK ONR ENSREG related 'National Action Plan'	Total = 158

The investigation and review undertaken by ONR generated a total of 158 findings. Many of the ONR recommendations were specific to UK nuclear facilities and had limited relevance to radioactive transport. Of the 158 recommendations, around 22 were considered to warrant further consideration for transport.

Of these 22 findings, there was a degree of overlap, where this occurred the findings were grouped together: These findings were then divided into the following categories.

- Strategic Emergency Planning
- Emergency Response Team Considerations
- Communications
- Transport Package Design
- Human Factors

The Weightman findings below have been summarised and are shortened versions of the original recommendations.

STRATEGIC EMERGENCY PLANNING

Recommendation IR-3: Review National Emergency Arrangements The Nuclear Emergency Planning Liaison Group should instigate a review of the UK's national nuclear emergency arrangements in light of the experience of dealing with the prolonged Japanese event.

Recommendation IR-5: Cliff-edge Effects Once further detailed information is available and studies are completed, ONR should undertake a formal review of ONR's Safety Assessment Principles to determine whether any additional guidance is necessary in light of the Fukushima accident, particularly for "cliff-edge" effects.

Recommendation IR-7: Beyond Design Basis Events ONR should review the arrangements for regulatory response to potential severe accidents in the UK to determine whether more work needs to be undertaken to prepare for such low probability events.
This should include:
a) enhancing access during an accident to relevant, current plant data on the status of critical safety functions, i.e. the control of criticality, cooling and containment, and releases of radioactivity to the environment, as it would greatly improve ONR's capability to provide independent advice to the authorities in the event of a severe accident; and
b) review of the basic plant data – this has much in common with what we suggest should be held by an international organisation under Recommendation IR-1.

Recommendation IR-6: Prolonged Severe Events ONR should consider to what extent long-term severe accidents can and should be covered by the programme of emergency exercises overseen by the regulator.

This should include:

a) an evaluation of how changes to exercise scenarios supported by longer exercise duration will permit exercising in real time, e.g. hand-over arrangements, etc.; and

b) recommendations on what should be included in an appropriate UK exercise programme for testing nuclear emergency plans, with relevant guidance provided to Radiation (Emergency Preparedness and Public Information) Regulations 2001 (REPPIR) duty holders.

Recommendation FR-1: **Periodic Safety Review** All nuclear site licensees should give appropriate and consistent priority to completing Periodic Safety Reviews (PSR) to the required standards and timescales, and to implementing identified reasonably practicable plant improvements.

Recommendation FR-4: Probabilistic Safety Analyses The nuclear industry should ensure that adequate Level 2 Probabilistic Safety Analyses (PSA) are provided for all nuclear facilities that could have accidents with significant off-site consequences and use the results to inform further consideration of severe accident management measures. The PSA's should consider a full range of external events including "beyond design basis" events and extended mission times.

EMERGENCY RESPONSE TEAM CONSIDERATIONS

Recommendation IR-11: Multiple serious concurrent events The UK nuclear industry should ensure that safety cases for new sites for multiple reactors adequately demonstrate the capability for dealing with multiple serious concurrent events induced by extreme off-site hazards.

Recommendation IR-8: Loss of Off-site Infrastructure The UK nuclear industry should review the dependency of nuclear safety on off-site infrastructure in extreme conditions, and consider whether enhancements are necessary to sites' self sufficiency given for the reliability of the grid under such extreme circumstances.

Recommendation FR-2 IR-13 IR-22: **Resilience of Emergency Structures, Systems and Components** The UK nuclear industry should ensure that structures, systems and components needed for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, are adequately protected against hazards that could affect several simultaneously.

Recommendation IR-19, IR-20: Safety Related Cooling The UK nuclear industry should review the site contingency plans for 'safety essential' reactor cooling under severe accident conditions to see whether they can and should be enhanced given the experience at Fukushima.

COMMUNICATIONS

Recommendation IR-23: Effectiveness of Off-site Communications The UK nuclear industry, in conjunction with other organisations as necessary, should review the robustness of necessary off-site communications for severe accidents involving widespread disruption to mobile and landline communications.

Stress Test Finding STF-67: **Communications with the Emergency Services** Review communication systems used by site fire and rescue teams (e.g. radios) to ensure there is compatibility with equipment used by external emergency services, especially at identified radio shielded areas.

Recommendation IR-4: Open, Transparent and Trusted Communications Both the UK nuclear industry and ONR should consider ways to drive and enhance more open, transparent and trusted communications, and relationships, with the public and other stakeholders.

Recommendation FR6 FR-7: **Real-time Communication of the 'Dose Impact' to People and the Environment** Review the adequacy of arrangements for environmental dose measurements and for predicting dispersion and public doses and environmental impacts, and to ensure that adequate up to date information is available to support decisions on emergency countermeasures.

Recommendation IR-1: Timely and Efficient Provision of Information to National Regulators, Other Stakeholders & IAEA Consider the efficient provision of authoritative information to national authorities and International mechanisms such as the IAEA for communicating information between national governments, to ensure that improved arrangements are in place for the dissemination of timely authoritative information relevant to a nuclear event anywhere in the world.

TRANSPORT PACKAGE DESIGN

Recommendation IR-25: Severe Accident Scenarios & Beyond Design Basis Considerations The UK nuclear industry should review, and if necessary extend, analysis of accident sequences for long-term severe accidents. This should identify appropriate repair and recovery strategies to the point at which a stable state is achieved, identifying any enhanced requirements for central stocks of equipment and logistical support.

We would expect industry to:

a) identify potential strategies and contingency measures for dealing with situations in which the main lines of defence are lost. Considerations might include, the capability to undertake repair, mitigate or recover.

b) consider the impact of potential initiating events on the utilisation of such equipment;

c) ensure it has the capability to analyse severe accidents, to properly inform and support on-site severe accident management actions and off-site emergency planning. Further research and modelling development may be required;

d) ensure that sufficient severe accident analysis has been performed for all facilities with the potential for accidents with significant off-site consequences, in order to identify severe accident management and contingency measures. Such measures must be implemented where reasonably practicable and staff trained in their use; and

e) examine how the continued availability of sufficient on-site personnel can be ensured in severe accident situations, as well as considering the effects of acute and chronic stress at both an individual and team level (this is linked to Recommendation IR-24).

HUMAN FACTORS

Human Capabilities and Capacities

Recommendation IR-24: Resilience of Responders When faced with an extended severe accident scenario, consider the resilience of emergency responders with respect to the potential demands they are likely to face;

- Adequacy of Training
- Consider the impact of 'loss of infrastructure' and the ability to effectively mobilise sufficient numbers of the emergency response team

- Effective tactical and strategic decision making throughout each phase of the severe event;
    - the acute phase
    - stabilisation phase,
    - recovery and clean-up phase
- Physical endurance
- Emotional and cultural aspects
- Managing acute and chronic stress at both an individual and team level.
- Effective handover of information to new team members
- Consider and develop 'Severe Accident Guidelines' where required.

Recommendation FR-11: **Promoting Safety Culture** - UK nuclear industry should continue to promote sustained high levels of safety culture and promote 'nuclear professionalism' amongst all its employees, through making use of the National Skills Academy and other schemes.

EXTRACTED LEARNING FOR TRANSPORT

From the above recommendations which are focused on UK nuclear facilities, we now consider how these translate and impact nuclear transport safety.

STRATEGIC EMERGENCY PLANNING

Review National Emergency Arrangements

This learning equally applies to emergency planning and response arrangements for the transportation of radioactive materials. In the UK, the Department of Energy and Climate Change (DECC) is currently in the process of placing a contract for this work to be carried out. Permanent membership at the National Nuclear Emergency Planning Liaison Group should be sought where applicable.

Cliff-edge Effects

Within a nuclear facility the failure of key safety systems can cause catastrophic failure or damage to the facility.

In the case of Fukushima, failure of 'mains' power and the subsequent 'failure of the diesel generator back up power' resulted in the inability to cool the core, which resulted in a 'core melt' followed by the hydrogen explosions and loss of containment. For Fukushima, failure of all the diesel generators was considered to be an unrealistic scenario.

For transport this learning may translate into defining a strategy for responding and dealing with the consequences of highly unlikely events and how these events could be effectively managed in the event of an emergency. Events under consideration may include a criticality event or complete loss of package contents during transport. Analysing the initiating sequence of events leading to such an occurrence may have limited value, the value here lies in considering the 'unexpected and unlikely' and preparing the strategic emergency planning teams to consider this type of 'what if' scenario. The time spent on studying 'unexpected and unlikely' cliff edge type scenarios requires careful consideration. These scenarios clearly have a role to play, but they should by no means be the dominant consideration in terms of strategic emergency planning.

Prolonged Severe Events / Beyond Design Basis Events

There has been a multitude of studies carried out considering the adequacy of the transport safety principles with respect to the suite of tests required to simulate 'accident conditions of transport'. These studies were performed, either looking at the response of packages to severe accident simulating tests or at what additional mechanical and thermal stresses beyond those provided by the regulatory test standards are needed to begin to challenge the safety integrity of transport packages. Such tests included consideration of high speed impact, extended fire and explosive testing involving scale model and full scale packages. Other studies have looked at real life severe accidents to consider and assess the performance of a radioactive transport package should it be subjected to such a severe environment.

Clearly it will always be possible to create extreme scenarios that begin to challenge the integrity of the flask but from these studies it is reasonable to conclude that radioactive transport packages prepared and operated in accordance with the transport regulations provide an excellent margin of safety for the transport of radioactive material.

From a strategic perspective it may be valuable to consider the time available to safely recover a transport package. In many cases the transport flask is likely to require minimum intervention to retain its inherent safety. During a severe natural event which is likely to have wider consequences, this information may be useful in terms of deploying the emergency teams to other higher priorities, such as saving life or protecting a nuclear facility.

Periodic Safety Review

Weightman identified that nuclear facilities should give appropriate and consistent priority to completing ‘Periodic Safety Reviews’ to required standards and timescales.

For transport ‘Periodic Safety Reviews’ are inherent within the certificate renewal process. On renewal of a certificate the safety basis is considered prior to the issue of the Certificate of Approval.

Probabilistic Safety Analysis

The findings on this issue were that nuclear facilities which have a capacity for accidents with significant off-site consequences should ensure that a high level of probabilistic safety analysis is carried out to identify any safety weaknesses.

The Weightman reports identified that this probabilistic approach is often applied to nuclear facilities in different ways. In the UK, these facilities operate within a ‘goal based’ regulation regime. This ‘goal based’ probabilistic approach can result in some inconsistency between national facilities and in particular with the regulatory approaches of other countries.

For transport, we apply a common deterministic approach, on an international scale which provides us with a strong and consistent ‘fundamental safety basis’.

EMERGENCY RESPONSE TEAM CONSIDERATIONS

Multiple serious concurrent events

Here the ONR has identified that sites with multiple reactors must demonstrate the capability for dealing with multiple serious concurrent events.

Sites having multiple nuclear facilities have significant capacity to impact people and the environment.

In a serious event scenario, impacting multiple facilities and in-transit radioactive packages, due consideration must be given to the priorities of the emergency team. These considerations would include the likely radioactive consequences and priorities of the emergency teams in terms of :

- the potential for saving life of others affected
- avoiding unnecessary risk to the emergency team
- preventing any 'avoidable' further catastrophic facility events which have the capacity for national and international consequences.
- diverting emergency response team resource where required.

Loss of Off-site Infrastructure

The ONR requested that the UK Nuclear Industry should review its dependency on 'off-site infrastructure' in the provision of emergency response. Essentially, how reliant are 'transport emergency response' systems on maintaining existing 'land based' infrastructure? The loss of off-site infrastructure has the potential to significantly impact the ability to respond to a transport event.

Is it possible to get people, plant and equipment to the scene of a transport event?
Are there sufficient essential provisions to sustain the response should it be extended? Specifically in terms of food, water, conventional fuels, power and staff. Where a serious event has occurred and roads may be inaccessible or damaged, how do we deploy the emergency teams and emergency equipment to the scene. In order to manage this type of scenario, INS has contracted access to helicopters and air support to assist in this area.

Resilience of emergency structure, systems and components

This learning is related to ensuring that systems and components for managing and controlling a serious event are adequately protected and available when needed.

INS already operates with significant redundancy in terms of emergency equipment stores. However, the INS store based at Tokai Mura was lost during the Tohoku Tsunami. Following this loss INS has reviewed the strategic location of its emergency equipment stores located on each vessel, within UK territory and those based internationally. Both the levels of redundancy and the revised location of emergency equipment stores now provide additional resilience assuring the ability to respond.

This requirement translates well to transport putting a strong emphasis in 'business continuity' and sufficient levels of redundancy with respect to access to emergency equipment when it is needed.

Safety Related Cooling

This learning was directly related to loss of a reactor's ultimate heat sink and where failure to cool would have catastrophic consequences such as a core melt. For a transport package the radioactive inventory and capacity to cause harm is much reduced from that of a nuclear facility. However, the containment integrity of any heat generating package can be challenged by restricting its ability to lose heat. For 'heat generating' radioactive contents transported in a form which may be easily dispersed, further controls and considerations 'such as shipment approval' may be a worthwhile future consideration.

Where heat generating packages could be affected by a serious event, the emergency team will need to assess whether any heat generated by the contents continues to be effectively and safely dissipated. Where the ‘capacity to cool’ becomes compromised, avoiding any over pressurisation of the containment boundary must be an area of key focus for the emergency response team.

COMMUNICATIONS

Effective off-site Communications

Routine mobile communications may be unavailable or saturated in the event of a severe event, review and consider the ability to effectively communicate with the emergency services. Increase awareness of any potentially ‘radio shielded’ areas likely to be encountered in the process of responding, such as tunnels and within the hold of a ship.

Industry should review the robustness of any necessary off-site communications for severe accidents.
Within INS we have access to satellite phones to maintain the ability to communicate when landlines and mobile systems are damaged or saturated.

Communications with the Emergency Services

The Office for Nuclear Regulation recommendations identified that ‘site emergency teams’ should be able to communicate with the external emergency services. INS are currently investigating gaining access to the ‘critical communications network’ system used in the UK.

Open, Transparent and Trusted Communications

Communications to external stakeholders are vital during a serious event. Industry should ‘review’ and ‘exercise’ effective and efficient stakeholder communications.

TRANSPORT PACKAGE DESIGN

In terms of ‘package design’, safety integrity is assured through the IAEA regulatory requirements. Here we consider how these requirements would likely perform in the severe even scenario.

Burial of Packaging

The burial of packages during a severe natural event is credible. The following two scenarios are considered further:

- Burial under building debris.
- Burial in soft ground e.g. sand, mud, silt or marsh

A key consideration for the burial scenario is related to packages containing heat generating contents and retaining their ability to satisfactorily dissipate sufficient heat to avoid compromising the containment system.
The possibility of containment failure of a ‘buried’ heat generating package is likely to be a gradual process, with pressures and temperatures beginning to increase over several days or more likely a number of weeks. Under these conditions it is proposed that there is sufficient opportunity for the emergency team to located and provide external cooling and recovery as required.

Various studies have already been carried out in relation to this matter. The general conclusions of these studies are that the level of existing regulatory protection bounds the postulated burial scenarios listed above.

Seismic Resilience

The performance of radioactive transport packages under a seismic event is considered to be already bounded by the IAEA credible accident scenario approach.

Package Immersion

Radioactive transport packages have always been faced with the prospect of immersion following an accident. Immersion in a river, lake or sea or perhaps a flooding event is highly credible and can occur during transport. The existing regulatory approach is considered to already bound this scenario.

Packages with Heat Generating Contents Reliant on Passive or Mechanical Cooling

Heat generating packages are worthy of further consideration particularly under severe natural event scenarios.

Internal Hydrogen Generation

Although hydrogen may be generated through radiolysis with certain package contents and under certain transport conditions, for example the transport of spent fuel in a wet flask, the author considers that the existing regulatory framework already adequately bounds this scenario and it would be extremely unlikely for a ‘hydrogen related’ safety significant explosion to occur following a severe natural event.

HUMAN FACTORS

Resilience of Responders

When faced with an extended severe accident scenario the resilience of responders must be a key consideration. Adequacy of training, physical endurance, managing acute and chronic stress will have a significant impact on effective response. Although extended severe accident scenarios for transport are unlikely, they should be a strategic consideration.

Promoting Safety Culture

For transport, human error is recognised as a significant risk area. If the package is not properly prepared for transport then there is significant loss in defence in depth. The nuclear industry should continue to promote sustained high levels of safety culture.

CONCLUSION

The scale of the Tohoku Tsunami, it’s impact on reactor safety systems overwhelmed and forced the Nuclear Power Plant emergency responders to depart from their existing Emergency Plan and enter an unforeseen ‘crisis situation’.

From the UK ONR review, we have established that there are some valuable lessons to be learned from Fukushima, and some of these clearly do translate and crossover for the consideration of radioactive transport. Important learning was identified in each of the categories discussed above, particularly, in terms of 'human factors', 'communications' and preparing the 'emergency response teams'.

The question is 'how well prepared are transport packages that meet the IAEA transport regulations in responding to severe natural events?'

The existing 'deterministic', 'accident based' and 'internationally applied' approach of the transport regulations provides a consistent and strong fundamental safety basis, which is already well prepared to withstand a severe transport event.

One of the most important considerations for transport is for us to consider the 'consequences of failure'. What capacity exists within the transport package contents to cause harm!

We must consider whether a serious accident involving the transport of radioactive material has the capacity to cause harm on a 'Local' 'National' or 'International' scale?

The key nuclides used to categorise accidents against the International Nuclear Event Scale is based on Caesium and iodine. A typical spent fuel flask inventory is a small fraction of that of a nuclear facility.

The potential impact on people and the environment and the capacity for harm, is much reduced compared to that of a nuclear facility. Even in a 'worst case' scenario it is reasonable to assume that the consequences for a transport event would be on a local scale.

This paper has reviewed the ONR recommendations and extracted learning which is also relevant to radioactive transport.

This paper concludes that the international regulatory structure governing the radioactive transport regulation provides a strong fundamental safety basis and has many advantages over the bespoke 'case by case' regulatory approach which is applied to many existing nuclear facilities around the world.

In particular, the existing IAEA regulatory approach for transport is already well prepared to withstand severe natural events.

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