Risks to Scotland from nuclear weapons and submarines

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Summary

Planning for emergencies is regulated by the Civil Contingencies Act and Regulations. REPPIR regulates aspects of nuclear emergencies. The extent to which REPPIR applies to nuclear weapons and nuclear submarines should be clarified.

HSE regulate licensed nuclear sites, however none of the defence nuclear sites in Scotland is licensed. HSE have a key role in implementing REPPIR. HSE's involvement in MoD nuclear activities is limited by their lack of access to key design information. This means that they are unable to fully scrutinise the MoD's assessment of which scenarios are reasonably foreseeable.

There are difficulties in applying ALARP to MoD activities. ALARP depends on the assumption that there is a benefit to society from nuclear weapons. HSE do not question this. Nor to they question other military criteria which place MoD activities in conflict with civil ALARP considerations.

The MoD risk assessment process deals separately with the risk of a nuclear explosion and the risk of the release of radiation. With regard to a nuclear explosion they have a single target frequency. They do not separately assess the likelihood of higher and lower yields. However the consequences of a nuclear explosion would vary substantially, depending on the yield.

The current Trident system does not comply with several of the design requirements for British nuclear weapons in the MoD's Regulations.

The Guidelines issued to local authorities say that there is no possibility of a nuclear explosion in a warhead transport accident. However the MoD's safety case publishes an estimated frequency for a nuclear explosion, and this is not much above than the Basic Safety Limit in the MoD's regulations. The safety case claims that the warhead packaging complies with IAEA regulations, but these regulations should not be applied to the transport of nuclear weapons.

There could be a reactor Primary Containment Failure Accident on any nuclear-powered submarine. This scenario is not considered in safety schemes.

On a Trident submarine there could be a complex accident involving several nuclear weapons and/or the reactor. This could be triggered by a missile explosion. The most hazardous type of accident is most likely to happen in Scotland.

Recent Boards of Inquiry give grounds to question the risk assessment process for submarines and whether the MoD prioritises operation and training requirements above safety. This gives grounds to question the MoD's assessment of the likelihood of more serious accident scenarios.

The risk of terrorist attack is not adequately addressed in current risk assessments or safety schemes. Terrorist attacks on a nuclear weapons' convoy or the Clyde Naval base would appear to be reasonably foreseeable.

The current safety schemes only deal with less severe accidents at some locations. There are grounds to suspect that there are other reasonably foreseeable scenarios that are not covered by these safety schemes. There are no specific schemes for an accident at sea, but the frequency of submarine incidents would suggest that a significant nuclear accident is reasonably foreseeable.

The Nuclear Emergency Planning Liaison Group recommends that consideration should be given to nuclear accidents that are not reasonably foreseeable. It can be argued that this is particularly the case for MoD accidents. Some military nuclear accidents can be more severe than any civil accident and there is no any independent regulatory system for military nuclear activities in Scotland.

Abbreviations

ADA	Approval and Design Authorities
ALARP	As Low As Reasonable Practicable
AWE	Atomic Weapons Establishment
BSL	Basic Safety Limits
BSO	Basic Safety Objectives
CND	Campaign for Nuclear Disarmamant
DC&FF	Damage Control and Fire Fighting
DNSR	Defence Nuclear Safety Regulator
EHJ	Explosives Handling Jetty
FOIA	Freedom of Information Act
HE	High Explosive
HIRE	Hazard Evaluation and Risk Assessment
HSE	Health and Safety Executive
JSP	Joint Services Publication
LAESI	Local Authority and Emergency Services Information
LOCA	Loss of Coolant Accident
LOD	Line of Defence
MoD	Ministry of Defence
mSv	Millisievert
NII	Nuclear Installations Inspectorate
NRTE	Naval Reactor Test Establishment, HMS Vulcan, Dounreay
NSD	Nuclear Safety Division, HSE
NW	Nuclear Weapon
NWR	Nuclear Weapons Regulator
PIRER	Public Information for Radiation Emergency Regulations 1992
RA	Radioactive
RAMP	Revalidation and Assisted Maintenance Period
RC	Reactor Compartment
REPPIR	Radiation (Emergency Preparedness and Public Information) Regulations 2001
SAPs	Safety Assessment Principles
SCOG	Self Contained Oxygen Generator
SV	Sievert
TCHD	Truck Cargo Heavy Duty
WH	Warhead

Glossary

As Low As Reasonable Practicable (ALARP)	A legal requirement under REPPIR and NII licensing regulations to keep risks as low as reasonably practicable.
Atomic Weapons Establishment (AWE)	This includes Aldermaston where the radioactive components of nuclear weapons are manufactured and designed and Burghfield where warheads are assembled and disassembled.
Basic Safety Level (BSL)	Frequency of event which should not be exceeded.
Basic Safety Objective (BSO)	Higher target than BSL. If the frequency of an event is between BSL and BSO the operator has to show that ALARP has been applied.
Clyde Naval Base	This includes Faslane where submarines and surface ships are berthed and were maintenance work is carried out, including within the Faslane shiplift and Coulport where nuclear weapons can be stored and inspected and missiles can be stored.
EDC 37	High Explosive in Trident warhead. Not insensitive.
Line of Defence	Measure which will reduce the frequency of an event resulting in a consequence by a factor of 10^{-3}.
PD AWG 516	Package used for Trident warheads for road transport inside special vehicles
Popcorning	A low nuclear yield from one warhead leading to a significant yield from another warhead which is nearby.
Single Point Safe	Detonation of explosive at one point will not result in a nuclear yield of more than 2 kg TNT equivalent.
Truck Cargo Heavy Duty (TCHD)	48 ton 7 axle articulated truck purpose built for nuclear weapons transport.
Yield	Fission or fusion of nuclear weapon. Measured in comparison to explosive power of a quantity of TNT. For example a 1 kiloton yield has an explosive power equivalent to 1,000 tons of TNT.

Legislation and Regulations

Scotland Act

Emergency Planning and Civil Defence are not reserved in the Scotland Act 1998. The Concordat between Scottish Ministers and the Secretary of State for Defence lists a number of areas where there is consultation. This includes nuclear accident planning.[1]

Civil Contingencies Act and Regulations

Under the Civil Contingencies Act 2004 Scottish Ministers may make regulations about the extent of duties imposed on Local Authorities and Emergency Services and about the method in which these duties are performed.[2] These duties include assessing the risk of an emergency occurring and maintaining and publishing appropriate plans.[3] An Emergency is an event that causes serious damage to human welfare or the environment, or war and terrorism which threatens serious damage to the security of the United Kingdom.[4] The definition includes the contamination of land with radioactive material.

The Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005 say that Scottish Ministers may issue guidance about the likelihood of a particular emergency and the extend to which it could damage human welfare and the environment.[5]

These regulations also clarify the duties of local authorities and emergency services. However these bodies need not perform these duties in relation to an emergency which is a radiation emergency within the meaning of the Radiation (Emergency Preparedness and Public Information) Regulations 2001 (REPPIR) which results from work with ionising radiation to which these regulations apply.[6]

Application of REPPIR to UK nuclear weapons and submarines

A report by the Health and Safety Executive (HSE) on the Regulation of Weapons and Naval Programme Activity says that REPPIR applies to Naval Bases and to Z berths and that HSE regulate the application of REPPIR to these sites.[7]

The Ministry of Defence (MoD) publication, Regulation of the Nuclear Weapons Programme JSP 538, says that REPPIR applies to all aspects of the nuclear weapons programme in the UK, except movements by road using Class B Packages.[8]

The basis for the application of REPPIR to military activities and consequently the extent to which the regulations apply is not entirely clear.

REPPIR applies when there is a radioactive substance, above a specified quantity, on any premises.[9] A premise includes one or more installations. The definition of installation includes equipment, structures, quays and jetties, including floating jetties.[10] REPPIR applies to the rail transport of some radioactive substances, but not to transport by road, sea or air.[11]

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[1] Concordat between Scottish Ministers and the Secretary of State for Defence, Section 2, para A.2.
[2] Civil Contingencies Act 2004 Part 1 Para 2 (4)
[3] Civil Contingencies Act 2004 Part 1 Para 2 (1)
[4] Civil Contingencies Act 2004 Part 1 Para 1
[5] Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005 Part 3 Para 11 (1)
[6] Civil Contingencies Act Regulations 2005 Part 2 Para 9 (c)
[7] Regulation of weapons and naval programme activity, Nuclear Safety Directorate, HSE, 2/2/07
[8] Regulation of the Nuclear Weapons Programme, JSP 538 Annex A page 5
[9] Radiation (Emergency Preparedness and Public Information) Regulations 2001, Regulation 3 (1) a
[10] REPPIR Regulation 2
[11] REPPIR Regulation 3 (1) b & c

REPPIR applies where a radioactive substance is used in connection with the operation of a vessel when it is at a mooring or berth, except a mooring or berth at a licensed site or under the control of the Secretary of State for Defence.[12]

Despite the statement in JSP 538 that REPPIR applies to all aspects of the weapons programme, the current guidelines issued by the Ministry of Defence to local authorities and emergency services on Defence Nuclear Materials Transport Contingency Arrangements only mention REPPIR in the glossary.[13]

It would appear to be that, for the purposes of REPPIR, submarines are not regarded as a means of transport but as premises. The Hazard Identification and Risk Evaluations written by the MoD for several Z berths say that REPPIR applies because nuclear submarines are "defined as premises under the regulations".[14]

The earlier Public Information for Radiation Emergency Regulations 1992 (PIRER), are still in force with respect to the transport of radioactive substances by road and sea. PIPER says that it is the duty of the employer "who conducts an undertaking from which a radiation emergency is reasonably foreseeable" to ensure that the public who are liable to be affected are provided with information on radiation, types of emergency, their consequences and emergency measures. This requirement does not apply where, in the opinion of the Secretary of State for Defence, this would be "against the interests of national security".

<u>Exemption of foreign warships from REPPIR</u>

REPPIR permits the Secretary of State for Defence to exempt some activities from the regulations. This power has been used to exempt foreign warships visiting the UK.[15] This will cover foreign nuclear-powered submarines and aircraft carriers as well as foreign military vessels that are carrying nuclear weapons when they visit Scottish berths or sail in Scottish waters.

<u>Responsibilities under REPPIR</u>

REPPIR requires that local authorities have in place arrangements to supply information to the public on any radiation emergency howsoever it may arise.[16]

With regard to all premise to which REPPIR applies, the operator must make a Hazard Identication and Risk Evaluation (HIRE) and submit it to HSE. This assessment must be revised when there are material changes. After 3 years the operator must either submit a new assessment or declare to HSE that there has been no change of circumstances.[17]

Local authorities are required to prepare an adequate off-site emergency plan where there are premise within their area to which REPPIR applies. The plan is required for reasonably foreseeable radiation emergencies which have been identified in the operator's risk assessment.[18]

A local authority may charge the operator for performing their functions in relation to the off-site emergency plan.

With regard to transportation, where REPPIR applies, the carrier is required to consult with local authorities when drawing up his emergency plan.

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[12] REPPIR Regulation 2, definition of premises.
[13] Local Authority and Emergency Services Information (LAESI) Edition 5,
[14] Broadford Bay, Report of Assessment of the Hazard Identification and Risk Evaluation, MoD, 7 February 2005; Loch Ewe, Report of Assessment of the Hazard Identification and Risk Evaluation, MoD, 7 February 2005; Liverpool Z Berth, Report of Assessment of the Hazard Identification and Risk Evaluation, MoD, 7 February 2005.
[15] REPPIR Regulation 18 (2) and JSP 538 Annex A page 5
[16] REPPIR Regulation 17
[17] REPPIR Regulations 4 -6
[18] REPPIR Regulation 9

The Health and Safety Executive's role in defence nuclear safety

The annex to the Concordat between the HSE and the Scottish Executive says with regard to Nuclear Safety:

> "This is a reserved matter. However, the Scottish Ministers have an interest because of the part they would play in the event of a nuclear incident – they have, for instance policy responsibility for the civil emergency services in Scotland – and because of the connection between nuclear safety and the protection of the environment, which is a devolved matter."[19]

The HSE's nuclear functions are largely carried out by the Nuclear Installations Inspectorate (NII). The MoD has its own regulatory framework. The Defence Nuclear Safety Regulator (DNSR) has two subordinate regulators - a Nuclear Weapons Regulator and a Nuclear Propulsion Regulator.

The HSE has a distinct role at those sites which are licensed by the NII. They have more limited role in other the defence nuclear activities.

(1) Defence sites licensed by NII

The key MoD nuclear sites in England are licensed by the NII. These include the Atomic Weapons Establishment at Aldermaston and Burghfield, the refit dockyard at Devonport and the naval fuel core fabrication facility in Derby.

At licensed sites there are two regulatory systems, the NII and the MoD regulator. The NII does have considerable power to limit developments at these sites. Their work is limited to those areas of the sites to which the license conditions apply. They are also unable to question warhead or reactor design. Recent correspondence on problems at Burghfield show that the NII may require the MoD to state that a specific proposal is required to support the nuclear deterrent. However they do not question whether the proposal is in fact essential.[20]

None of the defence nuclear sites in Scotland are licensed. The apparent reason is that the sites in Scotland remain under the operation of the Ministry of Defence, rather than a contractor. However this is a legal rather than a practical difference. Maintenance work at Faslane is carried out by Babcocks and the Naval Reactor Test Establishment (NRTE) at Dounreay is, in practice, operated by Rolls Royce.

The Revalidation and Assisted Maintenance Period (RAMP) carried out on HMS Torbay in 2007 is an illustration of this anomaly. This nuclear submarine is based at Devonport and the major upgrade would normally have been carried out in Devonport dockyard, a facility licensed by the NII. However the work was carried out by Babcocks in the shiplift at Faslane, which is not licensed by the NII.

(2) Non-licensed defence nuclear activity

At unlicensed sites, such as the Clyde Naval Base and NRTE, formal regulation is by the MoD's regulator, DNSR. This is similar to that of HSE's Nuclear Safety Division (NSD) -

> "On non-licensed sites that are formally 'authorised', DNSR exercises a non-statutory regulatory role similar to NSD's statutory licensing process with accountability to the Secretary of State for Defence through the Chairman of the Defence Nuclear Environment and Safety Board".[21]

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[19] Annex to the Concordat between the Health & Safety Executive and the Scottish Executive
[20] HSE website Freedom of Information documents, correspondence over AWE Burghfield
[21] NII Regulation of Non-Licensed Naval Nuclear Sites, Nuclear Safety Directorate, HSE, 19/3/07, para 41.

This means that, for sites in Scotland, the MoD are self-regulating. The HSE powers are limited to those specified in REPPIR, the Health and Safety at Work Act and the Ionising Radiation Regulations.[22]

For those defence nuclear risks which are covered by REPPIR the MoD must submit a Hazard Identification and Risk Evaluation (HIRE) to HSE. HSE may reasonably request a detailed assessment of any of the particulars in a HIRE.[23]

The inspection work carried out by the NII at sites such as the Clyde Naval Base and HMS Vulcan is limited -

> "NII practice in the exercise of its enforcement duties is to concentrate on a relatively low level of compliance inspection, complemented with joint NII/DNSR reactive work as required and effective NII/DNSR information exchange"[24]

However the NII's access to information is even more limited at non-licensed sites than it is at licensed sites. An HSE report on the Regulation of Non-Licensed Naval Sites says:

> "Reference has been made .. to the need to adopt a holistic approach to risks and hazards across the whole of the naval programme. Without routine access by the NII to relevant safety cases, it is not as easy for NII inspectors to do this for non-licensed sites as it is for licensed activities, although information contained in evaluations and reports made under REPPIR reg 4 and 6 will help."[25]

At both licensed and non-licensed sites the HSE are restricted by their agreement with the MoD -

> "Under the terms of the MoD/HSE Agreement (naval programme) and the legal requirements of AWE Act 91 Amendment Order 1997 (weapons programme), the NII will not seek to influence reactor/weapon design."[26]

This is a significant restriction on the HSE's ability to regulate work at licensed sites and to assess risks from defence nuclear activity. The MoD do not provide the NII with detailed information on reactor or warhead design. The NII are able to scrutinise some elements of the MoD's risk assessments, but they are not able to question the basic calculations which lie at the heart of the assessments of the risks and effects of nuclear weapons and naval reactor accidents.

An example is the assessment of the risk that a warhead accident could result in a nuclear yield. This relies heavily on the assumption that the warhead is Single Point Safe, ie that a detonation of the explosive at one point will not produce a nuclear yield. This cannot be verified by the NII because they are not given access to appropriate warhead design information.

Similarly the probability of a Containment Failure accident on a nuclear-powered submarine cannot be calculated without access to information on the design of the reactor. This information is not provided to the NII.

The HSE have questioned the application of a "Defence Imperative" to Health and Safety. Rather than being regarded as unique they have received advice that this is "no different in principle from other imperatives such as Fire Service imperatives". They also point out that the term "Defence Imperative" was not intended to apply to situations such as the refuelling of nuclear submarines. The HSE view is -

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[22] Regulation of weapons and naval programme activity, Nuclear Safety Directorate, HSE, 2/2/07 para 5.8
[23] REPPIR Regulation 6 (5)
[24] NII Regulation of Non-Licensed Naval Nuclear Sites, Nuclear Safety Directorate, HSE, 19/3/07. Para 5.1
[25] NII Regulation of Non-Licensed Naval Nuclear Sites, Nuclear Safety Directorate, HSE, 19/3/07. Para 5.3
[26] Regulation of weapons and naval programme activity, Nuclear Safety Directorate, HSE, 2/2/07, para 2.5

"defence needs should be taken into account as would be the case with the more strategic needs of any other stakeholder (for example in electricity supply, or vaccine for a potential flu pandemic), but that resolution of conflicts between NII expectations for safety and MoD interests should be part of the normal ALARP process".

Application of As Low as Reasonably Practicable (ALARP)

Nuclear operators are required, by REPPIR, and licensing regulations, to keep risks As Low As Reasonably Practicable (ALARP).

In the section on the Application of ALARP, the MoD regulations JSP 538 say:

"An underlying assumption is that the ownership of NW is justified and brings a net benefit to society".

JSP 538 goes on to explain how operational requirements have priority:

"Some ALARP measures identified may affect weapon system performance or availability requirements. These measures and their justification shall be brought to the attention of appropriate MOD authority which can then consider the operational implications and decide if and when they should be implemented".

The HSE recognise that there are anomalies in the application of ALARP to MoD activities -

".. what is acceptable in ALARP terms for civil practice may not be achievable for some MoD activities. This is because of the particular constraints imposed on the design of the hazard that arises from its incorporation into weapons of war and the fact that the NII is precluded from seeking to influence this design. In some cases, military requirements prevent the levels of designed safety that would be expected in a civil design, and the overall level of risk that might be acceptable at the ALARP point is higher than that for civil practice (lower levels may also be achievable)."[27]

In applying the ALARP principle to MoD activities, the HSE do not consider:

"Present siting of MoD licensed sites.
The need to sustain a nuclear weapons capability.
The use of nuclear plant to power submarines.
Proximity of explosives to some nuclear activities."[28]

The acceptance of these points distorts the HSE's assessment of whether defence nuclear activities are ALARP and so increases the risk to the public and the environment. If the justification, that nuclear weapons bring a net benefit to society, is not valid then it can be argued that the MoD are not complying with ALARP.

The HSE have implemented Safety Assessment Principles (SAPs) for the nuclear industry. These principles are designed to assist NII inspectors in assessing the safety of nuclear facilities, including ALARP judgements. While they are used for defence nuclear sites which are licensed by the NII, the HSE recognise that the current SAPs may not apply to the design of nuclear weapons or reactors and that

"the extent of application of these principles to safety cases associated with defence-related activities will be judged on a basis consistent with the ALARP principle, *taking due cognisance of the unique operating purpose and that NII regulation only applies to discrete periods of their operating life-cycles*".[29]

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[27] ibid Annex D ALARP Factors para 1
[28] ibid Annex D ALARP Factors para 5
[29] Safety Assessment Principles for Nuclear Facilities, 2006, HSE; introduction para 24.

The current designs of nuclear submarines fail to comply with a number of principles in SAPs. These include proximity to explosives and other hazardous materials, fire-fighting capacity and having diverse and segregated safety systems. (see Annex B)

Reasonably foreseeable and other accidents

REPPIR requires that an off-site plan is prepared for "reasonably foreseeable accidents" at sites where REPPIR applies. The assessment of which scenarios, at what locations, are "reasonably foreseeable" has a substantial impact on the extend of planning for nuclear emergencies.

The Nuclear Safety Division (NSD) of HSE is involved in assessing which scenarios fall into this category. But they are dependent on information supplied by the MoD -

> "MoD will facilitate NSD forming an opinion on the area within which members of the public need to be supplied with information on radiation emergencies under REPPIR." [30]

JSP 538 defines as reasonably foreseeable those accident scenarios that are likely to occur with a frequency of less than 10^{-6} per year.[31]

The Nuclear Emergency Planning Liaison Group has published guidelines on provision for accidents which fall outside the "reasonably foreseeable" category.[32] They recommend that some consideration should be given to scenarios that are less likely but would have more serious consequences. Emergency response organisations should consider the extended release scenario outlined in the NII booklet Outline Emergency Planning for Licenced Nuclear Power Stations -

> "The extendibility scenario represents a radioactive release which is well beyond that resulting from accidents or events that can reasonably be foreseen".

In this scenario shelter and distribution of Potassium Iodate Tablets would be considered out to 15 kms and shelter out to 4 km. However this particular scenario, and the proposed countermeasures, may not be adequate for some MoD nuclear accidents.

JSP 538 describes a number of ways in which nuclear weapon (NW) accidents are unique:

> "a. the consequences of unintended yield from a nuclear weapon are of a different order to most other potential nuclear accidents;
>
> b. unlike a reactor/facility accident it is infeasible to take steps to mitigate a developing accident sequence once yield has started;
>
> c. nuclear weapons are commonly positioned in the vicinity of other nuclear and explosive facilities/devices and so yield from an NW is likely to cause 'knock on' nuclear accidents;
>
> d. space and weight constraints prevent NW designers from adopting the degree of segregation of lines of protection which would otherwise be desirable."[33]

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[30] Regulation of weapons and naval programme activity, Nuclear Safety Directorate, HSE, 2/2/07Annex C, Constrains imposed by the HSE/MoD agreement para 5
[31] JSP 538 Annex F page 6
[32] Nuclear emergency planning liaison group: consolidated guidance, Department for Business Enterprise and Regulatory Reform Chapter 9 Extendibility,
[33] JSP 538 Annex Q page 3

Within civil nuclear facilities there is a requirement for containment systems with a prescribed ability to prevent a major release of radioactive material. However this principle cannot be applied to the nuclear weapons programme because -

> "there are no containments in the nuclear weapon system able to withstand the explosion of enough warheads to cause a large release".[34]

There are several scenarios that are not covered by current public guidelines for nuclear accidents, on the grounds that the MoD considers that they are not reasonably foreseeable. Some of these are listed in Table 7.

MoD's principles of warhead risk assessment

The safety principles for nuclear weapons are based on Lines of Defence (LOD). With regard to inadvertent yield, the number of LODs for each type of environment is indicated in Table 1 [35]

Table 1 Lines of Defence and Environments

	Normal Environment	Specified Abnormal Environment	Severe Abnormal Environment
Number of full independent LODs to withstand the environment	3	2	1

The frequency with which the warhead is exposed to a Specified Abnormal Environment must be less than 10^{-3} per year and the frequency of exposure to a Severe Abnormal Environment must be less than 10^{-6} per year.

The probability of a full independent LOD failing must be no greater than 10^{-3} per demand.

Examples of a full LOD are:

(1) The PD AWG 516 package which is used to protect the warhead from a fire.

(2) The arrangement of explosives in the warhead to make it Single Point Safe, so that the detonation of the explosive at one point will not lead to a nuclear yield.

In addition there are partial Lines of Defence. These reduce the risk by at least one order of magnitude. An example is the provision of a fire tender as part of a nuclear convoy.

The regulations say - "physical LOD are preferable over Procedural LOD. Procedural LOD against yield should be avoided whenever practicable".

It is likely that the safety of key parts of the nuclear weapons programme is dependent on procedures rather than physical defences. This is probably the case in the transport of nuclear weapons, the loading of warheads at Coulport and the operation of nuclear-armed submarines.

The Regulations point out the dangers of relying on questionable data –

> "When conducting a quantitative safety assessment of a NW System, where the probability of failure is low and the consequences of failure is high, there is danger of placing over-reliance on figures that cannot be justified with confidence".

[34] JSP 538 Annex K page 5
[35] JSP 538 Annex H page 7

Shortfalls in the Trident system

Table 2 shows a number of areas where the current Trident system does not comply with the Regulations for the Nuclear Weapons Programme, JSP 538

Table 2 Design requirements and Trident

JSP 538 Annex G	Trident
"It should be a design objective to make nuclear warheads Multi Point Safe".[36]	Trident warheads are not Multi Point Safe.
"An Insensitive High Explosive (IHE) ... should be used for the supercharge".[37]	Trident warheads use EDC 37 as the supercharge. EDC 37 is not an IHE.
The rocket motor should meet the Insensitive Munitions Criteria.[38]	Trident D5 rocket motors are not Insensitive.
"It should also be the aim that a high order event from the motor should be *Unlikely* to lead to the detonation of the WH's supercharge."[39]	Unlikely means less frequent than 10^{-3} per event. Trident is probably unable to meet this aim.

The failure to use Insensitive explosives in the Trident warhead and missile is a significant contributing factor to the risk of a nuclear accident.

MoD risk targets for nuclear warhead accidents

Two targets are to be used in drawing up safety cases – the Basic Safety Level (BSL) and the Basic Safety Objective (BSO). Both are expressed in frequency per year. JSP 538 says that where an accident is more likely to occur than the BSL the activity is not justified in peacetime. Where the probability is between the BSL and the BSO then there is a requirement to demonstrate to the MoD regulator that ALARP has been considered.

The same criteria are used for each of 4 Life Cycle Phases – manufacture (Aldermaston and Burghfield), transport, Clyde Naval Base and deployed. The regulations say that this has little impact because the phases are largely carried out at different locations. However the Clyde estuary area is at risk from nuclear weapons transport and submarines at sea as well as from an accident at the Clyde Naval Base.

There are two types of targets – for an inadvertent yield and for the dispersal of radioactive material.

<u>(1) Inadvertent Yield.</u>

The BSL for inadvertent nuclear yield is 10^{-8}. This applies to all nuclear yields. The regulations themselves point out the weakness of this approach:

> "Although a single BSL value is applicable for all levels of yield, it is recognised that different levels of yield would have widely different consequences. BSLs have not been set for different yield events because of the difficulty of accurately predicting the magnitude of yield".[40]

A yield is defined as greater than 2 kg TNT- equivalent. For a yield of this scale the 10^{-8} frequency may be adequate. However the unboosted detonation of the primary of a Trident

[36] JSP 538 Annex G Page 2
[37] JSP 538 Annex G page 9
[38] JSP 538 Annex G page 11
[39] ibid
[40] JSP 538 Annex F page 17

warhead could possibly result in a yield of up to 1 kiloton and the 10^{-8} frequency target would not be sufficient for a yield of this magnitude.

No Basic Safety Objective (BSO) is set for inadvertent yield. The explanation in JSP 538 is that it is not practicable to achieve a convincing quantitative demonstration of a BSO significantly below the BSL level of 10^{-8}.

(2) Release of radiation.

Tables 3 and 4 are based on JSP 538. They show the MoD's estimates of the effect of nuclear warhead (WH) accidents in which Radioactive Material (RA) is dispersed.[41] This risk is assessed separately from nuclear yield. The plutonium shown is the amount of respirable plutonium dispersed into the atmosphere. No estimate for plutonium is given for a category F accident. The dose is the 50 year dose received by members of the public 1 km from the accident.

Table 3 Dispersal of plutonium in warhead accidents

Cat	Examples	Plutonium	Dose @ 1 km	BSL	BSO
A	One or more WHs consumed in fire but RA material effectively contained within a facility.	3 g	10^{-1}-1 mSv	10^{-1}	10^{-4}
B	1. Up to 4 WHs consumed in fire. 2. Large partial HE event.	3-30 g	1-10 mSv	10^{-2}	10^{-5}
C	1. One or more WH detonations with RA material contained within a facility. 2. More than 4 WHs consumed in fire. 3. One or more WHs consumed in fire, subsequent low energy criticality of debris when flooded.	30-300 g	10-10^{2} mSv	10^{-3}	10^{-6}
D	1. Uncontained WH detonation (up to 3 WHs). 2. One or more WH consumed in fire & subsequent low energy criticality of debris when flooded causing additional release of RA material.	0.3-3 kg	10^{2}-10^{3} mSv	10^{-4}	10^{-7}
E	Uncontained WH detonations (4-30 WHs).	3-30 kg	1-10 Sv	10^{-5}	10^{-8}
F	Detonation of one or more missiles in a submarine with subsequent release of RA material from WHs.		10-10^{2} Sv	10^{-6}	10^{-9}

Table 4 Dispersal of Tritium in warhead accidents

Cat	Examples	Tritium	Dose @ 1 km	BSL	BSO
A	Limited tritium leak.	6g	10^{-1}-1 mSv	10^{-1}	10^{-4}
B	Total tritium reservoir failure.	6-60 g	1-10 mSv	10^{-2}	10^{-5}
C		60-600 g	10-10^{2} mSv	10^{-3}	10^{-6}

[41] This table combines information from tables F-2 and F-6 in Annex F and Table J-1 in Annex J of JSP 538.

Estimated effects of accidental nuclear explosions

In 1957 and 1958 the US conducted tests on several early warhead designs to establish if they were Single Point Safe.[42] Several tests did produce a yield, showing they were not Single Point Safe. The yields produced, shown in Table 5, indicate the range of yields that might be expected in a nuclear weapons accident.

Table 5 Yield from safety test failures

Date	Name	Yield
26/7/57	Pascal A	55 tons
27/8/57	Pascal B	300 tons
6/9/57	Coulomb B	300 tons
9/12/57	Coulomb C	500 tons
12/9/58	Otero	38 tons
17/9/58	Bernalillo	15 tons
21/9/58	Luna	15 tons
28/9/58	Mars	13 tons
5/10/58	Hidalgo	77 tons
5/10/58	Colfac	5.5 tons
14/10/58	Neptune	115 tons
15/10/58	Vesta	24 tons
24/10/58	Catron	21 tons
24/10/58	Juno	1.7 tons

The first three tests had been expected to produce yields of 1-2 lbs, but actually resulted in substantial explosions, with yields of 55 tons and 300 tons. The fourth test was an overtest. It was designed to demonstrate the maximum yield that might be encountered in a Single Point Safety test failure. The yield produced was 500 tons.

Table 6 estimates the effects of accidental nuclear explosions. The calculations were carried out by Scottish CND using the Hotspots programme written by Los Alamos Laboratory. They assume a windspeed of 3 metres/second and show the 50 year effective dose that could be received by members of the public downwind of the accident.

Table 6 Public dose from nuclear explosions

Yield	1 km	5 km	10 km	20 km
0.1 ton	36 mSv			
1 ton	1.4 Sv			
10 tons	8.7 Sv	180 mSv	6.6 mSv	
50 tons	21 Sv	1.4 Sv	170 mSv	
100 tons	33 Sv	2.6 Sv	460 mSv	32 mSv
500 tons	130 Sv	7.5 Sv	2.4 Sv	440 mSv
1 kiloton	290 Sv	11 Sv	3.9 Sv	950 mSv
10 kilotons	23,000 Sv	52 Sv	15 Sv	5.3 Sv
100 kilotons	63,000,000 Sv	1000 Sv	96 Sv	21 Sv

The Trident warhead uses tritium to boost the yield of the primary (fission) stage and has a secondary (fusion) stage. Tritium boosting and a secondary yield are only likely to occur when the warhead is triggered by its internal Arming, Fuzing and Firing System, which includes a number of safety features. If the fission reaction was boosted by tritium the yield would be in the range of 1 – 10 kilotons. In an accident, without tritium boosting, the yield from a single

[42] http://nuclearweaponarchive.org/Usa/Tests/

nuclear warhead would be expected to be below 1 kiloton and probably in the 0.1 ton to 500 ton range. The total yield could be greater in an accident involving several warheads because of the cumulative effect of several explosions and the popcorning effect.

The Nuclear Weapons Transport Safety Case indicates that the public dose from a nuclear explosion would be in the 1-10 Sv range. The calculations above would suggest that the safety case is based on a scenario where the yield was between 1 ton and 10 tons. If there was a larger yield the public dose could be significantly higher.

Transport of Nuclear Weapons

Nuclear weapons are transported regularly from the assembly/disassembly facility at Burghfield to the store at Coulport. Over the last 20 years convoys have made the double trip between 2 and 10 times a year.

Scottish Local Authorities affected

The MoD has published guidelines for local authorities and emergency services (LAESI). The 2nd edition of LAESI said that roads in regular use by nuclear weapons convoys were within or adjacent to 16 Scottish Council areas: Argyll & Bute, Borders, Edinburgh, Glasgow, Dumfries & Galloway, East Ayrshire, East Dumbartonshire, East Lothian, East Renfewshire, Falkirk, Midlothian, North Lanarkshire, Renfrewshire, South Lanarkshire, Stirling and West Lothian.

The current 6th edition of LAESI covers the transport not just of nuclear weapons but also of a range of defence nuclear material. It has a longer list of Councils through which some defence nuclear material might be moved by road, rail or air. However the 16 Councils listed in the 2nd edition are all included in the current version. This suggests that this list is still correct.

Dispersal of plutonium

The LAESI guidelines for a nuclear weapons accident are based on a scenario where a proportion of the nuclear material in a warhead is dispersed into the air following a fire or conventional explosion in which there is no nuclear explosion.

The MoD have released, under the Freedom of Information Act, a heavily redacted summary of the Safety Case for Nuclear Weapons Transport. This gives the estimated frequency for an accident which would not cause a nuclear explosion but which would result in members of the public 1 km away receiving a dose of 1-10 mSv. The frequency of this is given as 1.7×10^{-7} per year. This is significantly less likely than the BSL, 10^{-2}, and is also below the BSO, 10^{-5} for this degree of public exposure. The Safety Case says -

> "this is mainly due to the risks from vehicle accidents"

The same frequency figure, 1.7×10^{-7} per year, appears elsewhere in the safety case as the overall risk of a worker being killed. The explanation of this item says -

> "the key risks to operators arise from vehicle accidents, in particular a collision between a TCHD and a fuel tanker".[43]

The repetition of the same frequency suggests that the main scenario used in the Safety Case for the 1-10 mSv public dose is a collision between a fuel tanker and a nuclear weapons transporter (TCHD).

JSP 538 says that this dose, 1-10 mSv, would result from an incident in which up to 4 warheads were consumed in fire or a "large partial HE event". The amount of respirable plutonium released in these scenarios would be up to 30 g. Each warhead contains 3-4 kg of

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[43] Operational Safety Case for Transport of Nuclear Weapons para 58. TCHD is the Truck Cargo Heavy Vehicle, which is used to transport nuclear weapons.

plutonium. So the safety case assumes that only around 1 % of the plutonium would be released into the environment, in a respirable form, in this scenario.

Other scenarios could result in the dispersal of substantially more plutonium. JSP 538 says that in an unconfined explosion just under a quarter of the dispersed plutonium aerosol is in a respirable form. The regulations also indicate that the uncontained detonation of up to 3 warheads would result in the dispersal of 0.3–3 kg of respirable plutonium and would result in members of the public receiving a dose of 0.1–1 Sv at 1 km. The redacted safety case does not include any estimate of the probability of this category of accident.

Nuclear explosion

A nuclear explosion would have far more serious consequences than the dispersal of plutonium. But this scenario is not considered in the LAESI guidelines which say -

> "An inadvertent nuclear yield greater than a few pounds of TNT equivalent is therefore not possible".[44]

The summary of key emergency actions in the guidelines says:

> "There is no risk of an 'atomic bomb' type of explosion"

However the safety case contradicts this. It shows that there is a risk of a nuclear explosion and says the frequency of such an event is estimated to be 2.4×10^{-9} per year.[45] While this may appear a very remote possibility, it is close to the BSL target of 10^{-8}.

The estimate frequency for a nuclear yield is 24 % of the BSL. JSP 538 explains that the same BSL is applied to each of four Life Cycle Phases in the nuclear weapons programme.[46] If however the BSL was to be split equally between these four phases then the BSL for the transport phase would be 2.5×10^{-9}. This would be very close to the estimated frequency of 2.4×10^{-9} per year.

The safety case includes a short explanation of the main hazards that could lead to a nuclear explosion:

> "The key fault contributors to the overall frequency are vehicle accident in the event of multiple failures of LODs [Lines of Defence], due to the predominance of vehicle accidents, and aircrash, as the NW may not retain its SPS [Single Point Safe] nature."

The safety case deals separately with the risk of dispersal of radioactive material. It says that the frequency of an incident that would result in a public dose of 1–10 Sv is 2.4×10^{-9} per year. This level of radiation dose is 1000 times higher than the fuel tanker scenario that is likely to form the basis for the LAESI guidelines. The explanation for the larger release is –

> "The risk in the 1-10 Sv category ... is predominantly due to the risk from an aircraft crash"

The estimated frequency for a nuclear explosion is identical to that for a 1-10 Sv dose. Both are likely to be based on the same scenario, an aircraft crash.

The main factor in accessing the frequency of a nuclear explosion from an aircraft crash will be the probability that an aircraft will crash out of the sky. The general frequency of an accidental aircraft crash is likely to be over 10^{-6} per year, and may be in the region of 7×10^{-7} per year.[47]

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[44] Local Authority and Emergency Services Information Edition 6, MoD, 2006 (LAESI), page 2

[45] Operational Safety Case for Transport of Nuclear Weapons Executive Summary, Nuclear Movements and Nuclear Accident Response Group, January 2005, para 40. Redacted copy declassified under FOIA.

[46] The four Life Cycle Phases are manufacture, transport, Clyde Naval Base and deployed.

[47] The Aftermath of the US attacks: The End of Probabilistic Risk Analysis, John Large.

The figure in the convoy safety case may be slightly higher to take account of the route and location of stopping points.

In the light of JSP 538 it would be expected that, where the assessed frequency is close to the BSL, there would be a significant effort to reduce the risks to ALARP. However the safety case says:

> "there are considered to be no additional protective measures that would reduce the frequency associated with these faults."

Given the concern about an aircraft crash one obvious way to reduce risks would be to avoid routing nuclear weapons convoys close to airports. Yet convoys have travelled recently on the M9 under the final approach to Edinburgh airport. In the past convoys have also travelled under the final approach to Glasgow airport on the M8 and this probably remains an authorised option.

The principles in JSP 538 show that there should be in place one Line of Defence (LOD), which is practical and not procedural, that will prevent an aircraft crash from resulting in a nuclear explosion. However the figures above give grounds for suspecting that this may not be the case.

Nuclear weapons transport containers

A major factor in the safety case for nuclear weapons' transport is the container used to protect nuclear weapons in transport, the PD AWG 516 package. The safety case says:

> "The design of the package has been approved by RAMTAP as meeting all the relevant requirements including the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials ...
>
> "... the PD AWG 516 packaging employed in the movement of NWs, have all been produced for the specific purpose for which they are used and designed in order to fulfil the requirements of the IAEA Transport Regulations".[48]

This refers to IAEA Regulations for the Safe Transport of Radioactive Materials 1985.[49] However these regulations state –

> "packages .. shall be segregated during transport .. from other dangerous goods".[50]

In 1993 Scottish CND was told by the Director of HSE that these IAEA regulations should not be used to prove the safety of the transport of nuclear weapons.[51] The claim in the safety case that PD AWG 516 fulfils the requirements of the IAEA transport regulations is not correct and is misleading. This is significant because there is a substantial difference between the transport of civil nuclear material, which might be dispersed if exposed to an external fire, and a nuclear weapon, within which there could be an explosion, possibility a nuclear explosion.

It is likely that the safety case estimates that the package would not protect the warhead in the event of an aircraft crash.

Nuclear-powered submarines

The worst-case reactor accident considered in safety schemes for the Clyde Naval Base and Z Berths is a Loss of Coolant Accident (LOCA) in which a proportion of nuclear material is

[48] Operational Safety Case for Transport of Nuclear Weapons paras 12 & 17
[49] Operational Safety Case for Transport of Nuclear Weapons reference ES8
[50] IAEA Regulations for the Safe Transport of Radioactive Materials 1985, para 460. The IAEA introduced newer regulations in 2005 and these include the same principle.
[51] Letter from JD Rimmington, Director HSE to Scottish CND, 15/11/1993.

slowly released into the atmosphere. A Navy training manual describes the standard accident as one in which 0.1 % of the iodine and caesium isotopes are released over a 24 hour period.[52]

This manual also describes a far more serious Primary Containment Failure accident -

> "it is just conceivable that for some reason both primary and secondary containment fail, or are by-passed, (eg penetration of the hull). In this extremely unlikely event it is possible that the entire contents of the RC could be released in a very short time (minutes)."[53]

In this scenario 100 % of the iodine and caesium isotopes could be released into the atmosphere in 10 minutes. An accident on this scale would have a far greater effect on human health and the environment over a much wider area than the LOCA scenario.

Nuclear-armed submarines

Trident nuclear submarines are normally armed with missiles and warheadas when in the Clyde Naval base. A small number of warheads are replaced on submarines at Coulport for surveillance and maintenance. However warhead loading and unloading operations are kept to a minimum, because the process is slow and hazardous. As a result the submarines are normally armed with 48 warheads when berthed at Faslane. The exception is when a vessel is about to go into refit, or when it has just returned after a refit. The submarines are normally also armed when they sail around the West coast of Scotland on training exercises and in passage to their operational patrol areas.

<u>Complex accident scenarios</u>

In addition to the risks of a very low yield nuclear explosion and of a reactor Primary Containment Failure accident there are other complex accidents which could take place on a Trident nuclear submarine, or any a future submarine which replaces Trident.

(1) Release of plutonium from several nuclear warheads.

JSP 538 indicates that the uncontained detonation of between 4 and 30 warheads, without a nuclear yield, could result in an effective dose of 1 - 10 Sv at 1 km. The detonation of one or more missiles in a submarine with the subsequent release of radioactive material, but no nuclear yield, could result in an effective dose of 10 - 100 Sv at 1 km.[54]

(2) Significant yield from a sequence of nuclear explosions (popcorning).

Nuclear weapons at the Clyde Naval Base are not isolated -

> "nuclear weapons are commonly positioned in the vicinity of other nuclear explosive facilities/devices and so yield from an NW [Nuclear Weapon] is likely to cause 'knock on' nuclear accidents".[55]

It is possible that a very low yield from one warhead can trigger a larger yield from a second warhead. This phenomenon is called popcorning -

> "it is possible for a very small nuclear yield from one WH to enhance the yield from another WH in the detonation sequence"[56]

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[52] Hazards of a Reactor Accident, Department of Nuclear Science and Technology, Royal Naval College Greenwich.
[53] Hazards of a Reactor Accident,, Annex A page 1.
[54] JSP 538 Annex F Table F-6
[55] Regulation of the Nuclear Weapons Programme, JSP 538, Annex Q, Page 3
[56] JSP 538 Annex F page 11

The risk of popcorning depends on the array geometry, ie how warheads are positioned relative to each other on the submarine. However the Nuclear Weapons Regulator need not normally be informed of the actual number of warheads on each missile on each submarine. The MoD only have to supply their internal regulator with a generic diagram of where warheads can be placed on the submarine.[57] This means that the Regulator is not supplied with sufficient information to fully assess the risk of popcorning.

The consequences of a significant nuclear yield would be greater than the release of plutonium from a series of warheads as described above.

(3) Combined warhead and reactor accident.

Nuclear missiles are stored close to the reactor on a Trident submarine. The reactor could be affected by a warhead accident, or vice-versa. A major conventional explosion on a submarine could result in a Primary Containment Failure accident. The probability of this is likely to be high in the event of a significant nuclear yield. This would result in the rapid dispersal of radioactive isotopes from the reactor and of plutonium from some of the warheads, on top of the effects of a nuclear explosion.

Missile explosion hazard

Trident missiles have three solid-fuel rocket motors. Each motor is classified in the US as 1.1 High Explosives, the most hazardous explosive designation. The motors contain a proportion of HMX military explosive. Each missile has an explosive power equivalent to 70.3 tonnes of TNT. Although submarines have 16 missile tubes they normally carry only 14 missiles. These 14 missiles have a combined explosive power equivalent to 980 tonnes of TNT.

In 1994 Stefan Michalowski co-authored a report on Trident safety. In June 2008 he told Rob Edwards of the New Scientist that he is still concerned about the dangers of a Trident missile accident:

"The explosion of a boatload of missiles in a port would be an unimaginable catastrophe. ... It's a very, very scary thought".[58]

The joint report on Trident had described how the nuclear warheads or Reentry Vehicles (RVs) are located around the explosive third stage of each missile. The authors argued that this arrangement could lead to a nuclear explosion:

".. what happens if, as a result of gunshot for example, a detonation is initiated on the periphery of the rocket motor directly adjacent to one of the RVs? A non-symmetric shock could generate flying case fragments that would strike that RV causing a one-point detonation of the warhead. As the detonation front proceeded through the propellant, creating additional case fragment impacts on RVs, fragments from the first warhead would be striking adjacent warheads. If the timing were just right, one might argue that the HE of an adjacent RV could be detonated at more than one point, perhaps creating sufficient compression to produce some nuclear yield"[59]

Assessing the safety of nuclear weapons when loaded on Trident missiles will depend on the supply of information from the United States. The JSP 538 regulations show that this flow of information is limited and the Nuclear Weapons Regulator (NWR) does not adequately question any shortfalls in US assessments -

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[57] JSP 538 Annex B page 38

[58] Could warheads go off 'like popcorn', Rob Edwards, New Scientist, 28 June 2008.

[59] Nuclear Weapons Safety: the case of Trident, John Harvey & Stefan Michalowski, Science and Global Security, 1994. Stefan Michalowski is now senior scientist at the OECD in Paris and John Harvey is head of policy at the US National Nuclear Security Administration.

"It is recognised that many components of the Trident Strategic Weapon System are provided by the US under government to government agreements which do not necessarily allow full design disclosure. NWR does not directly address this issue with US authorities; his questioning of US safety justifications seeks to establish the degree to which the UK ADA understand any limitations and if any UK-based work can be done to mitigate their impact".[60]

When Trident submarines are lifted in the Faslane shiplift for maintenance they are normally fully armed with 14 missiles and 48 nuclear warheads. In 2003 a review was conducted of risk assessments for a Trident submarine in the shiplift.[61] This revealed a number of significant failings:

(1) The risk assessments did not take proper account of the fact that the platform and cradle of the shiplift would collapse if a large aircraft crashed into it.

(2) The probability of a Trident missile exploding in a fire, "cook-off", was not clear. Two different figures were used in the risk assessment. As fire is a serious risk on a submarine, the probability of "cook-off" is a major factor in assessing the probability of a missile explosion.

(3) It was possible for a Trident missile to ignite spontaneously as a result of internal chemical reactions. This had been ignored in the risk assessments.

Submarine safety

Nuclear submarines do not comply with many of the Safety Assessment Principles that were drawn up for the civil nuclear industry, such as the proximity of hazardous material to radioactive material and the need for segregated independent safety systems (see Annex B)

Any serious incident on a submarine has nuclear safety implications. For example a fire could be started as a result of a submarine running aground and the fire could endanger the nuclear reactor and nuclear weapons.

Three Boards of Inquiry into serious incidents involving nuclear submarines over the past 6 years show there are failings in the risk assessment process for nuclear submarines. They also illustrate how operational and training requirements can undermine safety and that the relationship between safety critical factors on a submarine is complex. (see Annex A)

In 1990 and 1991 the MoD continued to deploy Polaris submarines on patrol despite the fact that they knew there was a generic fault affecting all submarines. Other submarines were withdrawn from service until the problem was fixed, but one Polaris submarine was kept at sea at all times.[62] Following a reactor leak on HMS Tireless in May 2000 almost all British submarines were withdrawn from service until repaired. However HMS Triumph continued to be deployed and Trident submarines were kept at sea. In both 1990 and 2000 all submarines should have been withdrawn from service. The MoD failure to do so may have been because they placed operational demands above safety considerations.

An analysis of submarine incidents from 1950 to 1988 suggests that the fleet of Trident submarines might experience 5.9 fires throughout their planned life. The estimated number of collisions was between 1.9 and 4.7, including between 0.6 and 1.2 collisions with other

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[60] JSP 538 page 2-9; ADA is Approving and Design Authorities

[61] Review of Radiological Accident Probability Assessments and Radiological Probabilistic Assessment for Vanguard Class SSBN whilst on the Shiplift at HMNB Clyde, Atkins for MoD, March 2003. Redacted copy declassified under FOIA for Scottish CND.

[62] Cracking Under Pressure: the response to defects on British nuclear submarines, Scottish CND 1992.

submarines.[63] A further analysis of 63 collisions involving British or US submarines showed that 73% occurred at sea and 27 % when the submarine was berthing or in a harbour area.[64]

Terrorist scenarios

The threat level issued by the Home Office in Summer 2008 is 'severe'. This means that the assessment is that a terrorist attack is highly likely. In November 2007 the Security Service said that they were tracking around 2,000 suspects in the UK, in 200 terrorist networks and that 30 active plots were under investigation.[65]

Al Qaeda have shown that they have the ability to carry out complex attacks that require careful planning and preparation and they can recruit supporters who are willing to take part in suicide attacks. They are adept at conducting attacks that result in substantial publicity and have political effect. An attack on nuclear weapons in transit or on a Trident submarine would have a symbolic impact that was even greater than the direct damage to human health and to the environment.

It remains difficult for Al Qaeda to build or acquire a nuclear weapon and to use it. However an attack on part of the British nuclear weapons' system would be easier and could have a similar effect.

Emergencies arising from terrorist acts are within the remit of the Civil Contingencies Act 2004. However it would appear that the risk of a terrorist attack on nuclear weapons or nuclear submarines may not be properly addressed within the current MoD safety regime.

The Safety Assessment Procedures (SAPs) for nuclear facilities issued by HSE mention these risks:

> "Terrorist or other malicious acts are assessed as external hazards"[66]

However it is not clear to what extent HSE consider that REPPIR assessments should take account of terrorist risks, and if so whether this should include threats to defence nuclear activities.

With regard to the Z Berth at Liverpool the HSE advised Sefton Council in November 2002:

> "terrorist threats were not considered to be reasonably foreseeable in the context of REPPIR planning"[67]

The Regulations for the Nuclear Weapons Programme, JSP 538, do not take account of terrorist risks:

> "In certain circumstances hostile acts could present a threat to nuclear safety. Chapter 2 does not address this issue explicitly and the probabilistic safety requirements in Annex B exclude radioactive releases due to hostile acts. However Authorisees and designers of weapons and plant are encouraged to take the possibility of hostile acts into account as an 'external hazard' in a manner consistent with any threat which may arise, as advised by local and central security departments."[68]

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[63] The Safety of Trident, An assessment of the radiation risks associated with the UK Trident programme, Scottish CND, February 1994.
[64] ibid
[65] How the Threat has developed, Security Service Website http://www.mi5.gov.uk/output/Page549.html
[66] SAPs para 208
[67] Minute of Discussion between NII and Sefton Council on REPPIR and Liverpool Z Berth, 8 November 2002
[68] JSP 538 page 4-16.

The Nuclear Weapon Safety Principles and Safety Criteria, Annex F of JSP 538, says :

> "Hazards associated with security issues and deliberate malevolent acts are not addressed"[69]

There is no mention of terrorist risks in the redacted version of the Safety Case for the Transport of Nuclear Weapons, or the review of the Faslane shiplift risk assessments.

An obvious hazard is that a terrorist group could deliberately fly an aircraft into a defence nuclear facility. Published MoD reports reveal two significant vulnerabilities:

(1) An aircrash into a nuclear weapons convoy could result in a nuclear yield.[70]

(2) The Faslane Shiplift would collapse if a large aircraft crashed into it when it had an armed Trident submarine inside.[71]

A third vulnerability is the Explosives Handling Jetty (EHJ) at Coulport which loads/unloads Trident warheads onto missiles and less frequently loads/unloads the missiles themselves. In a section on the terrorist threat to naval munitions, a MoD manual says -

> "Loading/unloading operations in the Explosives Handling Jetty will require the latest intelligence on probabilities of attack to be determined with appropriate measures taken as required."[72]

This suggests that the MoD are concerned about a terrorist attack on the EHJ. When warheads are loaded/unloaded the missile hatch is open and the missile is partially raised. The explosives in the missile and warhead are vulnerable to an external event, such as a fire or explosion inside the EHJ. The explosion of all the rocket motors on the submarine would be equivalent to 980 tons of TNT. A blast of this magnitude could trigger a significant nuclear explosion and disperse all the radioactive material in the submarine's reactor.

It is likely that the published safety case for the transport of nuclear weapons only takes account of an accidental aircraft crash. A terrorist aircraft crash is almost certainly much more likely.

The convoy safety case considers the risk from an accidental collision with a fuel tanker. However the risk of a terrorist group using a fuel tanker in a deliberate attack is probably higher. It is also possible that terrorists could conduct an attack in such a way as to cause greater damage than in an accident.

Terrorists are not restricted to those scenarios that are already considered in nuclear safety schemes. They could use large quantities of explosives or conventional weapons. Nuclear weapons in transit are probably protected against bullets but the lorries and containers are unlikely to provide protection against munitions that were designed for use against armoured vehicles.

A terrorist group is likely to plan an attack on a nuclear weapons' convoy at a point where the incident would cause the maximum amount of damage to members of the public. An overall assessment of the probable consequences of a terrorist attack should be based not on the average population density on the convoy route, but on the highest population density on the route.

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[69] JSP 538 Annex F page 4.
[70] Operational Safety Case for Transport of Nuclear Weapons Executive Summary, Nuclear Movements and Nuclear Accident Response Group, January 2005. Redacted copy declassified under FOIA.
[71] Review of Radiological Accident Probability Assessments and Radiological Probabilistic Assessment for Vanguard Class SSBN whilst on the Shiplift at HMNB Clyde, Atkins for MoD, March 2003. Redacted copy declassified under FOIA for Scottish CND.
[72] Design Standards for Explosives Safety in MOD Ships and Submarines, Part 2 Submarines, Defence Standard 00-101, MoD, 11 February 2005, page 14.

Specific safety schemes

The MoD has produced guidelines for local authorities and emergency servives for the transport of defence nuclear materials - the Local Authority and Emergency Services Information (LAESI). Argyll and Bute Council has produced an Off-Site Contingency Plan for the Clyde Naval Base. Highland Council has produced the Highland Safety Scheme for Z berths at Broadford and Lochewe and the Off-Site Contingency Plan for the NTRE Vulcan, Dounreay.

Table 7 shows potential scenarios and the scope of existing safety schemes. These are listed in approximate order of severity with the incidents which would have greatest effect last.

Table 7 Accident scenarios and safety schemes

Scenario	Location	Safety Scheme	Notes
Loss of Coolant Accident at prototype reactor	NRTE Vulcan	Vulcan Off-site	
Loss of Coolant Accident on a British nuclear-powered submarine	Loch Goil & Rothesay Bay Z berths	Clyde Off-site	
Loss of Coolant Accident on a British nuclear-powered submarine	Broadford Bay & Loch Ewe Z berths	Highsafe	
Loss of Coolant Accident on a British nuclear-powered submarine	At sea	None	1
Loss of Coolant Accident on a British nuclear-powered submarine	X berths at Clyde Naval Base	Clyde Off-site	
Loss of Coolant Accident on a foreign nuclear-powered vessel	Clyde Naval Base, Z berths & at sea	None	2
Plutonium dispersal from a limited nuclear weapons accident, no nuclear yield	Nuclear weapons convoy routes	LAESI	
Plutonium dispersal from the detonation of 3 or more nuclear weapons	Nuclear weapons convoy routes	None	
Plutonium dispersal from the detonation of 3 or more nuclear weapons	Clyde Naval Base, Z berths & at sea	None	
Primary Containment Failure at prototype reactor	NRTE Vulcan	None	
Primary Containment Failure accident on a British nuclear-powered submarine	Clyde Naval Base, Z berths & at sea	None	
Primary Containment Failure accident on a foreign nuclear-powered vessel	Clyde Naval Base, Z berths & at sea	None	
Low yield from a nuclear weapon	Nuclear weapons convoy routes	None	
Low yield from a nuclear weapon on a submarine	Clyde Naval Base, Z berths & at sea	None	
Significant yield from sequence of nuclear explosions in storage (popcorning)	Reentry Body Magazine, Coulport	None	
Significant yield from sequence of nuclear explosions on a submarine (popcorning)	Clyde Naval Base, Z berths & at sea	None	
Plutonium dispersal from several warheads on a submarine plus Primary Containment Failure Accident	Clyde Naval Base, Z berths & at sea	None	
Nuclear yield plus Primary Containment Failure Accident	Clyde Naval Base, Z berths & at sea	None	
Nuclear weapons and reactor accident on a foreign vessel	All locations	None	3

Notes

(1) In some areas the risk of an accident at sea is significantly higher than the risk at most Z berths. For example submarines frequently transit between Dunoon and Gourock but there are no preplanned countermeasures for these towns.

(2) The MoD do not hold information on the design of reactors and nuclear weapons on visiting warships and so they are unable to verify that an accident is not "reasonably foreseeable".

(3) This is potentially more serious than an accident on a British submarine because US Trident submarines carry a larger number of missiles, 24, and nuclear warheads.

Relative risks in Scotland

If this table were extended to cover all risks across the UK then it would be apparent that the scenarios with the worst potential consequences are largely limited to Scotland. This is because the worst scenarios involve fully armed Trident submarines. A missile explosion on a Trident submarine at the Clyde Naval base or off the West Coast of Scotland could result in a significant nuclear yield together with the radiation hazards from 47 other nuclear weapons and the rapid dispersal of all the radioactive material in the reactor.

The MoD's decision to introduce nuclear fuel cores that will be in service throughout the life of a submarine also shifts the risk from Devonport to Scotland. By reducing the need for in-service refuelling the risk to workers and the public at Devonport is reduced. However the radioactive inventory in the submarine's reactor becomes more hazardous the longer the submarine is in service. The consequences of a Primary Containment Failure Accident from a fuel core which has been in service for 30 years is more severe than from a fuel core which has been in service for 10 years.

While Scotland is at greatest risk from the most dangerous kinds of accident, there is less regulation in Scotland than in England. The main restriction on the MoD's self-regulation is the NII's role in licensing some MoD facilities. However the only MoD facilities that are licensed are those in England.

Trident Replacement

Safety will be a significant factor in the MoD's assessment of options for a future system to replace Trident.

1. With regard to the warhead the MoD may choose either to keep the current warhead in service until 2055, or to build a new warhead. If they choose the latter then the new warhead is likely to use Insensitive High Explosives.

2. Rolls Royce are currently developing a New Generation Nuclear Propulsion Plant for the Future Submarine Programme. This reactor will use a passive cooling system which will be designed to reduce some risks.

3. The MoD may be considering replacing the Faslane shiplift with a dry-dock.

Points for further clarification

Below are some questions that arise from this report:

1. Which nuclear-weapons and nuclear-submarine activities are covered by REPPIR and which are not covered ?
2. What locations are covered by REPPIR ?
3. In what geographical areas are submarines covered by REPPIR when at sea ?
4. What is the basis for determining which activities are covered by REPPIR ?
5. To what extent can Scottish Ministers question whether arrangements made under REPPIR are adequate ?
6. Why are the Clyde Naval Base and HMS Vulcan not licensed by the NII ?
7. Can the MoD and HSE provide an acceptable level of verification that some scenarios are not reasonably foreseeable ?
8. Which scenarios could be consequences of a reasonably foreseeable terrorist incident ?
9. Even if they are not reasonably foreseeable, should there be "extendibility" planning for some scenarios because of the scale of the consequences ?
10. If the deployment of nuclear weapons does not bring benefit to society, can it be argued that the risks associated with them are not ALARP and are unacceptable ?

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Annex A Recent submarine incidents

Board of Inquiry into the grounding of HMS Trafalgar on Fladda-Chuain on 6 November 2002

HMS Trafalgar was taking part in a submarine command course in the Fladda-Chuain chain North of Skye. Navigation aids had been deliberately concealed. This was done "to increase the degree of navigational difficulty and hence pressure on the students"[73]. There was confusion on the submarine as to who was formally responsible for navigation. The trainee in control was from a foreign Navy. He was using tracing paper which concealed some of the information on his chart. He did not properly take account of the significant tidal stream around Fladda-Chuain. As a result the submarine struck the bottom heavily at a speed of 14.7 knots.

The Board of inquiry concluded that HMS Trafalgar grounded because of human error. The Commanding Officer and the course teacher were both disciplined in a Court Martial. The inquiry report said "Although a safety organisation was in place [on the submarine] and had worked effectively up until then, it failed to operate when most needed".[74]

The report said that there was "good reason" for depriving the trainee commander of navigation aids and did not recommend that this practice should cease. Submarine Command Courses have continued to take place using nuclear submarines off the West coast of Scotland. The training deliberately places the trainees in difficult and confusing situations. The trainees control the submarine as they conduct a series of exercises some of which are at high speed and close to other vessels.

Board of Inquiry into the collision of HMS Tireless on 13 May 2003

HMS Tireless was carrying out an exercise in the Marginal Ice Zone when she hit the keel of an iceberg 60 metres below the surface.[75]

The submarine manual SMP 27 gave the false impression that an iceberg could be reliably detected by passive sonar. The crew of HMS Tireless assumed that this was correct and were relying on their passive sonar. This system gave no advanced warning of the iceberg which they hit.

After the collision withdrawal from the area was difficult because of the presence of a number of large icebergs in the area. For this reason some damage control checks were not carried out immediately.

The Navy required that specific training had to be carried out before a submarine was deployed under pack ice. But this did not apply to deployments in the Marginal Ice Zone. Fleet HQ had not considered the hazards of icebergs in this zone. No under ice training had been arranged for HMS Tireless for this deployment. The assessment on the vessel was that there was only a faint possibility of small icebergs with drafts not exceeding 30 metres. The submarine was operating relatively close to the surface because the area was poorly charted and there was a danger of running aground.

The Board of Inquiry conclusions includes the following:

"The focus of RN submarine environmental effort is in tactical exploitation and there was insufficient focus (HQ and on board) on the hazards to submarine safety presented by icebergs".[76]

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[73] Board of Inquiry into the Grounding of HMS Trafalgar on Fladda-Chuain on 6 November 2002, HMS Montrose, 12 November 2002, para 5.

[74] BOI Trafalgar 2002 para 30

[75] Board of Inquiry into the collision of HMS Tireless on 13 May 03, Faslane Flotilla, 5 June 2003.

[76] BOI Tireless 2003 para 26 g.

Board of Inquiry into an explosion on HMS Tireless on 20 March 2007

HMS Tireless was operating under the icepack when a Self Contained Oxygen Generator (SCOG) exploded killing two sailors and starting a number of small fires. A large part of the submarine, including the designated damage control headquarters, was out of action because of fumes. There was a delay of 44 minutes before access was gained to the casualties at the site of the explosion, and a similar delay before the submarine was able to surface at a gap in the ice 2 miles from the scene of the explosion.

Two major failings in submarine safety which can be deduced from the Board of Inquiry report are:

(1) It is difficult for the crew to respond to an explosion or fire on a submarine.

A large part of HMS Tireless including the Ward Room, which should have been the Damage Control Centre, could not be used because of fumes. Visibility was limited by smoke and inadequate emergency lighting. Communications after the accident were very difficult because the VHF radios were ineffective and piped messages could not be heard over the background noise. Messages were passed through the submarine by word of mouth.[77] A fire hose was deployed to the wrong room and the nozzle detached, making it unworkable. The team sent to control the fire did not feel competent to fight a fire in the particular circumstances they were faced with.

Submarines crews are not trained how to respond to an accident of this magnitude – "Neither the pre-deployment training package nor general FOST [Flag Officer Submarine Training] safety training exercises a scenario whereby such a large volume of the submarine atmosphere is out of specification from the outset."[78]

The fire on HMCS Chicoutimi in October 2004 should have alerted the Royal Navy to these problems - "Many of the DC&FF [Damage Control and Fire Fighting] lessons identified in the HMCS Chicoutimi incident in 2004 have been repeated in this incident".[79] 3 years later the Navy still failed to properly assess the likelihood of a large part of the submarine being out of action in a fire or explosion.

The report found that this accident could have been much worse - "The small fires caused by the explosion could easily have taken hold and a major conflagration ensued, with very serious consequences, if [name deleted] had not had the stamina and presence of mind to use all available means to extinguish them".[80] The sailor concerned was the one survivor from the compartment where the explosion occurred. He was seriously injured in the accident.

The ability of the crew to respond to a serious incident is a critical part of the risk assessment for a nuclear accident on a submarine. The problems identified in this report would suggest that the crew's ability to bring an incident under control may not have been properly evaluated in these risk assessments.

(2) The risk of an Oxygen Generator explosion had been ignored.

The inquiry report found that the SCOG had become contaminated with oil and that this was the cause of the explosion.[81]

Before the accident the MoD had commissioned a safety case into SCOGs. This had assessed that the contamination of a SCOG was "non credible", ie that it was "extremely unlikely to

[77] BOI Tireless 2007 para 48 & 49
[78] BOI Tireless 2007 para 214
[79] BOI Tireless 2007 para 268 x
[80] BOI Tireless 2007 para 8
[81] BOI Tireless 2007 para 16

occur during operational life of the unit".[82] Following the accident, tests were carried out on a sample batch of 258 SCOGs. 10.5 per cent were found to be contaminated with oil or grease.[83] "Extremely unlikely" is defined in JSP 538 as 1 in 10^9.[84] However the actual occurrence was 1 in 10.

The SCOG safety case did not consider the possibility of a SCOG exploding during operation. This omission was particularly concerning as the manufacturers' safety data sheet for SCOG had described the danger of an explosion resulting from contamination.

One of the Board of Inquiry's conclusions was - "There are many systematic failings that contribute to the TIRL explosion which can be collectively viewed as inadequate risk management of the hazard that SCOGs present".[85]

The inquiry report does not mention the implications of this for nuclear risk assessments. However it would be likely that this risk had not been considered in wider assessments of the risks of nuclear accidents on submarines.

Immediately after the explosion the Captain of HMS Tireless operated the Battleshort, overriding the reactor safety systems. This is a standard Emergency Operating Procedure [EOP]. The inquiry report explains – "The Battleshort switch overrides the automatic reactor protection and is made as part of the flooding EOP because it is deemed that the safety of the submarine cannot be jeopardised by a spurious automatic reactor shutdown".[86] In this case the flood warning was a false alarm triggered by the blast from the explosion. The Captain's ability to override the reactor safety system is a fundamental weakness in the safety regime for nuclear submarines and no equivalent system is permitted in civil facilities.

[82] BOI Tireless 2007 para 122
[83] BOI Tireless 2007 para 135
[84] JSP 538 Annex F page 6
[85] BOI Tireless 2007 para 268e
[86] BOI Tireless 2007 para 38 and footnote 65.

Annex B Application of Safety Assessment Principles (SAPs) for Civil Nuclear Facilities to submarines

The military requirements for submarines conflict with some of the engineering principles in SAPs. Some of these are listed below.

The quotes in italics indicate the difficulties applying each principle to nuclear submarines. These comments are taken from an HSE table that has the title "NRP ALARP constraints".[87]

<u>Design for Reliability: Redundancy, diversity & Segregation EDR.2</u>

"Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components important to safety"

"Limited redundancy, diversity and segregation of safety system" and *"Limited space on a submarine for passive (and active) engineered safeguards."* This is due to *"space limitations arising from small diameter of pressure hull"* and the *"high degree of cross-connection of systems"*

<u>External & internal hazards: Fire, explosion, missiles, toxic gases etc</u>

<u>- use & storage of hazardous material EHA.13</u>

"The on-site use, storage or generation of hazardous materials should be minimised and controlled and located so that any accident to, or release of, the materials will not jeopardise the establishing of safe conditions on the facility"

<u>– sources of harm EHA.14</u>

"Sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipes failure effects, or internal and external flooding should be identified, specified quantitatively and their potential as a source of harm to the nuclear facility assessed ... This identification should take into account: ... the adequacy of protection of the nuclear facility from the effects of any incident in an installation ..."

<u>– effect of water EHA.15</u>

"The design of the facility should include adequate provision for the collection and discharge of water reaching the site from any design basis external event or internal flooding hazards or, if this is not achievable, the structures, systems and components important to safety should be adequately protected against the effects of water."

<u>- fire detection and fighting EHA.16</u>

"Fire detection and fire-fighting systems of a capacity and capability commensurate with the credible worst-case scenarios should be provided."

<u>- use of material EHA.17</u>

"Non-combustible or fire-retardant and heat-resistant materials should be used throughout the facility"

"Limited ability to provide protection against fire and explosion hazards" in a situation of *"proximity of explosives and other high-hazard materials".* There is also *"extensive use of high pressure air and hydraulic systems".*

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[87] The Regulation of weapons and naval programme activity, Annex D Table 1 ALARP Constraints indicates how the naval programme relates to these principles. NRP – Naval Reactor Programme

Human factors: Task analysis

"Analysis should be carried out of tasks important to safety to determine demands on personnel in terms of perception, decision making and action."

"High 'shift' workload" because of the *"limited space for crew members"*

Key Principles: Defence in depth EKP.3

"A nuclear facility should be designed and operated that defence in depth against potentially significant faults or failures is achieved by the provision of several levels of protection".

"Limited space on a submarine for passive (and active) engineered safeguards."

Layout: Minimisation of the effects of incidents ELO.4

"The design and layout of the site and its facilities, the plant within a facility and support facilities and services should be such that the effects of incidents are minimised"

"Limited scope for minimising potential for interactions between safety-related plant and systems and failed structures against internal and external hazards."

Maintenance, inspection & testing: Reliability claims EMT.6

"Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components to safety in service or at intervals throughout plant life commensurate with the reliability of each item"

"Compact reactor plant layout with limited opportunity for significant in-service maintenance and inspection".

Reactor Core: Monitoring of safety-related parameters ERC.4

"The core should be designed so that safety-related parameters and conditions can be monitored in all operational and design basis fault conditions and appropriate recovery actions taken in the event of adverse conditions being detected."

"Limited ability to monitor core conditions during operation". The submarine has a *"highly reactive core"* and *"small reactor".*

Safety systems: Time for human intervention ESS.9

"The practice on UK civil nuclear power reactor facilities is that no human intervention should be necessary for approximately 30 minutes following the start of a requirement for protective action."

There is *"high reliance on operator intervention"* and the *"30 minute risk may not be applicable".*

Human Factors: Workspaces EHF.6

"Workspaces in which plant operations and maintenance are conducted should be designed to support reliable task performance, by taking account of human perceptual and physical characteristics and the impact of environmental factors"

"Limited space for optimising man-machine interfaces" and *"extensive remotely operated systems"*

Human factors: User Interfaces EHF.7

"User interfaces, comprising controls, indications, recording instrumentation and alarms should be provided at appropriate locations and should be suitable and sufficient to support effective monitoring and control of the plant during all plant states."

"Limited space for optimising man-machine interfaces" and *"extensive remotely operated systems"*

Human factors: Personnel competence EHF.8

"A systematic approach to the identification and delivery of personnel competency should be applied"

"High training demands on qualified staff"