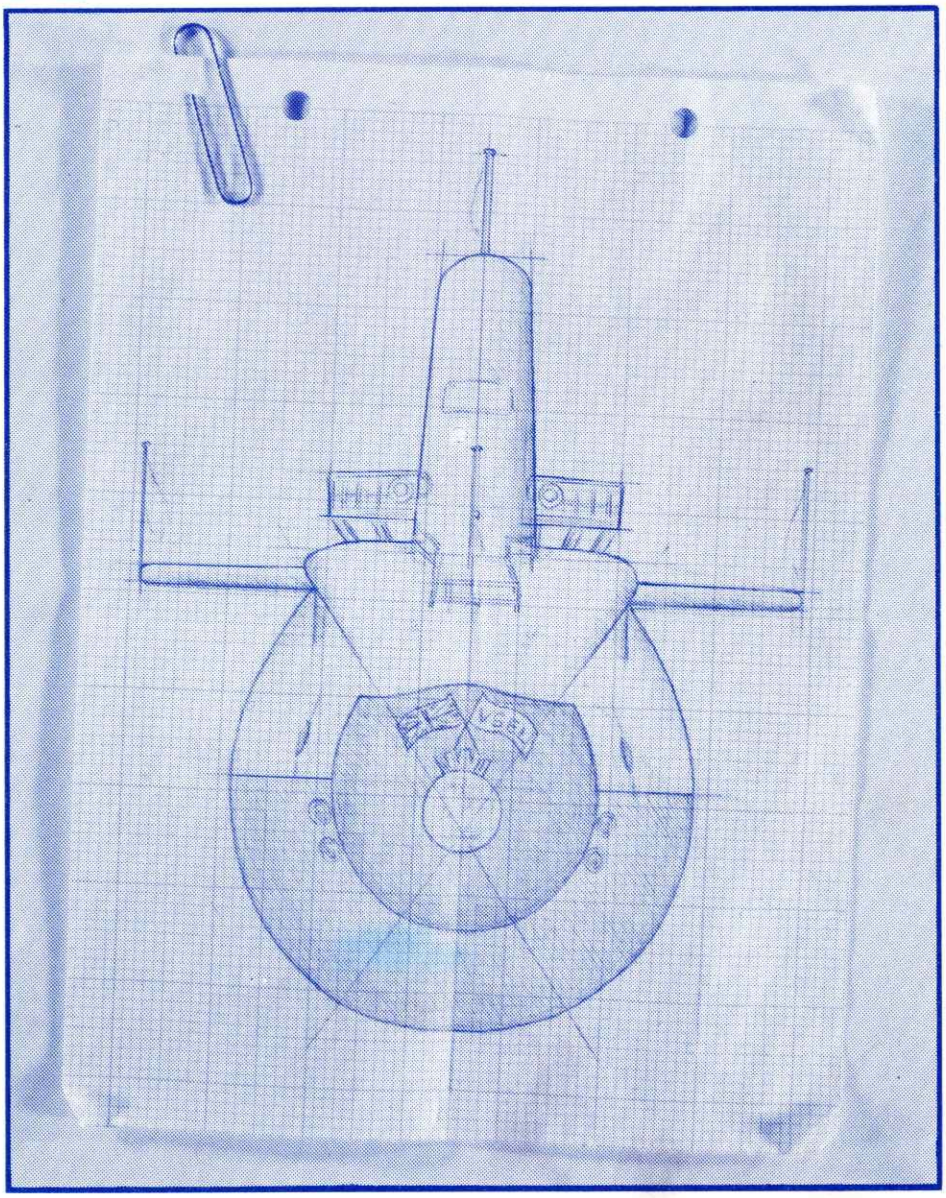
THE SAFETY OF TRIDENT



An assessment of the radiation risks associated with the UK Trident programme

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Scottish CND
February 1994

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INTRODUCTION

In a recent review of nuclear weapons safety the Chief Scientific Adviser at the Ministry of Defence noted that safety issues were compartmentalised and that there was a need for a general overview of the safety of the whole Trident system. If there has since been a review the details have not been made public. This report looks at the overall safety of the Trident programme. Consideration is given to the nuclear cycle from uranium mining to decommissioning and waste storage as well as to the risks and consequences of major accidents involing nuclear warheads or a submarine reactor.

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ABSTRACT

A major accident could occur on a Trident submarine, on which there is both a nuclear reactor and nuclear armed missiles. A reactor accident could be on a scale similar to the Chernobyl disaster. There could be an accident involving nuclear warheads during their assembly, transport or storage which would scatter plutonium dust over a wide area and subsequently induce cases of cancer. There are risks associated with the production of radioactive materials for the Trident programme. Large quantities of nuclear waste will be produced, some of which will remain a radiation hazard for thousands of years. The risks are both past, present and future. They affect a wide area within and beyond the UK and are particularly great around the Clyde Submarine Base.

John Ainslie
Administrator
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February 1994

ABBREVIATIONS

AWE	Atomic Weapons Establishment
BNF	British Nuclear Fuels
Bq	Becquerel
EAGL	Emergency Action Guidance Level
EHJ	Explosives Handling Jetty, Coulport
ERL	Emergency Reference Level
HSE	Health and Safety Executive
HEU	Highly Enriched Uranium
Hex	Uranium Hexafluoride
IAEA	International Atomic Energy Authority
ICRP	International Commission for Radiological Protection
MEA	Mechanical Engineering Artificer
MEO	Mechanical Engineering Officer
MoD	Ministry of Defence
MSU	Missile Service Unit
mSv	Millisievert
NII	Nuclear Installations Inspectorate
NRPB	National Radiological Protection Board
Pu	Plutonium
PWR	Pressurised Water Reactor
RBM	Re-entry Body Magazines
RBPB	Re-entry Body Process Building
RCT	Resin Catch Tank
RIM	Ready Issue Magazines
RNAD	Royal Naval Armaments Depot
RRA	Rolls Royce and Associates
RSPB	Royal Society for the Protection of Birds
RV	Re-entry Vehicle
SMCS	Submarine Manoeuvre and Command System
SRD	Safety and Reliability Directorate of the UKAEA
Sv	Sievert
TCHD Mk 2	Truck Cargo Heavy Duty Mark 2
UCTPs	Used Cores Transport Packages
UKAEA	United Kingdom Atomic Energy Authority
VSEL	Vickers Shipbuilders Engineering Limited

1. PRODUCTION AND DEVELOPMENT

The 3 main radioactive materials used in the Trident programme are uranium, plutonium and tritium. There are dangers associated with the production and handling of all three. Nuclear warheads are assembled using old facilities at Aldermaston and were tested at the Nevada test site. The submarine reactors are similar to a full scale prototype which operates in a Ministry of Defence (MoD) establishment at Dounreay. Figures 1 and 2 are flow charts which show the overall cycles for reactor cores and nuclear warheads including materials production.

1.1 URANIUM

Within the Trident programme uranium is used in 3 ways. Firstly, a Trident nuclear warhead may contain 10 - 20 kgs of Highly Enriched Uranium (HEU)[1]. Secondly, HEU is used as the fuel for submarine reactors[2]. Thirdly, uranium is used in magnox fuel for reactors which produce weapons grade plutonium for warheads. The total amount of natural uranium (0.7% U^{235}) required for the Trident programme is estimated at around 1,300 tonnes.

Mining

Natural uranium used in the British nuclear programme is imported from the US, Canada and Australia. A Nuclear Energy Agency report says "Uranium miners ... are routinely among the most highly exposed workers in the nuclear fuel cycle"[3]. Workers are exposed to gamma radiation and can breathe in uranium dust which emits alpha radiation. The general public can be exposed to radiation hazards from the "tailings" which are left from mining and there is a particular hazard from radon gas.

Conversion

The British Nuclear Fuels (BNF) site at Springfields is used to convert natural uranium into uranium hexafluoride (Hex). The Hex is used for both civil and military purposes. The main hazard during the production of Hex is from the toxic chemicals involved[4]. Springfields makes fuel rods for land based reactors and may play a part in fuel rod fabrication for submarine reactors. There is the potential for accidental criticality during fuel rod fabrication[5].

Enrichment

BNF Capenhurst is a uranium enrichment facility which is involved in the 3 aspects of uranium procurement related to Trident. Capenhurst has been used to produce HEU for use in nuclear warheads. It also enriches uranium for magnox reactors which produce weapons grade plutonium. Capenhurst is involved in the first stage of enrichment for submarine reactor fuel. The second stage is carried out at a plant in Portsmouth, Ohio, US, where the uranium is enriched to 95 - 97 %[6]. Around 1980 a new plant was proposed for Capenhurst which would be dedicated to military production and separate from civil facilities[7]. The main risk associated with enrichment is accidental criticality, "nuclear criticality is always a concern when working with enriched uranium"[8].

Reprocessing

Separation and processing of uranium is carried out at Sellafield. See Section 1.2.

FIGURE 1. TRIDENT REACTOR CORE FLOW CHART

uranium mining	Canada, US & Australia
conversion to uranium hexafluoride	Springfields
initial enrichment	Capenhurst
final enrichment	Portsmouth US
fuel rod fabrication	Derby
transport fuel rod modules	
PROTOTYPE	
1st core load	Dounreay
in operation	Dounreay
defuel reactor	Dounreay
transport used core	
store used core	Sellafield
2nd core load	Dounreay
in operation	Dounreay
defuel reactor	Dounreay
transport used core	
store used core	Sellafield
3rd core load	Dounreay
in operation	Dounreay
defuel reactor	Dounreay
transport used core	
store used core	Sellafield
SUBMARINE (x 4)	
1st core load	Barrow
in service	Faslane
defuel reactor	Devonport
transport used core	
store used core	Sellafield
2nd core load	Devonport
in service	Faslane
defuel reactor	Devonport
transport used core	
store used core	Sellafield
3rd core load	Devonport
in service	Faslane
defuel reactor	Devonport
transport used core	
store used core	Sellafield

Fuel fabrication

Rolls Royce and Associates (RRA) design and manufacture submarine reactors. Final fabrication of the fuel core modules for the Trident PWR 2 reactors is likely to take place at the RRA site in Derby.

1.2 PLUTONIUM

Plutonium is used in the Trident nuclear warhead. If each has 4 kg of plutonium then the total required is around 1.6 tonnes. Plutonium can be stockpiled for long periods of time. It can be removed from old nuclear weapons and after processing, reused in new nuclear weapons.

Production - graphite reactors

The original 2 graphite reactors at Windscale were established solely for the production of plutonium for nuclear weapons. Although they were closed in 1957 some of the plutonium produced there may be used in the Trident programme. Some of the plutonium will have been used, exploded in nuclear tests, but the remainder will have been recycled for use in successive generations of nuclear weapons, including Trident. The MoD has a programme for recycling over 90 % of the plutonium from old nuclear weapons[9].

On 20th October 1957 there was a major accident at the Number 1 Pile at Windscale. During a routine release of energy the reactor overheated and uranium and graphite caught fire. Fans were switched on to cool the reactor pile, but they actually made the fire more intense. The second reaction was to add carbon dioxide which also made the situation worse. The third solution was to flood the reactor with water. This was successful, but risky.

While the government claimed that the wind was blowing out to sea there was a temperature inversion and low level winds may have been blowing inland. A total of 14 workers were exposed to serious radiation doses[10]. The activity released from the chimney included 7.4×10^{14} Bq of Iodine ^{131}. A ban was placed on cows milk over a 520 km^2 area and it has been estimated that 95 people are expected to die from cancer throughout the UK between 1957 and 1997 as a result of the accident[11]. The official history of the event admits that it was inevitable[12].

During the fire polonium which is a dangerous, if short lived, alpha emitting radioactive isotope was dispersed into the atmosphere, however local authorities were not informed of its presence. Polonium was used as a trigger device in early nuclear weapons but this method soon became obsolete and by 1957 was regarded as outdated. In order to conceal the dependence of British nuclear weapons on polonium, the fact that it had been released at Windscale was kept secret[13].

Production - magnox reactors

Chapelcross and Calder Hall nuclear powers station each have 4 magnox reactors. The operators, BNF, have admitted that Calder Hall was built "with the primary function of manufacturing military plutonium"[14]. Chapelcross was built for the same reason with electricity production being secondary. These facilities were used to build up a stockpile of plutonium for the MoD and may have been used more recently to meet the requirements of the Trident programme. Plutonium is produced as a result of the fissioning of uranium during normal power generation in magnox reactors. In order to produce weapons grade plutonium the operating cycle of the reactor is adjusted to produce a higher proportion of Pu^{239}.

FIGURE 2 TRIDENT NUCLEAR WARHEAD FLOW CHART

MATERIALS PRODUCTION	Uranium Mining	Canada, US & Australia
	Conversion to Uranium Hexafluoride	Springfields
	Enrich to weapons HEU	
	Enrich to reactor grade	Capenhurst
	Early Plutonium Production	Windscale Chapelcross & Calder Hall
	Plutonium separation	Sellafield
	Early nuclear weapons	
	Removal of decay products	Sellafield
	Later Plutonium Production	Chapelcross & Calder Hall
	Plutonium separation	Sellafield
	Tritium production	Chapelcross
MANUFACTURE	Machine Plutonium pits	Aldermaston
	Machine HEU	Aldermaston
	non fissile parts	Cardiff, Burghf'ld & other sites
	Assemble fission device	Burghfield
	Add fusion component	Burghfield
	Transport to Coulport	
IN SERVICE	Store & load onto missiles	Coulport
	In service on submarine	Faslane, Coulport & at sea
	Unload/maintain/load	Coulport
	Unload from missiles	Coulport
SCRAP	Return to Burghfield	
	Dismantle	Burghfield
	Store Plutonium & HEU	Sellafield

There have been problems with the embrittlement of steel pressure vessels in magnox reactors operated by Nuclear Electric. Tests carried out at Risley on 6th October 1966 showed that a magnox pressure vessel could explode if it was subjected to temperatures higher than normal operating temperatures and if there were weaknesses in the structure. As a result Dr Irvine, a former employee of the Safety Division of the United Kingdom Atomic Energy Authority (UKAEA), has said that magnox reactors should be shut down[15]. While Chapelcross and Calder Hall use the same design, the Nuclear Installations Inspectorate (NII) has indicated that these reactors are less prone to the problem because of their particular operating regime. Nevertheless the likelihood of an accident may increase as the reactors become older. By 1994 Calder Hall will have been in operation for 38 years and Chapelcross for 36 years.

There was a serious incident at the Number 2 reactor at Chapelcross in 1967. The reactor had just been refuelled when it was discovered that the gas flow through one of the fuel channels was mechanically blocked. The fuel in the channel melted and must have been hotter than 1100° C. A major disaster was averted but the reactor was shut down for 2 years for repairs. At the time of the incident the reactor may have been about to produce plutonium for use in nuclear warheads. Some of the plutonium produced at this time will have been recycled for use in Trident nuclear warheads[16].

Unlike Chapelcross and Calder Hall, other magnox reactors were designed primarily for electricity generation, however they do have a secondary capability to produce weapons grade plutonium. Prior to 1967 it is likely that plutonium from some of these reactors was used to produce plutonium for military purposes. There has been speculation that reactors at Bradwell and Berkerley in particular may have been used in this way[17].

Reprocessing

Spent fuel from magnox reactors is taken into the B205 reprocessing building at Sellafield. From the spent fuel B205 separates plutonium and uranium. Some spent fuel consignments from Calder Hall and Chapelcross contain weapons grade plutonium. Military production has accounted for a significant proportion of the work carried out by B205 since it was opened in 1964. B205 is expected to continue to operate until beyond 2010[18].

In February 1986 there were a series of incidents at Sellafield which led to a Health and Safety Executive Inquiry. The inquiry found that, in B205, 17 % of equipment was substandard and there were defects in the ventilation system. The report said that "the condition of the B205 plant .. appears to us to have been subordinated to the requirements of current production"[19]. Almost half of 36 other buildings which were examined were found to be substandard. The report criticised attitudes to safety "the thoroughgoing and positive dedication to every aspect of safety that is characteristic of the best parts of the chemical industry has yet to be achieved"[20].

There are a wide range of hazards in reprocessing including the risk of criticality, dangers of fire, explosion and leaks. External factors such as weather and seismic events can lead to an accident. "The potential risk is increased by the fact that during all stages of the process the materials are in easily dispersible forms .. and are being subjected to sometimes vigorous chemical and physical reactions"[21]. There has been at least one occasion when there was a fire at Sellafield during decanning of fuel from magnox reactors in preparation for reprocessing[22]. A criticality incident occurred in a facility for recovering plutonium from residues at Sellafield on 24th August 1970 when flow stopped in a solution containing 2.5 kgs of plutonium [23]. On 26th September 1973 there was a substantial accidental release of radioactive ruthenium ^{106} from a facility for the initial treatment of oxide fuels at Sellafield[24].

There was also a facility within Sellafield which was designed to recycle plutonium from nuclear weapons. Weapons grade plutonium contains a proportion of plutonium^{241} which decays to americium^{241} an unwanted by-product. The building at Sellafield was designed to remove americium from plutonium from dismantled nuclear weapons. The plutonium would then be reused in other weapons. It has been reported that this facility closed in 1987 [25].

Concern has been expressed about some of the staff in the plant. Douglas Wilkinson, a clinical psychologist, was commissioned by the Senior Medical Officer at BNFL to look at staff at Sellafield. In his report he said that he found that some of the scientific staff were neurotic and incompetent. He said he was surprised "that such obviously unstable people were employed at the plant in the first place"[26].

1.3 TRITIUM

Tritium is an essential component of a boosted fission nuclear device, such as the Trident warhead. It is a gas with a radioactive half life of 12.5 years which decays at a rate of around 5.5% per year. It is believed that one nuclear test conducted by the UK in Nevada in 1974 was designed to test the effect of using aged tritium in a warhead. Initially tritium may have been procured from the US, subsequently a programme was initiated to produce tritium in the UK. Because it can only be stored for short periods there will be a programme to replace the tritium component in warheads every 7 - 8 years. If each warhead has 4 g of tritium then to keep 400 Trident warheads in service for 30 years would require around 4.8 kg of tritium.

In 1976 BNF was awarded a contract by the MoD to produce tritium at Chapelcross[27]. There are 3 stages in production: the production of lithium 6 targets, the irradiation of lithium in the reactor to produce tritium and the subsequent processing. Since 1980 Chapelcross has had special facilities for this 3 stage operation.

Figure 3. These vehicles are used to transport radioactive materials across Britain. The two in the photograph drove from Coulport through Helensburgh on 11th August 1993 under UKAEA Police escort and were probably transporting Tritium.

Chapelcross was due to be decommissioned but this has been delayed until 2004, probably so that the MoD can retain a tritium production capability[28]. There are fears that BNF may have plans to build another reactor capable of producing tritium at Chapelcross although at the moment the proposals are for a PWR reactor which would not be suitable. The US has a facility to remove decay products so that the remaining tritium can be reused but there is no equivalent in the UK An alternative approach to the long term supply of tritium would be to build up a large stockpile of tritium and then use US facilities to process this to remove decay products. This would mean increased production of Tritium at Chapelcross prior to 2004.

Discharges of tritium to the atmosphere from Chapelcross are higher than from other UK power stations. In Canada there is a reactor at Pickering which also discharges a large amount of tritium. There is concern that this may be the cause of birth defects in the area. In 1990 discharges of tritium from Pickering were 9×10^{14} Bq, while discharges from Chapelcross were twice as much, 1.9×10^{15} Bq. It has also been suggested that tritium could be a factor in the high incidence of birth defects around the Hanford nuclear site in the US and may be a source of other health problems near nuclear installations. The radiation from tritium is regarded in the nuclear industry as a minor problem, however dangers of the beta emissions from tritium may have been underestimated by the International Commission on Radiological Protection (ICRP) [29]. The Health and Safety Executive (HSE) report into Sellafield and leukaemia found a correlation between incidence of childhood leukaemia and the father's exposure to tritium during his work at Sellafield [30].

1.4 WARHEAD PRODUCTION

The Atomic Weapons Establishment (AWE) Aldermaston has been involved in the development of the Trident warhead since the mid 1970s with the main development period being from 1980 to 1987. This work has included the manufacture of warheads for tests in Nevada. Production of plutonium pits for Trident warheads began in January 1988 and has continued for 6 years using old facilities[31]. The A1.1 building which is vital for this production was first operational in 1952. Production is continuing in A1.1 and A45 until the new A90 plant is fully commissioned.

Following staff concern about radioactive contamination on site, a major investigation was carried out into safety at Aldermaston in 1978. The Pochin inquiry discovered that the levels of radiation monitored in many parts of the site, including plutonium processing facilities, were considerably higher than ICRP limits. Incidents of health problems among workers were also discovered, which could be attributed to their work with radioactive materials. The inquiry recommended that new facilities were needed[32]. There was also a need for new buildings because the old A1.1 and A45 buildings were not able to produce warheads fast enough to meet the demands of the Trident programme. Because of a series of delays the new building, A90, was not ready when production of plutonium pits began in 1988. Initial delays meant that the MoD decided to start Trident production in the old buildings and to continue producing the first batches of warheads until 1992. In early 1994, A90 is still not fully commissioned and A1.1 and A45 continue to be used 15 years after they were criticised for inadequacy by the Pochin inquiry. Peter Jones, who was director of Aldermaston until 1987 has said that these old facilities should never have been used at all for Trident production, because of concerns about their safety[33].

Aldermaston is involved in a wide range of work related to nuclear weapons research and production. It is involved in recycling old nuclear warheads and may take over the task of removing decay products from old warheads, which was done at Sellafield.

Other sites involved in warhead production include the UKAEA establishment at Harwell which may carry out some work on plutonium and AWE Cardiff[34]. The work at Cardiff involves handling beryllium which is a serious toxic hazard. The danger is that workers and members of the public could inhale particles of beryllium dust. Cardiff also carries out work o depleted uranium for the tampers of nuclear warheads. This also creates a radiation hazard. I 1983 AWE Cardiff was authorised to store 50 tonnes of natural or depleted uranium[35].

1.5 WARHEAD TESTS

The development programme for the Trident warhead included a number of tests which were conducted in the Nevada desert. The local people of the Western Sheshone Nation have been exposed to radiation with consequent health problems as a result of decades of nuclear tests. While these tests were conducted underground, they have contributed to the radioactive contamination of the area.

The Chief Strategic Systems Executive at the MoD, Rear Admiral Irwin, said in March 1993 - "There have been, I think, three - I wait to be corrected - specific tests to Trident"[36]. Between January 1980 and December 1987 the MoD carried out 11 underground nuclear explosions in the Nevada test site. Some of these may have been final tests of Chevaline warheads and others related to the development of a warhead for the Tactical Air to Surface Missile. At least three will have been specific Trident tests. Information obtained from other tests will have been used in the development of the Trident warhead.

1.6 REACTOR DEVELOPMENT

The MoD have a Naval Reactor Test Establishment at Dounreay. Known as HMS Vulcan the facility is operated by Rolls Royce and Associates who design and build Britain's submarine reactors. The prototype PWR 2 reactor at HMS Vulcan was handed over to the MoD in October 1987[38]. This type of reactor is only used on Trident submarines. The prototype will be used to test how the reactor functions through a simulated core life with probably 3 cores over a period of 20 - 30 years. There are hazards associated with the operation of this reactor, similar to many of those which affect submarine reactors, which are detailed in Sections 3 and 4.

1 *Enriched to up to 93.5 %, T Cochran et al, Nuclear Weapons Databook , Natural Resources Defence Council, Ballinger, 1984 Vol2 p 125 .*

2 *ibid.*

3 *NEA, The Safety of the Nuclear Fuel Cycle, OECD 1993, p81*

4 *ibid p86*

5 *ibid p93f*

6 *In 1980 it was planned that part of the HEU requirement for Trident would be produced at Capenhurst and a second part procured from the US. In 1982 the plan was altered to a two stage process using both Capenhurst and Portsmouth Ohio. Hansard 23/6/82 c128, the plan remained in force in 1993, Hansard 23/7/93 c127.*

7 *Hansard 23/6/82 c128.*

8 *NEA op cit p91.*

9 *Progress of the Trident Programme, House of Commons Defence Committee, HC 374 88 .*

10 *New scientist 7/1/88 .*

11 *D Summers et al, Rad ation risks , Tarragon Press, 1987, p174.*

12 *L Arnold, Windscale 1957, Macmillan, 1992.*

13 *In the 1950s it was proposed that a trigger device be tested in an nuclear test at Wick. This test would have used polonium. It was later carried out in Australia.*

14 *Guardian 17 /10/86.*

15 *Listener 17/7/86.*

16 *Don Arnott "Could it Happen Here" p 6, Chernobyl's Legacy - the lessons for the UK, National Steering Committee of Nuclear Free Local Authorities March 1992.*

17 *"Sellafield & the bomb" TV Eye, 30/3/86.*

18 *NEA op cit p110f.*

19 *Daily telegraph 12/12/86.*

20 *ibid.*

21 *NEA op cit p112.*

22 *ibid p119.*

23 *At the time called Windscale, ibid p204*

24 *At the time called Windscale, ibid p210*

25 *The UK Trident Programme, BASIC Report 93.5, p20*

26 *Guardian 11/2/86*

27 *D Campbell, The unsinkable aircraft carrier, Michael Joseph 1984, p107.*

28 *House of Commons Defence Committee, HC 50 88/89.*

29 *Ian Fairlie, Tritium the cause of leukemia, Safe Energy, Oct/Nov 92, p12]*

30 *Sellafield and Leukemia, HSE, Oct 93.*

31 *Progress of the Trident Programme, House of Commons Defence Committee, HC 374 88-89 p2.*

32 *Aldermaston - Inside the Citadel, Greenpeace, 1993*

33 *Secrets of the citadel, Panorama, BBC, 14/6/93.*

34 *Safe energy Dec 91/Jan 92 p17.*

35 *New Statesman 14/10/83*

36 *Progress of the Trident Programme, House of Commons Defence Committee, HC 549 92-3 p9.*

37 *T Cochran et al op cit.*

38 *Progress of the Trident Programme, House of Commons Defence Committee, HC 422 87-88 pxv.*

Assuming that the stockpile target is 400 Trident warheads, then the assembly bays at Burghfield will be used on at least 800 occasions for assembly and dismantling. If the warheads had to be returned for modifications then this would rise to 1600 operations. This suggests that there is a significant chance of an explosion which would disperse plutonium. Despite the protection provided by the assembly bay design there would be a major health risk to personnel within the establishment and to the local population downwind of an accident.

During assembly the tritium element is added. In a handling accident there could be a release of tritium which would be a serious problem for those in the immediate vicinity and a health hazard for the local population.

2.2 TRANSPORT

Once assembled, Trident warheads are stored temporarily on site. Later they are placed into containers and loaded onto lorries which travel in convoy to the Royal Naval Armaments Depot (RNAD) Coulport. From November 1992 to December 1993, these convoys of 3 to 5 lorries, plus escort, were making this journey once a month. On most occasions they took 3 days to travel from Burghfield to Coulport. The convoys normally passed London on the M25, on the M1/A1 to Newcastle then either West to the A74 or North around Edinburgh. All Trident convoys in 1992 and 1993 travelled through the centre of Glasgow on the M8.

Loading

Trident warheads are moved in containers which may measure around 3 m in length and 1.5 m in height and width[3]. Monitoring of the procedures for loading and unloading Chevaline warheads at Coulport gives grounds for concern. Chevaline containers are tied down inside the vehicles within 1 or 2 minutes after which the back door is closed and not opened again until the vehicle arrives at its final destination. Fixing of the container appears to be done without any lighting inside the vehicle. This suggests that procedures for checking and double checking tie down arrangements on Chevaline containers may not be sufficiently rigorous. The same may apply to Trident warhead containers.

If containers are not correctly tied down then the consequences of a minor road accident could be very serious. In a collision one container could be propelled into the second container in the trailer or into the trailer walls.

Vehicles

Nuclear warheads are transported within special articulated vehicles built by Foden, the Truck Cargo Heavy Duty Mark 2 (TCHD Mk2). It has been established by Nukewatch that each vehicle can carry 2 Chevaline containers. Similar vehicles are being built for Russia and the dimensions of the containers for Russia suggests that they will also have a maximum of 2 containers in each vehicle. Nukewatch has observed procedures within Coulport which suggest that 2 Trident containers can be carried in each vehicle.

The vehicles are built to a special design. Foden normally supply 3 axle tractor units for articulated lorries. The TCHD Mk 2 tractor units have 4 axles, 2 of which are steering axles. The additional axle is needed because of the exceptional weight of the vehicles, 48 tonnes. This is the Gross Train Weight of tractor plus trailer and is visible on the vehicle plates.

2. WARHEAD ASSEMBLY, TRANSPORT & STORAGE

The Deputy Controller (Nuclear) at the MoD, Mr Beaver, told the House of Commons Defence Committee "The circumstances seen by a weapon which could make it unsafe are varied and complex"[1]. When on the submarine the hazards are related to the overall safety of the vessel. This is discussed in Section 3. This section looks at the risks associated with the assembly, transport by road, and storage of warheads.

2.1 ASSEMBLY

British nuclear weapons are assembled at the Atomic Weapons Establishment Burghfield where work goes on around the clock. The procedures probably mirror those carried out at the US nuclear weapons assembly site, Pantex. At Pantex there are many sub-assembly bays where explosives are worked and shaped and a smaller number of main assembly bays where the explosives are placed around the fissile material. It is at this second stage that an accidental detonation of the explosives would lead to a release of plutonium. The main assembly bays at Pantex have 2-ton blast doors and the roofs are covered in 6 m of gravel [2]. This gravel is there to absorb some of the plutonium which would be dispersed in an accident. The conspicuous large half-domes at Burghfield may be of a similar design.

Every Trident warhead will be assembled at Burghfield. They are also expected to be dismantled here when they are retired. If there are problems with the weapons while in service the whole stockpile would have to be taken back to Burghfield, modified and reassembled - this happened in the 1980s with Chevaline warheads.

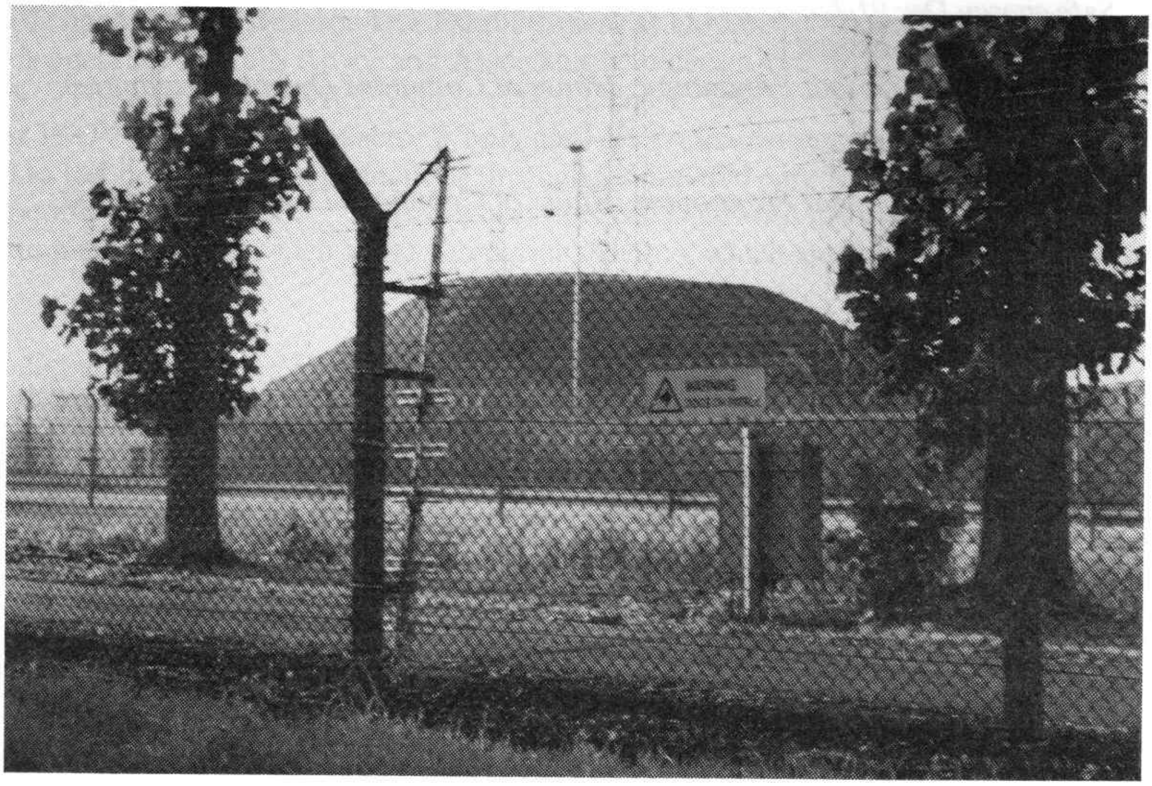


Figure 4. AWE Burghfield. This photograph shows one of the half-domes inside which nuclear weapons are assembled.

The first convoy of Fodens to Coulport in July 1992 broke down on the return journey. Since then there have been a series of mechanical problems. On 8th November 1992 smoke was seen coming from the rear axle of a carrier when it made an unscheduled stop on the A68 near Consett - local people were warned to stay out of the way because of dangerous fumes. An MoD spokesman has said that on a number of occasions brakes have overheated and that there was "a problem of brake adjustment between the tractor and trailer elements of the vehicle"[4]. The heat generated by the brakes could result in a fire which could engulf the nuclear warheads. Poor synchronisation of tractor and trailer brakes might also result in a vehicle crashing out of control.

Figure 5. Trident warhead carrier on the exit ramp of the Erskine Bridge after it had broken down on 18th May 1993.

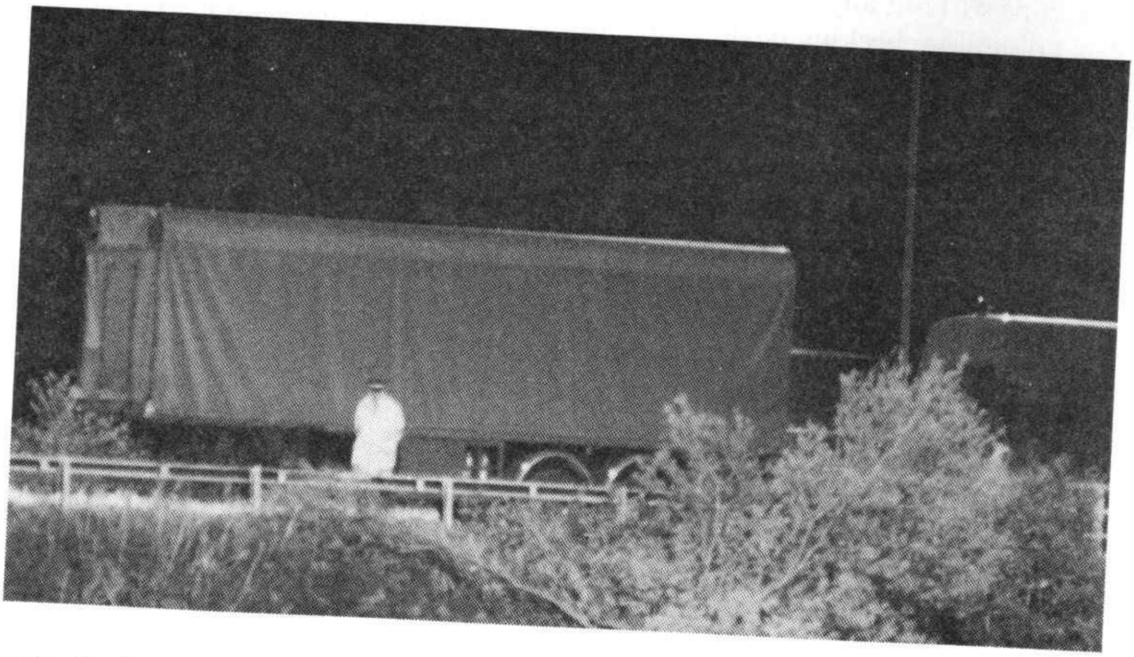


Figure 6. Trailer containing Trident warheads at the exit ramp from the Erkine Bridge while tractor units were being exchanged on 18th May 1993.

In the early hours of 18th May 1993 a convoy delivering Trident nuclear warheads left Burghfield. Instead of the usual 3 day journey, the convoy was attempting to travel all the way to Coulport in 1 day. The tractor units of one Foden broke down completely at the A82 exit from the Erskine Bridge, West of Glasgow. It was eventually towed away and replaced. During the change over the trailer, probably carrying two Trident warheads, was supported by the trailer props. Observation of practice at Coulport suggests that at no time is a tractor unit changed over while the trailer is loaded. At the time of the incident the trailer unit was in a dangerous position on the side of the road above a steep embankment. The convoy finally arrived at Coulport at 1 am on 19th May. The spare tractor unit may also have broken down earlier in the day as it was 2 hours late arriving on the scene.

During this incident a second carrier was in a dangerous position on the main road. Rather than split up the convoy, the remaining vehicles pulled into an adjacent lay-by. As this was too small to take the whole convoy, one vehicle, carrying Trident warheads, was parked in one lane of the A82, the main road North West from Glasgow.

There have been two further occasions when tractor units have been changed by the side of a road, once on the A1 and once on the M25. In all three of these incidents the problem was with the tractor unit. If there was a problem with the trailer this would have created even more difficulties. If the trailer was immobilised, then the Trident nuclear weapons would have to be moved into another vehicle. Such a transfer of nuclear weapons between carriers did take place when a convoy of old Mammoth Major carriers broke down on 1st December 1991. The M25 was closed and a crane was brought in to lift the nuclear weapons from one vehicle to another.

Convoys

The fact that nuclear weapons carriers travel in large convoys increases the risk of them being involved in an accident. They are bunched together with a large escort for reasons of security, not safety. The abnormal flow of traffic which this creates can lead to accidents. On one occasion there was a crash on the A814 near Faslane when a driver was distracted by a convoy travelling in the opposite direction. He collided with the car in front. In February 1993 a police car escorting a convoy caused a road accident on the M8 in the centre of Glasgow.

Nuclear weapons convoys are escorted by between 4 and 6 motorcycles driven by RAF police, MoD police and civilian police which are frequently redeployed from one end of the convoy to the other. Motorcycles are more likely to be involved in accidents than other vehicles. Observers from Nukewatch once saw a motorcycle escorting a convoy swerving wildly on the M8 in Glasgow when it had a burst tyre. On 11th August 1993 an outrider was seriously injured in a collision on the A1 near Alnwick. The initial police description of the incident was that the motorcycle had veered across the road, although later accounts suggested that the collision was caused by a skip lorry travelling in the other direction.

One of the more serious accidents in which a weapons carrier could be involved would be a collision with a fast moving heavy lorry. Convoys transporting Trident warheads consist of between 3 and 5 carriers each with gross vehicle weight of 48 tonnes travelling at 50 mph. The other weapons carriers in the convoy present a serious hazard. One collision between two Mammoth Major warhead carriers took place on 25th June 1985 in the middle of Helensburgh. One vehicle braked suddenly and the carrier behind collided with it - the rear vehicle was damaged and had to be towed back to Coulport.

Normally if a lorry driver suspects he has a problem he will pull off the road onto the hard shoulder, or into a lay by. In the same circumstances the driver of a nuclear weapons carrier has to contact the convoy commander by radio who then arranges for the whole convoy to stop. This must make it less likely that a vehicle will stop if there is a minor problem.

Off-road accidents

A carrier could be badly damaged if it went off the road and collided with the abutment of a motorway bridge or if it fell from a high embankment. All Trident nuclear weapons delivered to Coulport in 1992 and 1993 were transported over the Erskine and Kingston Bridges in Glasgow. There is serious concern about the structural stability of the Kingston Bridge and officials are considering diverting Heavy Goods Vehicles (HGVs) off the bridge when the flow of traffic is very heavy. The Fodens in a Trident convoy have a combined weight of 240 tonnes and often cross this bridge, which is in the centre of the city, during the early evening rush hour. There have also been a number of serious accidents when HGVs have fallen off this bridge which is the busiest river crossing in Europe. Elsewhere in Britain there has been an accident in which a nuclear weapons carrier went off the road. On 10th January 1987 a Mammoth Major nuclear weapons transporter slid off an icy road and landed on its side in a ditch near Dean Hill in Wiltshire. Trident warheads have been transported in dangerous weather conditions in the middle of Winter.

Collisions involving other road users

However well trained the Foden drivers are they can still find themselves caught up in an accident because of the behaviour of other road users. On 17th September 1988 on the A303 Illminster bypass an MG sports car crossed the road and collided head on with a Mammoth Major nuclear weapon transporter. The driver of the MG was killed and petrol from the car spilled around the Mammoth Major but did not ignite. The carrier ended up inches from a steep embankment.

A convoy transporting Trident warheads has been observed on one occasion travelling on the same stretch of the A74 as a vehicle carrying a large quantity of commercial explosives. Convoys are frequently on the same roads as tankers carrying petroleum products and highly inflammable chemicals. There has been one recorded incident where a fire engine was called to deal with a diesel tanker when smoke was coming from its overheated brakes on the approach road to Coulport - a convoy had been expected to leave at around this time, but did not leave until 24 hours later.

Gas mains

In June 1983 a gas main exploded in Cardross shortly after a nuclear weapons convoy had passed. The gas main may have been weakened by the weight of the Mammoth Major carriers. At 48 tonnes, the Fodens used to transport Trident warheads are over the maximum weight limit for HGVs. There is a risk that 4 or 5 of these vehicles travelling in convoy could weaken a gas main in the future and cause a very dangerous explosion.

Probability of transport accidents

The examples above illustrate that between 1982 and 1992 there were occasions where nuclear weapon transporters were involved in fatal accidents, when there were collisions between transporters and when vehicles crashed off the road. Similar accidents are likely to occur in the large number of journeys required to transport Trident warheads to and from Coulport.

National and international regulations

The Director of HSE has said that nuclear weapons must be transported in a way which complies with International Atomic Energy Agency (IAEA) guidelines[5]. He has also said that arrangements do comply with the guidelines, in that the packaging of nuclear weapons takes account of the explosive properties of the consignment. However the IAEA is concerned with the peaceful uses of nuclear energy and has said that these guidelines should not be used to prove the safety of nuclear weapons transport [6]. The guidelines were not drafted with nuclear weapons in mind and cannot be used as a basis for any safety case.

The provisions in the guidelines are intended to take account of the explosive properties **inherent** in some civil consignments of radioactive material. They do not permit a package of explosives to be in contact with a package of radioactive material - "packages ...shall be segregated during transport ... from other dangerous goods"[7]. The explosive properties of a nuclear weapon are not inherent in the radioactive material but come from the deliberate combination of radioactive and explosive components. To comply with the guidelines these components would have to be segregated - but they are not.

The guidelines also say that "Fissile material shall be packaged and shipped in such a manner that subcriticality is maintained under conditions likely to be encountered during normal conditions and in accidents"[8]. A ball of plutonium surrounded by high explosive in a format designed to create a supercritical mass would not be permitted if it was a civil consignment.

The transport of explosives alongside radioactive material is contrary to British regulations, however there is an exemption for "instruments of war"[9]. A nuclear weapon is no safer than an identical package which was being transported in the civil industry. Neither these regulations nor the IAEA guidelines can be used to argue that nuclear weapons are being transported safely. On the contrary, they show how safety considerations are secondary to political concerns. The MoD is allowed to do what, on safety grounds, is illegal in the civil nuclear industry.

2.3 STORAGE

When the transporters carrying Trident nuclear warheads arrive at Coulport they are parked in an open car park which is dominated by two lightning conductors. The vehicles are then taken one at a time to a transfer facility where each container is loaded into a large black box. This black box is probably designed to provide a controlled environment for the warheads. It is assumed that the warheads are normally stored in Re-entry Body Magazines (RBMs) although some have been seen in the Ready Issue Magazines (RIMs) which are designed to hold loaded missiles. At their peak the RBMs could contain 200 Trident warheads. It is assumed that this magazine area is designed to limit warheads exploding one after the other with a domino effect, nevertheless a major fire could engulf a large number of nuclear warheads. An investigation into safety at the Polaris compound in Coulport has shown that fire engines are called in almost once a week. Assuming that 75 % of these are false alarms there may still be a real fire alert around once a month.

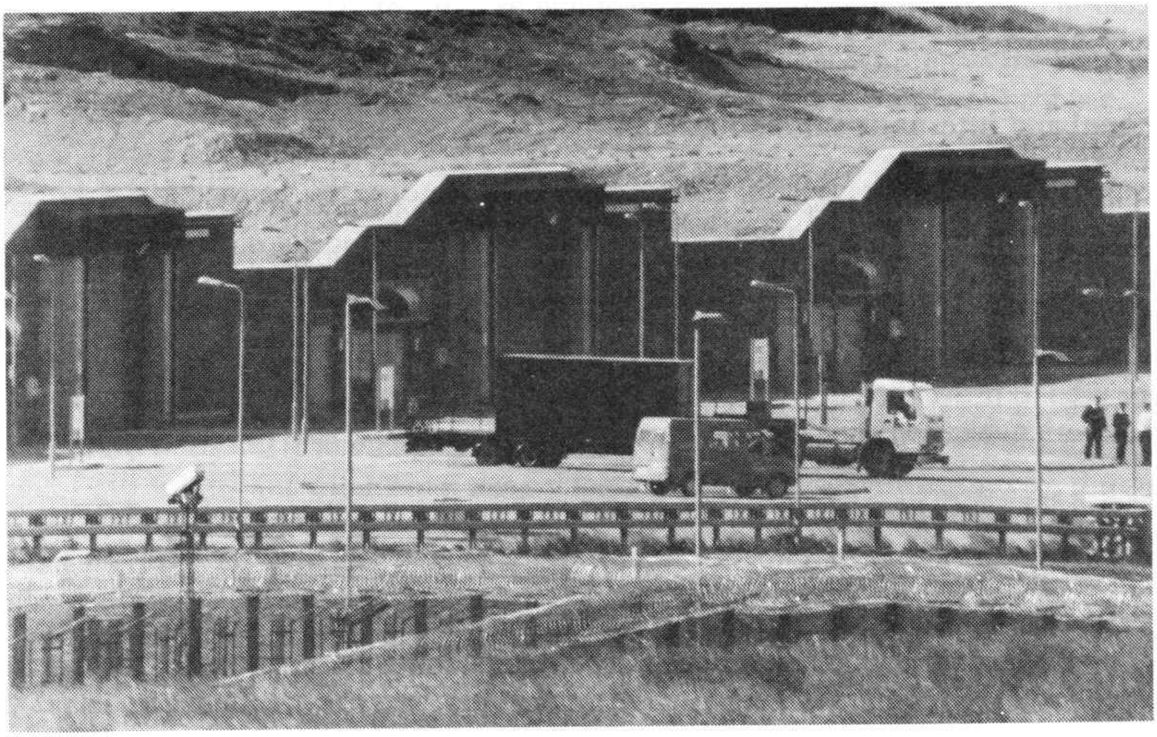


Figure 7. The large black container being taken into the RIMs bunkers at Coulport on 27th June 1993 probably contains a Trident nuclear warhead. The container came from an area where Foden transporters were being unloaded.

Warheads will be transported around Coulport from the RBMs to the Explosives Handling Jetty (EHJ) where they will be fitted onto missiles. The dangers in this operation are considered in section 3.4.

There is a Re-entry Body Process Building (RBPB) at Coulport which will carry out inspection of warheads and basic maintenance. An MoD spokesman has said "there are some lifed items within the warhead and they will need to be refurbished"[10]. One of the components which needs to be replaced every 7 or 8 years is the tritium element and the work will probably be done in the RBPB. With a stockpile of 400 warheads in service for 30 years, tritium replacement may be carried out 1200 times. This involves removing warheads from their containers and taking off at least the nose cones. In the event of a handling accident it is possible that the explosive in the warheads could detonate. A fire within this building might also have very serious consequences.

On 2nd May 1986 a container was being opened in the Polaris area at Coulport when radiation alarms went off - the container may have contained tritium. While there were no casualties from this incident, a more significant release could endanger workers and could result in radioactive material being dispersed into the atmosphere[11].

The RIMs at Coulport are designed to hold 16 Trident D5 missiles with warheads attached. The MoD state that this capability is not required on a regular basis, but might be needed if a Trident submarine had to be taken to Devonport for an emergency docking[12]. The MoD have also said that there could be other occasions when a smaller number of missiles will be removed for operational reasons[13]. The dangers of a missile accident are discussed in Section 3.1 and 3.4.

The RIMs are designed to prevent the detonation of one missile setting off all the adjacent missiles in a domino effect. However the MoD has had great difficulty in meeting this criteria with the reinforcement configurations for the bunkers being changed on several occasions and the contractors finding great difficulty meeting them[14].

In addition to handling Trident warheads and missiles, there are other explosives at Coulport. The depot will continue to maintain and store Polaris missiles and nuclear warheads until they are withdrawn, around 1998. Coulport also has a contract to service Tigerfish torpedoes. An accident at the Soviet Naval Ammunitions Depot at Severomorsk showed how dangerous it can be to have large quantities of explosives and missiles in the same place. In May 1984 there was an explosion in a conventional ammunitions magazine which set off sympathetic detonations in a weapons store and in an area where missile fuels were stored. Approximately 200 people were killed and one third of the surface to air and cruise missiles of the Soviet Northern Fleet were destroyed[15].

An accident could occur at any point during the handling of nuclear warheads within Coulport. While the greatest risks are probably at the EHJ and in the RBPB, an accident could occur during unloading, storage or transport within the depot.

The effects of a warhead accident are discussed in section 5.

1 *Progress of the Trident Programme, House of Commons Defence Committee, HC 549 92-3 p10 .*

2 *T Cochrane et al, op cit, Volume 3 p78.*

3 *Containers for Chevaline warheads consist of an inner cylinder approximately 1 m in diameter and 2.5 mlong. The cylinder is held within a structure of tubular metal which is around 3 m long and 1.5 m high and wide. Chevaline containers are lifted using 4 points, one on each corner. Containers which Britain is supplying for tranporting Russian warheads are 3.5 m long and more than 1.6 m high and wide. They weigh 3 tonnes when empty and have 8 tie down points, 4 on each side. AWE News Apr 1993 p6. Containers used for Trident warheads are likely to have similarities with the Chevaline and Russian containers.*

4 *N Whitney, Director Nuclear Policy and Security, MoD, 10/3/93, Progress of the Trident Programme, House of Commons Defence Committee, HC 549 92-93, p18.*

5 *letter to SCND from JD Rimmington, Director, HSE, 27 /8/3*

6 *letter to SCND from HA Selling, Nuclear Safety Division, IAEA, 15 /11/3*

7 *Regulations for the safe transport of radioactive substances, Safety Series 6, IAEA, 1985, para 460*

8 *ibid, para 562*

9 *Radioactive Substances (Carriage by Road)(GB) Regulations 1974 (No 1735) Section 6*

10 *The Progress of the Trident Programme, House of Commons Defence Committee, HC 374 88-89 p6, Mabberley 21/3/89.*

11 *Safe in our hands, SCND/Faslane Peace Camp, 15/7/93.*

12 *This did arise in the case of HMS Resolution which went to Rosyth in 1987, between refits.*

13 *MoD response to representations relating to its proposed development of the CSB June 1985 para 20.*

14 *MoD have "seen off the best of steel fixers and joiners", Contract Journal, Dec 91, p6*

15 *Glasgow Herald 14/9/84*

3. TRIDENT SUBMARINE

This section looks at the dangers which are inherent in operating nuclear powered and nuclear armed submarines. It considers the principal concerns of reactor and missile safet and the basic issues of human error and computer failure. There are risks from collisions, fires, torpedo explosions and systems failures. There are particular hazards related to missi loading, warhead loading, the Faslane shiplift and reactor defuelling.

3.1 PRINCIPAL CONCERNS

Reactor

The introduction of nuclear powered submarines into the US Navy was at the initiative of Admiral Hyman Rickover, who was recognised as the father of the nuclear navy. He play a key role in the introduction of nuclear power to submarines in the British fleet. In his later years Admiral Rickover became a strong critic of the project on which he had spent a large part of his life. He told the US Congress that the world would be a safer place if the whole nuclear navy was sunk.

There are fundamental problems with the safety of nuclear reactors on submarines. Containment is limited to that provided by the submarine's hull and bulkheads. The safet of the reactor can be compromised if something goes wrong elsewhere on the vessel.

British Trident submarines are powered by a pressurised water reactor, the PWR 2. The reactor provides power both to propel the vessel, support submarine systems and operate the reactor cooling pumps.

Reactor problems

A reactor accident could occur as a consequence of an incident elsewhere on a submarine, as a result of problems within the reactor itself. With regard to problems within the reacto one of the main dangers with a pressurised water reactor is if cold water is suddenly introduced into the coolant circuit. This may happen if there is a slug of cold water due to uneven flow in the primary circuit or if the steam generators remove too much heat. Cold water can speed up the nuclear reaction.

Older British submarines are powered by the PWR 1. There is a design problem affecting this type of reactor. Hairline cracks have been found where the primary coolant pipework joins the reactor pressure vessel and where it joins the steam generators. This defect led to the decommissioning of 2 submarines and was a factor in the decommissioning of 3 others. The refit of HMS Renown was extended from 2 years to 5 years for the same reason[1]. The cause of the problem has been identified as the water chemistry in the coolant system however this was not fully understood until late 1992. By this time construction of the firs Trident submarine, HMS Vanguard, had been completed. So the defect could also affect the PWR2 reactor used on Trident submarines.

The PWR 1 reactor uses hafnium control rods and it is assumed that these will also be used in the PWR 2. Hafnium can buckle and distort under certain conditions. Smooth operation of the control rods is vital for safe reactor operations.

PWR1 reactors have been involved in a number of incidents around the time when the reactor was being made critical. When the reactor is shut down at Faslane electricity is supplied from the shore, both AC and DC supplies are needed. On several occasions there have been fires and other incidents when supplies were switched from shore to submarine.

When at sea, a sudden loss of power could result in the submarine going into an uncontrolled dive. For this reason the Captain has a switch which carries out a "battleshort". This overrides reactor safety mechanisms and prevents an automatic shutdown. If the "battleshort" is used when there is a reactor problem, it could lead to a major accident.

When a reactor has shut down it cannot be immediately restarted. At the time of shut down there is a build up of xenon^{135} which inhibits attempts to restart the reactor. Xenon^{135} has a half life of 9.2 hours and there can be a delay of up to 3 days before the reactor will start up again. The start up procedure requires considerable power for the pressuriser and coolant pumps. If the shut down occurs at sea then the submarine becomes dependent on auxiliary power supplies both to maintain submarine systems and to restart the reactor.

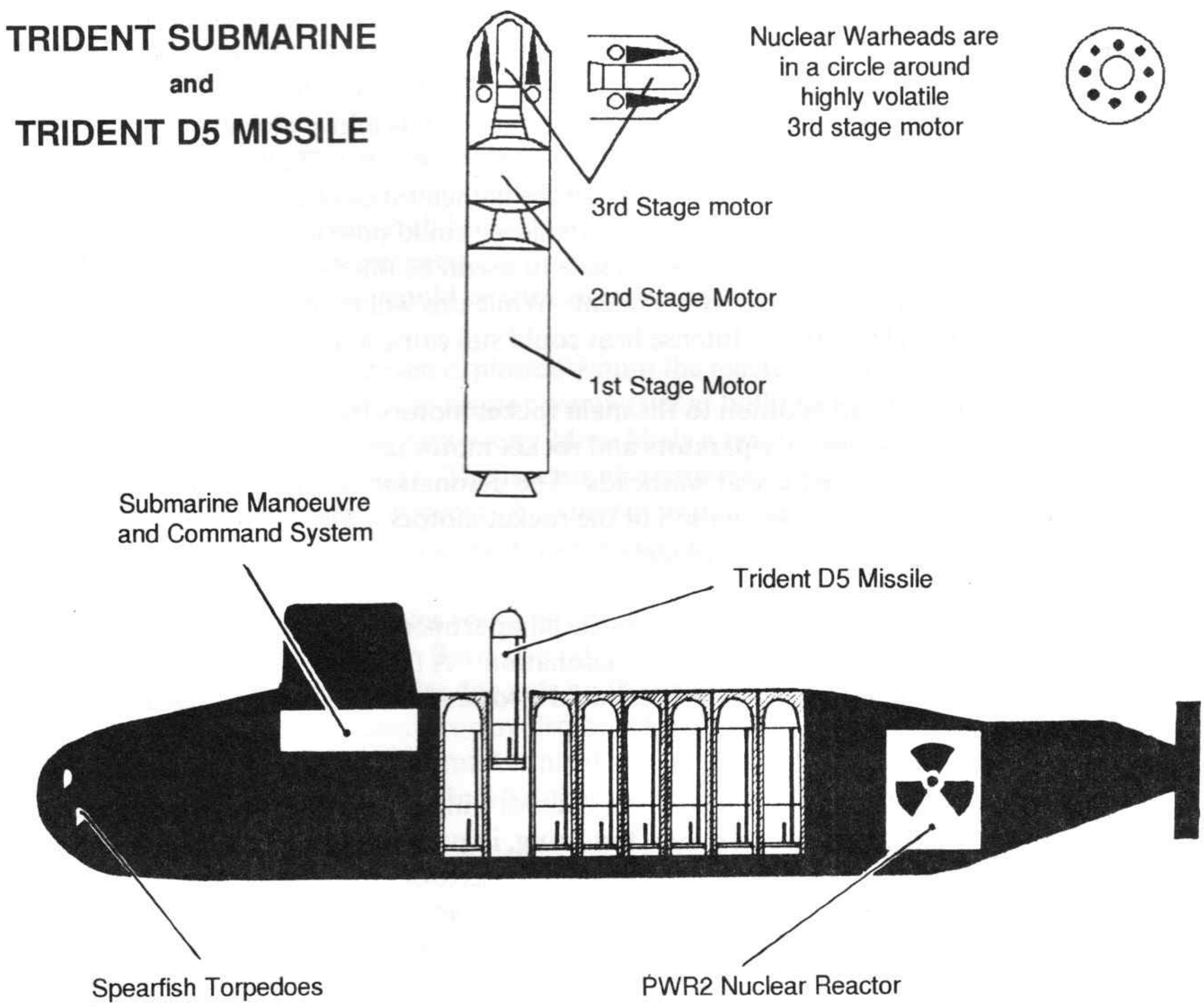


Figure 8. Trident submarine showing reactor and missiles on the port side. Detail shows 3 stage Trident D5 missile and nuclear warheads around the 3rd stage.

Missiles

The second main concern about Trident submarines is the nuclear armed missiles which the carry. On 3rd October 1986 a liquid fuelled SS-N-8 missile exploded on a Soviet Yankee I class nuclear powered submarine near Bermuda[2]. The vessel was severely damaged and san under tow on 6th October. The explosion had killed 3 sailors. Actual experience indicates that a missile explosion might occur more than once in 5,000 reactor years (estimate of tota nuclear powered ballistic missile submarine reactor years worldwide to date).

Each Trident submarine will carry 16 solid fuel missiles with a total of around 800 tonnes o high explosive in close proximity to the nuclear reactor, except when they are on initial trial or in refit. No nuclear safety regulator would allow a large amount of explosives to be placed near a land based reactor or to the amounts of plutonium in the warheads[3]. The explosives in the missile are designated by the US Department of Transport as Class A which means that in an accident the explosives can detonate[4]. The Trident D5 is a high performance solid fuel rocket and the performance is probably achieved by the use of an explosives formula which is sensitive to temperature and shock[5]. There are a number of factors which could lead to an explosion of a missile:

Heat. The safe temperature limits for the rocket are defined in transportation arrangements. The temperature within box cars within which Trident rocket motors are transported must be kept between -29° C and +49° C. The box cars have an environmental control system to maintain the temperature within these limits and a warning light goes on outside the box car if the environmental control system fails[6]. It is likely that the same temperature limits have to be maintained within the launch tubes of a Trident submarine and within the RIMs at Coulport. Fire on a submarine could pose a serious risk to missiles Polaris submarines have a system where a missile tube can be filled with nitrogen and it is assumed the same will be available with Trident. While this will reduce the possibility of ar explosion it does not eliminate it. Intense heat could still cause a missile to explode.

Explosive components. In addition to the main rocket motors the missile compartment contains gas generators, rocket separators and rocket motor igniters which are all explosiv There is also explosive in the nuclear warheads. The detonation of any one of these components could trigger the detonation of the rocket motors. The detonation of 0.3 g of explosives can cause the missile to explode[7].

Pressure. Prior to launch or jettison the missile compartment is pressurised. An accident during pressurisation could result in missile detonation. A failure in the hydraulic system which is used to raise and lower the missiles could also cause an accident. Pressure of 30 kilobars can cause the missile to detonate[8].

Shock. If a missile is dropped or if an object collides with it, then it could explode. A missile accident could occur during missile test firing, in particular when the 1st stage mot is ignited on the surface. There are also procedures to jettison a missile to prevent a missile accident. Jettisoning a missile could result in an impact between a missile and the hull. In the case of Polaris the submarine should be tilted 7 degrees before a jettison to reduce this risk. In a complex accident situation there may not be sufficient control over the vessel to tilt it to one side.

Electromagnetic radiation. The electromagnetic hazard to rocket fuel is a recognised hazard. An explosion of a rocket motor at the Morton Thiokol factory where Trident rocket motors are made has been attributed to this phenomenon. Given the large amount of electrical and electronic equipment on a submarine there is the potential for this to initiate an accident.

The effect of a Trident D5 missile explosion can be gauged by the arrangements which would be made in the event of an accident during the rail transport of rocket motors. If a fire reaches the cargo compartment then everyone, including fire fighters should be evacuated to at least one mile from the scene. Further indication of the force of the blast is evident in procedures surrounding Trident D5 tests at Cape Canaveral. These tests only took place under certain atmospheric conditions because of the fear that a rocket motor explosion could damage the nearby town and only essential personnel were allowed to remain within the test area[9].

The potential for a sophisticated rocket system to go wrong was shown when the space shuttle Challenger exploded in mid air. The explosion was initiated by a failure in a solid fuelled booster[10].

Relationship between missile and reactor systems

The two concerns, reactor and missiles, should not be considered as unconnected. The safety of a submarine should be considered as a whole and the relationship between reactor and missiles is particularly important.

The explosion of one or more missiles would have an effect on the reactor. The integrity of the reactor primary coolant circuit could be affected directly or indirectly from blast damage to the reactor compartment bulkhead, or from impacts on the hull. There could also be damage to the secondary steam circuit or to other systems related to the reactor. Fire resulting from an explosion could be the cause of a reactor accident.

A steam-zirconium or hydrogen explosion within the reactor compartment which produced sufficient pressure to breach the reactor compartment bulkhead could have sufficient force to cause a missile accident or explosion. More likely a reactor accident could result in a fire which would endanger missiles. The reactor also provides electrical power which supports missile handling and safety systems. An interruption in the regular power supply during a major reactor accident could endanger missile safety.

Both missile and reactor systems could be affected by an incident initiated elsewhere on the submarine, particularly a fire. Both also rely on some common support systems. The safe operation of reactor and missiles depends on the cooling system working properly. Operation of the diesel generators can also be affected by cooling system failure. On a Polaris submarine the environmental control system is located in a compartment several levels below the coning tower. On a Trident systems it is probably located somewhere at the aft of the vessel.

The physical relationship between the reactor and missile compartments is also important. On a Polaris submarine the missile and reactor compartments are separated by the diesel generator compartment which is approximately 6 m wide. The bulkhead between the diesel generator compartment and the missile compartment is not airtight. The bulkhead between the diesel generator compartment and the reactor compartment is part of the reactor containment and is designed to withstand pressure of around 300 psi. A Trident submarine is larger but the basic arrangement may be similar.

3.2 BASIC ISSUES

Human Factors

Stress

The crew of a ballistic missile submarine are in an unusual physical, social and psychological situation. They are living indoors for 3 months in a restricted space. They see no natural daylight throughout that time and are not exposed to the normal cycles of night and day. They are aware that they are on a vessel which is armed with nuclear weapons able to destroy a continent and powered by a nuclear reactor. Regular drills reinforce awareness of what could go wrong. They are cut off from family and friends and in close confinement with other men. Even a large submarine can be cramped with trainees sleeping in corners, having to "hot bunk". The actual number on board may be well in excess of the 130 crew for which the submarine is designed.

In the second half of 1990 and the first half of 1991 the Polaris submarine HMS Resolution carried out two 16 week patrols[11]. The patrols were extended from the normal 10 weeks because no other Polaris submarine was able to go to sea. The MoD's desire to keep one missile boat at sea at all times can increase the likelihood of an accident, both on technical and psychological grounds. A nuclear submariner has said "The worst thing is to tune your mind to a four-month patrol on a Polaris nuclear missile boat only to have it extended for another month or two a week before you are due to open the hatch again"[12]. Assuming that the Trident force is operated on the same basis of having one submarine on station at all times then Trident patrols will likewise be extended at the last minute, when the replacement vessel is not ready to go to sea.

In October 1993 a naval doctor said that problems with stress at the hunter killer submarine base at Devonport were on the increase. This was attributed to using these boats on longer and more frequent patrols[13]. The crew of a Trident submarine will spend more than 10 weeks at sea at a time.

Experience

The problems of submariners are compounded by the concerns of their families. The naval doctor at Devonport said ".. it is not just the understandable pressures of serving at sea, families become very worried and this adds to it all"[14]. Worried relatives can increase the stress felt by submariners. It can also lead to more submariners leaving the job. As a result there may be less experienced personnel in key positions.

The lack of experience of some of the individuals on duty on 26th April 1986 contributed to the accident at Chernobyl. The night shift contained fewer experienced staff. The reactor operator, Leonid Toptunov, had worked as a senior engineer at the reactor control for only 4 months. He died 2 weeks after the disaster from the effects of radiation[15].

Decision Making

The Captain of a submarine is regarded as "god" on his vessel. He will have completed a Perisher course which requires that he has the capabilities to be able to cope with complicated, critical, time urgent situations and make decisions under pressure. The extent of authority which a Captain has and the Perisher approach might in some ways be an asset in responding to an emergency, however there are also negative aspects to this. The Captain is not a reactor expert and yet he is in a position to override the advice of his reactor officer, the Mechanical Engineering Officer (MEO). The Perisher approach demands an element of aggression which may not be appropriate. Avoidance of an accident is very much dependent on the abilities and judgement of one individual and on his state of mind.

The dangers of operating a nuclear reactor within a strict social regime are evident from Chernobyl. A G Uskov was a reactor operator at Chernobyl and was on duty the day before the accident. When asked what he would have done if he had been given the same instructions that were issued that night, he said: "If I had been working at the control panels, I might perhaps have protested to the Chief Engineer, but I would not have had enough spirit to refuse categorically to carry out his command"[16].

One of the objectives of a nuclear missile submarine patrol is to remain undetected at all times. If there is a incident there will be a reluctance to compromise the vessel's position by sending out radio signals. Until this is done the only expertise which can be brought to bear on the problem is that possessed by those on the submarine. The shore base may only be informed of an incident after it has developed into a serious emergency.

The Captain of a submarine may not always tell his superiors when things go wrong, as was shown in a recent incident. In March 1992 HMS Valiant was sailing 8 miles off course when the vessel collided with an underwater mountain in the Norwegian Trench, damaging the hull. The Captain did not tell his superiors when he returned to base. The Admiralty only discovered what had happened 2 months later. The Captain was subsequently court martialled and dismissed from the service[17].

Concerns

In an emergency at a civil power station the management will have a number of concerns - exposure of workers to radiation, danger of fire, hazards to emergency services and the radiation hazards to the general public.

The concerns of the Captain or Officer of the Watch on a Trident submarine are more numerous. The dangers to the crew are not only from exposure to radiation, but also from fire, smoke, explosives and drowning. In addition to this there would be concern about other vessels in the area and about the radiation hazard to the general public.

These complex concerns are liable to add to the stress on men who are already in a very abnormal social, physical and psychological situation. Key personnel are less likely to make the best decision in the event of an accident on a submarine than in the event of a similar problem involving a reactor on land. In both the Chernobyl and Windscale accidents the initial responses had the effect of making the situation more dangerous.

Computers

The reliability of computer systems is a much greater factor in the safety of a Trident submarine than in was the case for earlier submarines. This affects not only the operation of the vessel but also the accuracy of safety assessments of key shore support facilities. The potential for safety critical computer systems to go wrong was shown when computer failure caused the collapse of the whole ambulance response service across London.

The design calculations for the shiplift and finger jetty at Faslane and the EHJ at Coulport have been particularly complex. Computer systems have been used to assess whether the likelihood of a major accident falls within certain parameters. Faults within the software could compromise the accuracy of these safety assessments. The potential for computer error could also undermine safety calculations affecting the design of the reactor and other systems on the submarine.

Control of a Trident submarine is carried out using a new Submarine Manoeuvre and Command System (SMCS). This uses 200 32-bit processors with a storage capacity of 2.5 gigabytes. This is 100 times the processing capacity of the system in service on earlier submarines[18]. There have been major delays in developing the software for SMCS. Contractors sea trials were carried out using a basic form of the software and a sequence of further issues of software were planned, with the final version not available for HMS Vanguard until it was well into its navy sea trials, 1993-94[19]. The problem lies with the infrastructure software which should be able "to support the layering of large amounts of Ada software across distributed processors in a time-critical, fault-tolerant environment with a large amount of changing data"[20]. The safety of a Trident submarine will depend on this software for SMCS. In the race to meet the inservice date of HMS Vanguard, bugs may be overlooked.

The operation of the control rods in the reactor is controlled by onboard computers. It has been said that there were problems in the operation of these computer controls during the contractors sea trials of HMS Vanguard.

The problems of reliance on complex computer systems for nuclear safety have been highlighted by recent concerns about civil nuclear establishments. There has been an incident at Sellafield when computer error led to radiation doors opening accidentally because of computer error. It was subsequently discovered that BNF had altered software after it had been approved by the NII. 2400 faults were discovered in BNF software for THORP. The software for Sizewell is so large that it cannot be fully tested[21].

3.3 HAZARDS ASSOCIATED WITH SUBMARINES

Collisions

On the basis of recorded incidents involving Polaris and other British nuclear powered submarines it can be projected that Trident submarines are likely to be involved in between 2 and 5 collisions with other vessels (see Note).

Trident submarines will regularly use shipping lanes in the Clyde frequented by tankers visiting the Finnart Oil Terminal as well as other merchant ships. Submarines also operate between the Northern Isles and the Mainland and through the Minches, both areas which are frequented by oil tankers. There is one unconfirmed report that the masts of a Polaris submarine were damaged in a collision with a tanker. A similar incident occurred on 18th August 1993 when the French nuclear powered submarine Rubin collided with a 277,000 ton supertanker in the Mediterranean. The tanker was damaged and oil leaked into the sea[22].

Submarines regularly cross the path taken by the following ferries: Gourock-Kilcreggan, Gourock - Dunoon, Wemyss Bay - Rothesay, Adrossan - Brodick, Claonaig - Lochranza, Stranraer - Larne, Uig - Lochmaddy-Tarbert, Ullapool - Stornoway, Kennacraig - Portellen-Port Askaig, Oban - Castlebay- Lochboisdale. Frequently submarines are on a path at 90 degrees to the line taken by the ferry and they have been regarded as targets in mock attacks by submarines. Submarines also regularly transit between Mull of Kintyre and N. Ireland and between Mull of Galloway and N. Ireland. When going to Devonport for refits they will transit through the West of the English Channel.

Trident submarines will operate in areas frequented by fishing boats during trials, in transit to patrol areas and possibly while on patrol. Incidents involving submarines and fishing boats happen every year on the West Coast of Scotland. It is likely that Trident submarine will be involved in several such incidents. These incidents will pose a serious hazard to the lives of fishermen and could initiate a submarine accident.

If there is a collision with a ship, on most occasions the damage to the ship will be greater than to the submarine, however it is possible that a collision could result in a reactor or missile accident. If the ship is carrying highly inflammable or explosive cargo there could be an explosion or serious fire.

While the hull of a ship might crumple and absorb some of the force of the impact, this would not apply to the same extent in the case of a collision between two submarines, both with substantial hulls. The chance of a Trident submarine being involved at some time over 30 years in a collision with an other submarine is between 60 % and 120% (see Note).

NATO and Soviet / Russian submarines are known to have collided while submerged on a number of occasions. One incident took place in the Barents Sea in 1982 and involved the HMS Sceptre. In another incident in the Barents Sea the USS Baton Rouge collided with a Russian submarine in 1992. These accidents occur as the result of the way in which submarines operate. By using active sonar they are able to accurately identify other vessels around them. However active sonar gives away the submarine's position. So they rely on passive sonar. This gives less accurate information which is difficult to interpret especially if the vessel is carrying out a serious of manoeuvres. When one submarine is following another, both using passive sonar, there is the danger of a collision. Such an incident could occur during operations or submarine - vs - submarine exercises.

Figure 9. There are a range of facilities and areas around the Clyde which will be regularly used by Trident submarines. Here HMS Vanguard is making its first visit to the noise range at Loch Goil on 9th December 1992.

Around 25 % of all collisions recorded involving British and American submarines took place either when a submarine was berthing or in the mouth of a harbour[23]. The most probable location of a Trident submarine collision is in the Clyde area, in particular Gareloch and Loch Long. A collision occurred involving 2 Polaris submarines at Faslane in January 1973 - the diving planes of HMS Repulse were severely damaged[24]. On 15th February 1967, 2 diesel submarines collided at the entrance to Portsmouth harbour[25].

Submarines do not always have a pilot on board when they approach the Faslane base. To enter and leave Faslane all vessels must navigate a 200 metre wide channel at Rhu Narrows. In September 1992 two submarines were seen approaching the channel from opposite directions at the same time.

By the late 1990s there are due to be 3 Trident and 4 other nuclear powered submarines operating from Faslane. The base is also used regularly by British submarines from Devonport and vessels from foreign navies, including French and American nuclear powered vessels. With as many as 7 submarines berthed at Faslane, arrivals and departures are a daily event, with sometimes several submarine movements on one day. Vessels normally enter the Gareloch under their own power escorted by tugs, but are sometimes towed into and out of the loch.

If a Trident submarine is involved in a collision this could result in a serious reactor and/or missile accident, particularly if the other vessel involved was also a submarine. An impact would be most serious if it involved a collision at an angle of around 90° or if it affected the reactor or missile areas. The reactor compartment and the missile section together take up around half the length of the vessel - it is not unlikely that a collision could be at one of these areas. A collision elsewhere could have effects such as a fire, loss of control, or a torpedo explosion - which could endanger reactor and missile safety.

Fire and fumes

On the basis of the frequency of fires on board Polaris and other British nuclear powered submarines it can be projected that around 6 fires are likely to occur involving Trident submarines during their 30 year lifetime (see Note). The dangers of fire were clearly shown in the accident which occurred on a Soviet submarine on 7th April 1989. There was a fire in the aft compartment of the Komsomolets. After several hours the vessel sank with the loss of 43 lives[26].

There are two forms of hazard associated with a fire on a submarine. The first is that the fire can directly damage and endanger systems on the submarine, including missiles and the reactor. Missiles, torpedoes and other explosive substances could detonate in a fire. A fire could result in a submarine sinking. A fire could also affect cooling and other systems, leading to a reactor accident.

The second hazard is that fumes from a fire could seriously restrict the ability of key personnel to carry out safety precautions and fire fighting. Toxic fumes are dangerous within the confined space of a submarine. In addition to the fire danger, there are a range of toxic fumes which can be present on a submarine which could be dispersed by accident.

On 2nd May 1976 there was a serious fire onboard HMS Warspite when it was visiting Liverpool. A coupling failed and oil was sprayed in the diesel generator room. The ensuing fire lasted for 5 hours and lagging was still smouldering many hours later. One sailor was seriously injured and four others taken to hospital[27].

In April 1992 there was a fire on board HMS Turbulent at Devonport. Maintenance work was being carried out on one of the two electrical switchboards when there was a short circuit and a bang followed by a fire. The switchroom is adjacent to the reactor compartment and separated from it by a bulkhead. The Mechanical Engineering Articifer (MEA) of the Watch was not wearing a face mask when he was required to carry out an essential safety task, Petty Officer Christian Checkley removed his face mask and handed it to the MEA. The essential safety task may have been to shut down the reactor. The reactor was producing power at the time of the fire but was quickly shut down. The consequences of the accident might have been much worse if Petty Officer Checkley had not taken this action - for which he received the Queens Commendation for bravery. The incident was officially described as "potentially lethal" and 23 sailors were admitted to hospital suffering from smoke inhalation[28].

On 19th August 1993 at Devonport toxic diesel exhaust fumes spread through part of HMS Torbay. All the 32 sailors who had been on board were taken to hospital. 13 were kept in over the weekend and some were still suffering from the effects of the accident several weeks later. Commenting on the incident, Captain Richard Sharpe, editor of Janes Fighting Ships said: "We are dealing with an incredibly small hull which is machinery intensive. The smallest amount of smoke spreads with amazing rapidity"[29]. Although Trident submarines are significantly larger than Trafalgar class the same basic problem exists.

In the incidents on HMS Turbulent and HMS Torbay it has been said that the submarine venting system did not function properly and that toxic fumes were dispersed around the vessel. In the case of HMS Torbay the submarine ventilation system was left open.

Torpedoes

A detailed investigation of naval accidents since the Second World War found that 33 % of all explosions on ships and submarines involved torpedoes and that 15 % of explosions occurred during the loading and unloading of weapons[30]. One of several fatal accidents took place on 17th June 1955 when the diesel powered submarine, HMS Sidon sank in Portland harbour after an explosion in the torpedo compartment[31]. A more recent incident showed how submariners are concerned that torpedoes may explode in a fire - sailors tried to unload torpedoes as quickly as possible from HMS Turbulent while the vessel was on fire in April 1992. The high explosives in the torpedoes may be heat sensitive, one type of explosive used in torpedoes, PETN has a melting point of 140° C[32].

Trident submarines will carry Spearfish torpedoes. These are particularly hazardous for two reasons. They contain a more powerful high explosive warhead than earlier models of torpedo and instead of battery power, they are propelled by Otto fuel, which is known to be dangerous. During early experiments on the use of this fuel for the Navy, 2 workers were killed. The Otto fuel is an explosive and toxic hazard in a fire.

Loading of Spearfish torpedoes will take place at the Finger Jetty in Faslane. They will be fired at the torpedo range near Applecross and also at a submarine trials area in the Bahamas. Although the torpedoes which are fired have dummy warheads there is the danger of a handling accident resulting in an explosion of the Otto fuel.

The high explosive in a Spearfish torpedo is designed to be sufficiently powerful to sink a modern submarine. An accidental explosion would be likely to lead to the loss of the vessel on which it occurred. USS Scorpion was sunk in 1968 by one of its own torpedoes. The torpedo was jettisoned after it had begun to arm itself. The rogue torpedo then turned and homed in on the USS Scorpion and sunk the submarine with the loss of all her crew.

Submarine systems

The Trident submarine contains a large number of new systems which are largely untried. There is a new sonar, new torpedo discharge system, new reactor, new periscopes, new electronic equipment and many other new components. While many of these are based on modifications of earlier models and some have been tried out on other submarines, they were only used together at sea when HMS Vanguard began its contractors sea trials in October 1992. The failure of one component could lead to a major accident. If different components do not interact properly this could also initiate an accident.

Because of the new systems, HMS Vanguard and later submarines will carry out months of trials - some of these trials involve considerable risk. A number of incidents occurred in the early 1990s, during trials on the new diesel powered Upholder Class submarines. The consequences of an accident on a nuclear powered vessel, such as a Trident submarine, may be much more serious.

The reactors at Chernobyl were made operational ahead of their planned date by missing out some time consuming safety tests. The omission of the tests at an early stage was a factor which contributed to the disaster in 1986. There may be very similar forces at work during the sea trials of Trident submarine, especially HMS Vanguard. Safety may be compromised in the rush to meet the in-service date.

3.4 HAZARDOUS STAGES

Loading and unloading missiles

Each submarine will visit the US Trident facility at Kings Bay in Georgia several times. The first occasion will be to load around 4 missiles, with dummy Re-entry Vehicles (RVs), onto the submarine for test firing. After these have been fired the vessel will return and load up with a full complement of 16 missiles. Before each major refit all the missiles will be unloaded at Kings Bay. At Coulport there are also facilities for loading, unloading and transporting missiles. If it is necessary to carry out an unscheduled docking of a submarine at Devonport then all 16 missiles would be unloaded and stored at Coulport. There are other undisclosed situations in which a few missiles would be unloaded at Coulport.

There has been one major nuclear missile handling accident in Britain. It took place at the US base in the Holy Loch on 2nd November 1981. A crane operator dropped a Poseidon missile which then collided with the side of the support ship. Fortunately the missile did not explode, if it had there would have been a major nuclear accident.

Fixing and removing warheads

After a submarine is loaded with missiles at Kings Bay it will go to the EHJ at Coulport where the nuclear warheads will be put in place. This operation will be carried out using specially built Missile Service Units (MSUs). These are boxes, 8 m high, which can be placed over a missile hatch on a submarine[33]. VSEL built 3 MSUs, one of which was dropped when it was being loaded onto a lorry prior to shipping from Barrow. Damage to the handling mechanisms or other parts of the MSU would increase the risk of an accident. Each MSU contains equipment to manoeuvre the 150 kg nuclear warheads. Each warhead will be placed in its position in a circle around the 3rd stage rocket motor. When all the warheads are in position and all connections and fittings have been completed, the nose cone will be replaced. A total of 8 - 10 lifting operations may be required for each missile.

This procedure carries with it the hazard that an object - nuclear warhead, nose cone, lifting or handling gear - could collide with the 3rd stage rocket motor with sufficient force to cause the motor to detonate. A US nuclear weapons safety investigation in 1990 identified this as a major problem - "if the third stage motor were to detonate in a submarine loading accident, for example, a patch of motor fragment could impact on the side of the reentry bodies encasing each warhead. The concern is whether some combination of such off-axis multi-point impacts would detonate the HE surrounding the nuclear pit and lead to plutonium dispersal or possibly a nuclear yield"[34].

Fire within the MSU is also a major hazard. A spark could be caused by contact between metal objects, by electrostatic build up or by an electrical malfunction. Cabling between the MSU and the jetty may be a particular concern.

The warheads will be placed on the missiles which are onboard a submarine in the water, inside the floating EHJ. Both the submarine and the jetty will be subject to the forces of tide, current and wind. Placing nuclear warheads on a Trident missile on land is a dangerous operation, carrying this out on the water is even more so.

Assuming there will be 96 nuclear warheads on each submarine, then for the whole Trident programme approximately 2400 operations will be carried out involving the attachment or removal of one warhead. This figure assumes that the warheads remain in place throughout an 8 year commission. If warheads are removed for inspection more frequently then 5000 or more operations would be needed. Each operation carries with it the risk of not only an accident, but also of a nuclear explosion.

Faslane shiplift

The shiplift at Faslane will be used to take submarines which are loaded with missiles and nuclear warheads out of the water for maintenance. If the shiplift failed, a nuclear accident could be initiated in one of the following ways:

a. Shock could affect the reactor, missiles or nuclear warheads.
b. Fire could endanger the reactor, missiles or nuclear warheads.
c. There could be damage to submarine systems which would then endanger the safety of reactor, missiles or nuclear warheads. Connections between the submarine and the shore would be particularly vulnerable.

If a submarine collided with the shiplift during berthing the structure could be weakened. High winds could also weaken it. To resist pressure on the shiplift from the side, 188 diagonal raker piles were placed at an angle in the sea bed. Many of these have been proven to be faulty. When some of the piles were tested, 66 % were found to be defective and had to be replaced. A further 82 piles which were inaccessible could not be tested. It is likely that the concrete in most of these 82 piles has not set. The piles will have lost their tension capability and if the steel degrades this will also reduce their compression capability. In addition, it has been calculated that the shiplift could, under certain circumstances move sideways by 75 mm[35].

The shiplift may be vulnerable to earth tremors. On 17th September 1985 there was a tremor which measured 2.5 of the Richter scale centred 12 kms from Faslane[36]. The design criteria for seismic risks is a horizontal acceleration of 0.2 g with an additional requirement that there be no unacceptable consequences at 40 % more than this. The UKAEA SRD are believed to have expressed concern to the MoD that this might be unattainable. On 27th March 1990 Commander RE Crawford, who worked for the Director General Submarines at Bath wrote that "the safety authorities expressed concern at the ability to meet this 40 per cent margin"[37].

The shiplift uses a series of wire ropes which are subject to problems from corrosion. One specialist firm, Hydranautics, had suggested that chains could be safer. However the MoD said that they did not have enough time to fully consider this option.

There have been many accidents involving shiplifts. In 1976 the hull of a 1000 ton trawler was punctured when the ship hit the concrete dock after the deck of the shiplift which it was on broke. The vessel initially dropped by the bow then rolled over. An accident in Iceland in 1972 was attributed to excessive wear on the wire and operator error. The catastrophic failure of a shiftlift in Peru was due to severe corrosion as a result of inadequate lubrication and lack of inspection[38]. The US Navy continues to use dry docks for submarine maintenance and has not adopted the use of shiplifts for nuclear powered submarines.

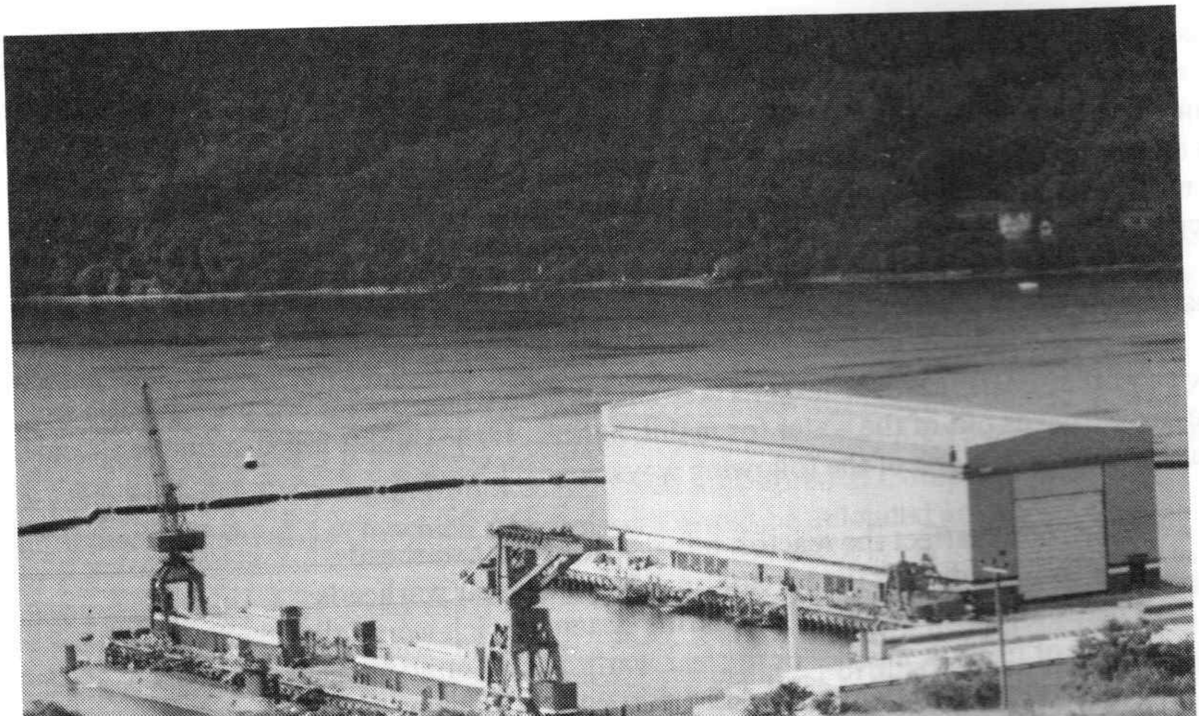


Figure 10. Trident area at Faslane showing the shiplift on the right and HMS Vanguard moored at the finger jetty on the left.

Defuelling and refuelling

The most serious accident in the history of nuclear powered submarines occurred during the refuelling of a Soviet submarine in 1985 and is described in Section 4. A total of 12 defuelling operations will be scheduled to take place on Trident submarines at Devonport Dockyard and 3 on the PWR 2 prototype at Dounreay. A gap of at least 6 months is normally left between when the reactor is shut down and when it is defuelled. This is to enable levels of radioactivity from the reactor to fall, however levels are still hazardous when defuelling is carried out.

A major accident could occur when the used fuel core is being moved from the reactor. In the new facilities at 5 Dock in Devonport the fuel core will be lifted 2 - 3 metres and then taken into a building. During the lift the core could be dropped and damaged[39].
There have been a number of fires reported during submarine refits which have varied in their degrees of seriousness. A fire could trigger off a series of events which could lead to an accident involving either the reactor or fuel cores in storage.

The city of Plymouth is particularly vulnerable to a nuclear accident. A major accident, at the level of Benchmark 6, would result in serious exposure around the base, the evacuation of a large part of Plymouth and sheltering in areas such as Exeter and Taunton, if there was a South Westerly wind.

Initial fuelling of reactors also takes place in a built up area, in the VSEL yard at Barrow in Furness. First power range testing of the reactors also takes place there. This involves the reactor being put through its paces for the first time and could result in a major accident.

NOTE: SUBMARINE ACCIDENT STATISTICS

Not including the first Trident submarine there have been 23 nuclear powered submarines in service in the Royal Navy. From when each was built to the end of 1993, or until scrapped gives a total of around 384 reactor years. This includes hunter killer submarines. The equivalent for Polaris is a total of around 102 reactor years.

Between 1950 and 1988 there were at least 19 fires and 6 collisions, 2 of which involved 2 submarines, on all British nuclear powered submarines. In the same period there were 5 fires and 4 collisions, 1 of which involved 2 submarines, on Polaris submarines.

4 Trident submarines in service for 30 years will be in service for a total of 120 reactor years. The projected number of incidents for the projected lifetime of Trident, based on the figures for Polaris and for all British nuclear powered submarines are as follows:

Incident	*Based on Polaris*	*Based on all submarines*
Fire	*5.9*	*5.9*
All collisions	*4.7*	*1.9*
Collisions with other submarines	*1.2*	*0.6*

An examination of a total of 63 collisions involving British or US submarines showed 73 % (46) occurred at sea and 27 % (17) when the submarine was berthing or in a harbour area.

1 *Cracking Under Pressure, SCND, Faslane Peace Camp, June 1992*

2 *W Arkin, J Handler, Naval Accidents 1945-88, Greenpeace 1989, p69*

3 *1st and 2nd stages contain 48,075 kg of explosives - US government bill of loading C-1256303, 4 Jun 1990, from Hercules Aerospace, Utah to SWF Kings Bay*

4 *Both Class A and Class B explosives can explode accidentally, in the case of Class A explosives, the explosion would spread at faster than the speed of sound. GP Sutton Rocket Propulsion Elements, J Wiles 1986, p304*

5 *The specific impulse of the rocket motors is 270 seconds. Report of the panel on nuclear weapons safety of the House Armed Services Committee, Dec 1990, (Drell report) p28*

6 *R Aldridge, Trident Resisters Handbook, Jan 93, p 5.2-3*

7 *Drell report p28*

8 *Drell report p28*

9 *R Aldridge, op cit, p5.2-3*

10 *Presidential Commission on the Space Shuttle Challenger Accident, 6/6/86*

11 *Cracking Under Pressure*

12 *Plymouth Evening Herald 27/10/93*

13 *ibid*

14 *ibid*

15 *Z Medvedev, The legacy of Chernobyl, Basil Blackman, 1990*

16 *ibid p38*

17 *Plymouth Evening Herald 3/6/92, 27/10/93*

18 *Janes Defence Weekly 18/4/93*

19 *Progress of the Trident Programme, House of Commons Defence Committee, HC 286 90/91 p6,22,23*

20 *Janes Defence Weekly 18/4/92*

21 *Safe Energy Dec91/Jan 92 p5, Oct/Nov 92, Dec93/Jan 93*

22 *Scotsman 19/8/93, Evening Times 19/8/93*

23 *Arkin/Handler op cit*

24 *Cracking Under Pressure*

25 *Arkin/Handler op cit*

26 *Facts and figures relating to the dumping of radioactive waste in the seas surrounding the territory of the Russian Federation, Administration of the President of the Russian Federation, Moscow, 1993, translated by Greenpeace. (Russian Federation report)*

27 *Guardian & Times 3/5/76*

28 *Plymouth Evening Herald 17 7/93, Western Morning News 12/3/93; Plymouth Dump Information Group Jul 93*

29 *Western Morning News and Plymouth Evening Herald 21/8/93*

30 *Arkin/Handler op cit*

31 *ibid p17*

32 *Encyclopaedia Britannica*

33 *VSEL Link Jan 93 p5*

34 *Drell report p29*

35 *Progress of the Trident Programme, House of Commons Defence Committee, HC 237 90-91, p69f, xviiif; Scotsman 2/5/90*

36 *Evening Times 17/8/85*

37 *Scotsman 2/5/90*

38 *ibid*

39 *Plymouth DIG minutes of Plymouth Meeting, 1/7/93; The danger is even greater at Rosyth and the old refuelling complex at Devonport where the core is lifted higher*

4. REACTOR ACCIDENTS

There are a range of accidents which could occur involving a PWR 2 reactor - three types are looked at. The most serious, a containment failure accident, is considered in detail, and compared with a Soviet submarine accident and with Chernobyl. The effect that such an accident could have on the central belt of Scotland is illustrated. The problems that arise when a nuclear powered and armed submarine is lost at sea are also discussed.

4.1 CORE DAMAGE ACCIDENT

A core damage accident is defined by the Royal Navy as an accident which is contained within the cooling circuit of the reactor. In a core damage accident, failure of the zirconium cladding on the fuel rods will lead to a release of fission products into the primary coolant circuit. Naval manuals suggest that this will not pose a major problem outwith the base, however there will be a long term problem of how to cope with such an incident[1]. Removal of the fuel core would be hazardous and the reactor would be heavily contaminated. The volumes of nuclear waste and hazards to workers would complicate defuelling.

The Russian Navy has major problems with reactors on submarines. It is unclear how many incidents may be identified as core damage accidents, loss of coolant accidents, or other reactor problems. In the Northern fleet, 6 reactors on 4 submarines have been dumped at sea - "it was impossible to offload the fuel from all six submarine reactors dumped with spent nuclear fuel because of the emergency condition of the cores"[2]. In addition 85 % of the submarines in the Northern Fleet which have been decommissioned have not been defuelled, in some cases this is because the reactor cores are damaged. There are similar problems in the Pacific fleet - "damaged reactors of three submarines are stored with nuclear fuel, it is also impossible to offload their spent fuel assemblies"[3]. The Russian experience shows that there is a significant chance of reactors reaching a condition in which defuelling is very difficult.

4.2 LOSS OF COOLANT ACCIDENT

This is a more serious accident. The Royal Navy's Loss of Coolant Accident scenario assumes that there is a breach in the primary coolant circuit which releases fission products into the reactor compartment, however it is assumed that the reactor containment remains intact. The scenario does take into account the seepage of a small proportion of radioactive material through weakpoints in the bulkheads. This would then spread through the submarine, with some becoming dispersed into the atmosphere, presenting a hazard to the general public. The MoD describe this as a Benchmark 3 accident and claim that the chance of this type of accident is 1 in 10,000 reactor years. Some of the Russian accidents may fall into this category but details are unclear.

A Benchmark 3 accident on a Trafalgar class submarine could result in the release of 4×10^{13} Bq of iodine ^{131} as well as other radionuclides[4]. The maximum figures for a Trident submarine could be higher, depending on the history of the reactor core. The whole body and single organ doses received have been calculated by the MoD for a Trafalgar class submarine accident. Risks of fatal cancer and thyroid cancer have been deduced on the basis of ICRP risk factors in the figure 11.

Figure 11. Loss of Coolant Accident dose and risk estimates

Distance	whole body dose	risk of fatal cancer	single organ dose	risk of thyroid cancer
500m	8 mSv	1 in 2,500	50 mSv	1 in 8,000
1km	3 mSv	1 in 6,700	10 mSv	1 in 40,000
2 km	1 mSv	1 in 20,000	4 mSv	1 in 100,000

At 1 km from the accident in the short term 2 mSv of the whole body dose will be from cloudshine and 0.7 mSv from inhalation. The remaining 0.3 mSv is the dose from groundshine over a 50 year period, with 0.06 mSv of this received in the first week.

4.3 CONTAINMENT FAILURE ACCIDENT

If there is a loss of coolant accident and the containment fails then this more serious accident can occur. A much larger proportion of the fission products could be released into the atmosphere creating a greater threat to the general public.

Probability of a containment failure accident

The total experience of the US Navy in operating nuclear powered submarines up until 1988 was 3,100 reactor years[5]. The Russian Navy may have 60 % of the submarine reactors in the world. This suggests that the total worldwide experience of operating nuclear reactors to date is around 10,000 reactor years. The MoD claim that the probability of a containment failure accident is less than one in a million years of reactor operations. However in 10,000 reactor years there has already been one such incident which involved a Soviet submarine at Chazhma Bay in 1985. This is described below.

Underestimating the probability of a major nuclear accident can in itself make such an event more likely. This was a factor in the Chernobyl disaster. A reactor operator working there on the day before the accident, AJ Uskov, said that they had been taught that such a chain of events was impossible - "..and already in the classrooms of their institutions they had beaten into their heads: a reactor cannot explode"[6].

Accident at Chazhma Bay

On 10th August 1985 a containment failure accident occurred on a Soviet Victor class submarine at Chazhma Bay, near Vladivostock. The submarine had two reactors. The port reactor was being refuelled when the accident occurred. A crane was being used to reposition the reactor lid when it became warped, triggering a nuclear reaction This caused a thermal explosion which ruptured both the aft bulkhead and the pressure hull. The freshly loaded core was thrown out of the reactor and the roof of the refuelling hut was thrown 70 - 80 metres away. The official casualty figures were 10 killed, 10 cases of acute radiation sickness and 39 other cases of radiation sickness . An eye witness described the devastation - "The submarine looked as if it had been trampled by a giant beast"[7].

There was a fire in the reactor compartment which was localised after 4 hours. Fission products were dispersed by the explosion and fire. Because the hull was ruptured fission products leached into the sea. The total amount of material released has been estimated as 1.85×10^{17} Bq not including 8.1×10^{16} Bq of noble gases. If these figures are correct the radioactivity released was around one seventh of the total released in the Chernobyl disaster.

In 1992, the chairman of the Soviet in the neighbouring town of Shkotovo-22 said "I consider the radiation conditions here remain unsuitable. Every Spring when the ground thaws a high level of radiation is released"[8].

Causes of a containment failure accident

The reactor containment may fail because it is damaged from the outside as a result of a collision or explosion. It may also fail if an explosion occurs within the reactor compartment. During a loss of coolant accident there could be a series of explosions, one of which might rupture the containment. The sequence can be described as follows:

If the reactor is operating at full power and there is a catastrophic break in the primary coolant circuit, water in the circuit will flash into steam causing the first pressure peak, 1 minute after the break. The heat of the reactor core will rise and at 900° C there will be an explosive reaction involving the zirconium cladding of the fuel rods, 3 minutes after the break. The heat of the core will rise until the core melts at 2000° C . There will be a build up of hydrogen which could result in a third explosion, 20 minutes after the break. A fourth explosion may also occur 3 hours after the break.

Effect of a containment failure accident on a Trident submarine in the Clyde

A Royal Navy manual estimates the levels of radiation in a Trafalgar class submarine. If the reactor core is at the end of its life and has operated at full power for the preceding 100 hours then it is likely to contain 4×10^{18} Bq of mixed fission products of which 4×10^{16} Bq is iodine ^{131}. Assuming that the plant is operating at normal temperature and pressure when there is a major accident and the containment is breached then there could be a release of 100% of the iodine, caesium and noble gases in the reactor and of smaller proportions of other radionuclides[9]. Most of this would be released within one hour of the accident.

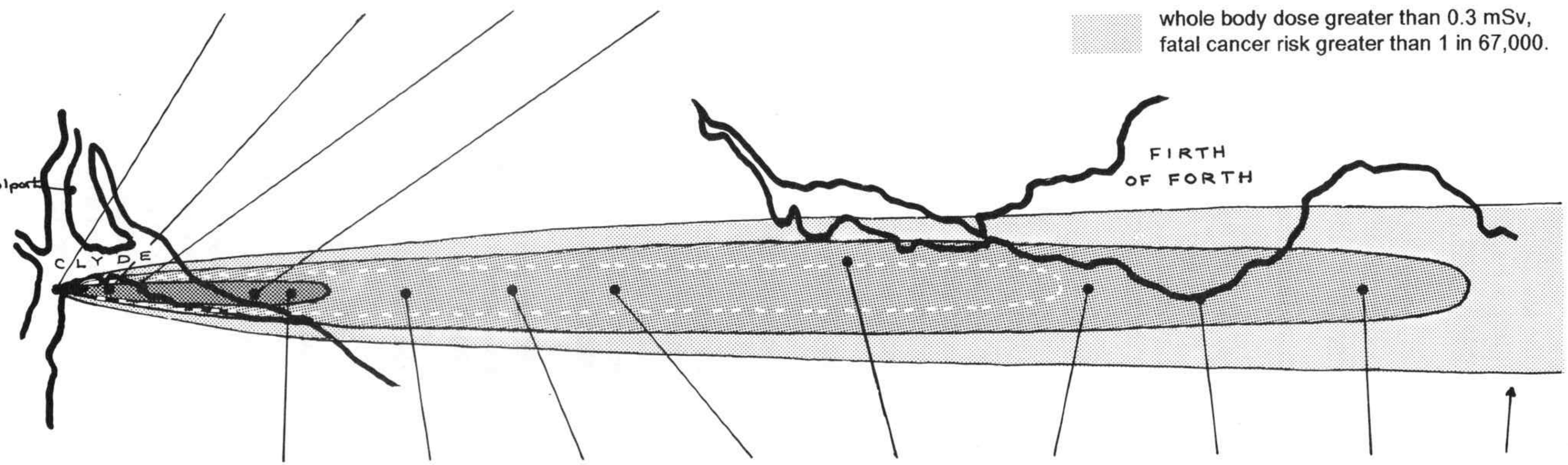
A second manual describes the possible effects of a Benchmark 6 accident, when the reactor containment fails. It is assumed that this relates to the scenario just described. The wind speed is 4 m/s, approximately 9 mph, and there is average air stability, category D. Whole body dose and thyroid dose figures at varying distances from the scene of the accident are indicated in a graph in the manual.

These figures have been used as the basis for the map in figure 12. The scenario in this case is a containment failure accident on a Trident submarine which takes place in the Clyde estuary at the point where two ferry routes and the two shipping lanes to Loch Long and the Clyde intersect. It is assumed that the radiation released is the same as in the Navy model; higher levels of fission products would be present in the reactor of a Trident submarine at the end of the core life than in a Trafalgar class submarine. Average wind speed and air stability conditions are assumed as in the Navy model. The wind is blowing from the West, which is the case around 5% of the time. This example was chosen because radiation levels at varying distances can be associated with specific towns across Scotland; this does not represent the worst case scenario, either in terms of accident site or weather conditions.

Figure 12. Effect of a reactor containment failure accident on a Trident submarine in the Clyde.

	McInroy Point	Gourock	Greenock	Dalreoch
Distance	1 km	5 km	9 km	17 km
Whole Body Dose	3300 mSv	250 mSv	110 mSv	50 mSv
Fatal Cancer Risk	1 in 6	1 in 80	1 in 500	1 in 400

- whole body dose greater than 300 mSv, fatal cancer risk greater than 1 in 67, evacuate.
- whole body dose greater than 30 mSv, fatal cancer risk greater than 1 in 670, shelter and consider evacuation.
- thyroid dose greater than 50 mSv, thyroid cancer risk greater than 1 in 8,000, issue potassium iodate tablets.
- whole body dose greater than 3 mSv, fatal cancer risk greater than 1 in 6,700, consider shelter.
- whole body dose greater than 0.3 mSv, fatal cancer risk greater than 1 in 67,000.



	Dumbarton	Milngavie	Kirkintilloch	Cumbernauld	Linlithgow	Edinburgh	Musselburgh	Haddington	Dunbar
Distance	21 km	36 km	47 km	56 km	80 km	100 km	112 km	127 km	140 km
Whole Body Dose	40 mSv	20 mSv	14 mSv	11 mSv	6 mSv	5 mSv	4 mSv	3.3 mSv	2.3 mSv
Fatal Cancer Risk	1 in 500	1 in 1000	1 in 1429	1 in 1818	1 in 3333	1 in 4000	1 in 5000	1 in 6061	1 in 8696

Radiation levels directly downwind from the accident are taken from Navy figures. Plume width is based on estimates of radiation level to the North and South of the direct line, calculated for the given weather conditions. These calculations do not take account of the effects of topographic features or of rain.

Whole body dose estimates are indicated by shading. 300 mSv is the National Radiological Protection Board (NRPB) upper Emergency Reference Level (ERL) at which evacuation is recommended. 30 mSv is the lower ERL at which evacuation should be considered and the upper ERL at which sheltering is recommended. 3 mSv is the lower ERL at which sheltering should be considered. The area within which the thyroid dose is estimated to be above 50 mSv is also shown - this is the MoD Emergency Action Guidance Level (EAGL) at which potassium iodate tablets should be issued.

From figure 12 it can be seen that sheltering should be considered at more than 100 km from the site, evacuation should be considered at 30 km and iodate tablets should be issued at 80 km. The probability of developing fatal cancer as a result of the accident is indicated for specific sites, these were calculated from the whole body dose estimates on the basis of the ICRP risk factor of 0.05 per Sv. The probability of developing thyroid cancer if iodate tablets are not taken immediately is estimated as 1 in 400 in Greenock, 1 in 2,700 in Milngavie and 1 in 10,000 in Edinburgh based on ICRP risk factor of 0.0025 per Sv.

Type of radiation exposure

The Navy manuals provide some information on how the doses were calculated. At 1 km from the scene 61 % of the whole body dose would be from inhalation, 4 % from cloudshine and 34 % from groundshine. The dose from inhalation and cloudshine would be received during the passage of the radioactive plume. The groundshine dose has been calculated over a 50 year period, with 20 % received in the first week and 50 % in the first year.

There would also be a risk from gamma shine in the immediate area of the accident. This would extend beyond the 550 m distance previously claimed by the MoD. The MoD argue that if the accident was at Faslane, buildings at the submarine base would limit the effect to this distance, but this would not apply at other sites, or even to the other side of Gareloch. Significant radiation doses from gamma shine could be received by those 1 km or more from the reactor. In the scenario described members of the public on the shore could be exposed to gamma shine.

Comparison with Chernobyl

Royal Navy training manuals refer to Chernobyl as a Benchmark 6 accident. The most serious type of submarine reactor accident detailed in the manual is also described as Benchmark 6. The amount of iodine ^{131} which was contained in the Chernobyl reactor has been estimated to be 7.5 x 10^{20} Bq. The total amount of iodine ^{131} in a PWR1 reactor in the model reactor scenario is estimated to be 4 x 10^{16} Bq. The equivalent for a PWR 2 reactor with the same core history could be twice as much. This suggests that the Chernobyl reactor had around 10,000 times as much iodine ^{131} as this PWR 2 reactor. However only a proportion of the iodine ^{131} was released into the atmosphere in the Chernobyl accident, the official estimate is 2.6 x 10^{17} Bq[10]. The Benchmark 6 scenario described in the Greenwich training manual assumes that 100 % of the iodine in the submarine reactor is dispersed. This would be equivalent to one third of the official figure of the amount released at Chernobyl.

Lessons from Chernobyl

A wide range of figures from less than 50 to many thousands have been produced as estimates of the long term fatalities which might arise from the Chernobyl accident. There were significant rises in radiation levels across Europe and beyond. Estimated doses in some parts of Scotland, Wales and North West England were higher than 1 mSv. The incident was extended over 10 days; as wind directions changed, so radioactive material was dispersed in different directions. Particles with a diameter of 1 - 20 microns were found in Sweden. It is estimated that 60 % of all radioactive isotopes from the Chernobyl accident were deposited within 20 kms of the site and 40 % dispersed more than 20 kms away. In the Ukraine 5 million km^2 were contaminated.

The highest doses of radiation were received by the reactor personnel and by the large number of people who were called in to deal with the accident. Fire crews who tackled the initial fires were particularly at risk. In an accident at a submarine berth, base emergency services, local fire and ambulance crews and personnel in the base assisting on the scene could be exposed to high levels of radiation.

A total of 600,000 people were exposed to radiation during the clean up operation. The Soviet army had many units trained in decontamination and most of them were deployed at some stage during the follow up operation. Clean up operations after a major submarine accident would involve radiation exposure to a large number of people.

Chernobyl provides some evidence of the effect of a nuclear accident on wildlife. Visitors to the nearby town of Pripyat commented on the dreadful state of animals and birds which they found 6 weeks after the accident. The local residents thought that they were only leaving for 3 days and so they left their pets, in other villages many of them were shot. " .. in Pripyat they (the animals) weren't shot. Here (they) crawled, half alive, along the road, in terrible pain. Birds looked as if they had crawled out of water ... unable to fly or walk ... cats with dirty fur, as if it had been burnt in places .."[11]. The visitor also reported that half of the animals were blind. It is estimated that after 6 weeks they may have accumulated doses of 7 - 10 Sv. Further from the site there were signs of the effects on animals. Deformed calves 100 kms from the site were believed to be due to the accident.

Radiation concentrated in lichen and in the bodies of reindeer in Northern Scandinavia. In 1993 the carcasses of 2,700 reindeer in Sweden were destroyed because of levels of radioactivity from Chernobyl. In the same year there were still some restrictions on sheep sales in Scotland because of the fallout.

Pine trees in a large area around Chernobyl died as a result of the accident. There were abnormalities observed in other species of trees, including oak, around the area.

Local Authority response

The effects of a major nuclear accident may be reduced if appropriate action is taken by local authorities. In order to do so they have to be given detailed information at an early stage. There are many examples of how the MoD has failed to inform Emergency Planners of incidents. One case was on 30th April 1992 when the MoD failed to inform Plymouth City Council immediately of a serious fire on a nuclear powered submarine at Devonport. Captain David Hall, the Chief Staff Officer (Nuclear) at Devonport later admitted - "It was a bureaucratic mess up. Unfortunately the message that we passed to our central authority for permission to speak to the public got lost in the system and we didn't get permission to speak out until quite late on. .... It was a Ministry of Defence cock up, as simple as that"[12].

4.4 RADIATION HAZARD FROM A SUNKEN SUBMARINE

There are already more than 5 nuclear powered submarines on the seabed which have sunk during accidents[13]. This suggests that the chance of a nuclear powered submarine being sunk in peacetime is greater than 1 in 2,000 reactor years.

In April 1989 the Soviet submarine Komsomolets sank to a depth of 1700 m near Bear Island. Sea bed examination of the vessel in May 1992 showed that there were cracks along the entire length of the titanium hull. Some cracks were of 30 and 40 cms width. The examination also found that the primary coolant circuit was not hermetic, ie fission products could leach out into sea water[14]. If a Trident submarine sank it is likely that there might be similar cracks in the hull and bulkheads, which form the containment of the reactor. Royal Navy submarines are designed with a maximum diving depth of around 400 m. The actual strength of each hull varies, depending on the history of the submarine.

If a Trident submarine is lost at sea, in addition to fatalities amongst the crew, the accident would create a long term radiation risk, even if there was no short term nuclear hazard. Radioactive products from the reactor would leach into the sea. There would be a particular problem from long lived isotopes which would eventually be released even if the primary circuit and the containment remained intact for several years. The plutonium in the warheads would present a long term hazard.

Radioactive products in the deep sea will be absorbed by organisms feeding on or near the sea bed; these then become food for whales, dolphins and other species. Over time some radioactive material will be moved from deep to surface waters by biological activity and also by sea currents. A small proportion of what was released into the sea would end up in the human food chain.

1 *Much of the detailed information in this section is based on information from training manuals used at the Naval College at Greenwich, Scotsman 19/8/93.*
2 *Russian Federation report p12*
3 *ibid p27*
4 *100 % noble gases, 0.1 % Cs, 0.025 % Ba and St, 0.01 % Te and Sb, 0.001 % Ru & others*
5 *Pentagon spokesman, Guardian 3/3/88*
6 *Z Medvedev op cit, p38*
7 *V Mezin, senior lieutenant, Special Accident Brigade, Mail on Sunday 2/2/92 ; incident also described in Russian Federation report*
8 *Mail on Sunday 2/2/92*
9 *25 % Ba and Sr, 10 % Te and Sb, 1 % Ru and others*
10 *D Sumner et al, op cit, p176, higher figures have also been suggested*
11 *Z Medvedev, op cit p173*
12 *Plymouth Dump Information Group minutes of meeting in Plymouth , 1/7/ 92*
13 *2 US & 3 Soviet nuclear powered submarines sunk & on seabed & probably 1 Soviet submarine sunk & salvaged. Arkin/Handler op cit, Russian Federation report table 7*
14 *Russian Federation report*

5. WARHEAD ACCIDENTS

This section looks at the inherent dangers of nuclear weapons and the consequences of an accident. Plutonium dispersal would endanger human health and present a long term environmental problem. The effects of a transport accident, a warhead accident on a submarine and a combined reactor/warhead accident are considered.

5.1 SAFETY OF NUCLEAR WEAPONS

Relationship between US and British Trident warheads

The small number of British nuclear tests specific to Trident suggests that the warhead is not a completely British design. It is likely that it is modelled on an American design. There is close cooperation between British and American nuclear weapons designers. The MoD has probably been supplied with design information relating to the relevant US warhead[1]. Britain will purchase the Mk4 RV for Trident. In the United States this is used for the W76 warhead which is a fission warhead boosted by tritium and deuterium[2].

The criteria adopted in the design of nuclear weapons in the United States was described in the Drell Report: "... a large nuclear weapon stockpile was built in the chilling environment of the Cold War. Modernisation and improvement programs gave priority to military requirements, such as achieving maximum yield to weight ratios for warheads and maximum payloads and ranges for missiles. Safety in general was not viewed with the same urgency"[3].

Safety assessment in Britain

A nuclear weapon is complex and contains a wide range of exotic components. The way in which these will change and decay over the years is difficult to predict. The Director of Nuclear Policy and Security told the House of Commons Defence Committee - "Any warhead is subject to aging processes. These are not necessarily wholly predictable"[4]. Another senior MoD official at this meeting was concerned about Aldermaston's ability to assess the safety of the warheads in future years. He was worried about a possible reduction in nuclear testing - "With a restriction in testing in the future the competency of the relevant people at Aldermaston will decay, fall off, until the point where they are unable or unwilling to say 'This is still safe'"[5]. The ability to assess the safety of warheads is in doubt and would appear to rest on the continued destruction of the environment in the homeland of the Western Sheshone, the Nevada desert.

Nuclear warheads are designed to withstand the effects of reentry from space and are tested to simulate these effects. However these circumstances are not identical to those which might be encountered in a complex warhead accident.

Amounts of plutonium, tritium and HEU

The complete fission of 5.7 kg of plutonium will produce a yield of 100 kilotons[6]. However 100 % fission will not be achieved even with tritium/deuterium boosting. A Trident warhead probably contains between 3 and 6 kg of plutonium, supplemented by HEU, which is more readily available. A reasonable estimate is 4 kg plutonium per warhead. Calculating the total US stockpile of tritium in the 1970s and dividing this by the number of nuclear weapons in the US arsenal produces a figure of 2.8 g of tritium per warhead[7]. Many of the weapons in the US stockpile at the time did not contain tritium. The amount of tritium in a British Trident warhead is probably around 4 g. The amount of HEU is not known possibly 10 - 20 kg.

Combination of plutonium and high explosives

Trident nuclear weapons contain a sphere of approximately 4 kgs of plutonium, plus HEU, surrounded by at least 20 kg of high explosives[8]. This combination is inherently dangerous. Guidelines issued by the MoD to local authorities state that in an explosion fragments could be propelled 600 metres from the scene[9]. The explosives used will be of a high energy formula which is likely to be sensitive to shock and heat.

Sensitivity to heat

Temperatures only slightly above normal could be dangerous. Explosives may detonate because of heat. Alternatively they may melt. After they have melted they will detonate very easily. Many US nuclear weapons contain PBX explosives which have a plastic, polybutadiene base[10]. The melting point of Trident warheads is not known. Conventional RDX explosives have a melting point of 203° C[11].

Sensitivity to shock and pressure

Warhead high explosive may detonate if it is subject to shock pressure of 20 kilobars. It may also detonate if there is an impact and the impact velocity is 100 mph[12]. The precise response of explosives to shock is difficult to predict. One batch of explosives with its own history may not behave in exactly the same way as another batch of the same material. The US has in the past used at least one type of explosive in nuclear weapons which could easily be detonated. LX-09 was used in the W 68 warhead on Poseidon missiles. Safety tests were carried out after a fatal explosion on 30th March 1977 in which 3 workers who had been handling the explosives were killed[13]. These tests established that LX-09 could detonate if a small weight was dropped from a height of 30 cms. In February 1959 two workers at Aldermaston were killed when unloading high explosives from a trolley[14]. Insensitive High Explosives (IHE) have been developed which will not go off so easily but IHE is not used on the US W76 warhead and is almost certainly not used on the British Trident warhead.

Other properties of warhead components

Small splinters of plutonium metal can spontaneously ignite in air. HEU in a dust form is also a fire hazard and a moderate explosive hazard. Beryllium is a moderate fire hazard and a slight explosives hazard[15]. The depleted uranium in the weapon is also a fire hazard in splinter or dust form. The warhead will contain lithium which has a melting point of 186° C and reacts with water. Plutonium melts at 639° C, uranium at 1132°C and beryllium at 1278°C. The warheads will also contain plastics and components which may melt at relatively low temperatures. The way in which a nuclear warhead responds to heat will be complex. If these reactions result in a very small chemical explosion, equivalent to one thousandth of an ounce of TNT, this could detonate the main high explosive[16].

5.2 NUCLEAR EXPLOSION

The MoD have said that the British Trident warhead was proved to be one-point safe on 13 March 1992[17]. "One-point safe" means that in a nuclear weapons accident if the explosive detonates at any one point the probability of a nuclear yield of more than 4 lbs TNT equivalent is less than 1 in a million[18]. There are two concerns about this information. The MoD Chief Scientific Adviser earlier expressed doubt that the safety of the Trident warhead could ever be properly assessed, given that the calculations would only be carried out at one installation, Aldermaston[19]. The Americans have argued that they need to have two establishments, Los Alamos and Lawrence Livermore, so that results can be cross checked. The second concern is that this approach does not address the situation where part of a missile explodes and fragments impact on the warhead from various directions.

5.3 PLUTONIUM DISPERSAL[20]

The more likely outcome of a serious nuclear weapons accident is the dispersal of plutonium dust over a wide area. This could occur during a fire or a conventional explosion. A conventional explosion is regarded as 100 times more serious than a fire, because the plutonium would be in the form of fine particles, which are more dangerous.

Absorption of plutonium into the human body

When plutonium has been dispersed into the atmosphere, the main way in which it is likely to enter the body in the short term is by the inhalation of dust particles. Small particles are particularly dangerous as they can remain in the lung and be transferred to other parts of the body where they remain for many years. Particle size is very important. Particles larger than 10 microns are likely to be cleared from nasal airways and swallowed. If the particles are smaller than 10 microns then the smaller they are the greater the proportion deposited in the lung. Large amounts of plutonium which are taken into the body can have serious toxic effects in addition to the effects of radiation.

If 100 particles of plutonium, each 1 - 10 microns in size, are inhaled then 8 of these particles are expected to reach the bone structure and remain there for many years. After 50 years, half of the particles would still be in the skeleton. Also of the 100, 7 more particles would be retained in various parts of the body for between 6 months and 40 years or more. The remaining particles would be removed from the body more quickly.

Alpha radiation is emitted from plutonium for thousands of years. While there is a risk from inhalation of plutonium, there is also a risk, particularly in the long term that a significant proportion will find its way into the food chain. The proportion of ingested plutonium which remains in the body is small. For plutonium dioxide, 0.1% of the amount ingested will remain in the body for a significant length of time. Higher amounts will be absorbed if the plutonium is in a soluble form or if the particles are extremely small.

Biological effects of plutonium

The alpha radiation from plutonium can only travel a very short distance and cannot penetrate the dead layer of skin around the body. However a particle emitting alpha radiation which is inhaled and absorbed can have a considerable effect on live cells in its immediate vicinity. The relative biological effectiveness of alpha radiation is greater than gamma or beta radiation by a factor of 20. A particle of plutonium can damage cells which are between 10 and 50 microns from it.

Cells have an ability to divide to create more cells. There are natural mechanisms to prevent this division when it is not needed, however the damage caused by plutonium particles and other forms of radiation, can have the effect of disrupting these mechanisms. This results in cells dividing and redividing when they should not. In this way, the inhalation of plutonium dust can result in cancer in the bones, lungs and other parts of the body.

There are also risks of genetic damage. In a male, 3 out of 1000 particles are likely to reach the gonads. In a female the proportion is 1 out 1000. These particles are likely to remain there for many years. They can damage reproductive cells in their immediate vicinity and break the DNA chains within cells. If these breaks are complex, the cell may be unable to repair the damage. This can result in genetic abnormalities in the offspring of the person who is exposed to radiation.

Assessing the probability of cancers and of genetic damage is very difficult and not very reliable. Damage to one cell from a small dose of radiation can result in cancer. While the chance of this happening is very small, the damage caused by exposure to a small dose is as great as for a larger dose. However, the larger the dose, the more likely it is that cancer will occur. The same is true of genetic damage.

Casualties

It has been calculated that if 8×10^{-5} g of weapons grade plutonium is inhaled and 15% is retained in the lung there would be a 100% risk of death from lung cancer[21]. Assuming that one Trident warhead contains 4 kg of plutonium then this is equivalent to 50 million lethal doses. If 2 warheads in a vehicle were to explode the total amount of plutonium involved could be equivalent to 100 million lethal doses.

The risk of contracting cancer would be roughly in proportion with the amount inhaled[22]. The proportion of plutonium which was inhaled as very small particles would be particularly significant. The risk factor for fatal cancer is given by the ICRP as 0.05 per Sv. The risk factor for all cancers is approximately to be 0.075 per Sv. The risk factor for hereditary effects for all future generations is given by the ICRP as 0.01 per Sv for all ages and 0.006 per Sv for people of a working age.

Long term behaviour of plutonium in the environment[23]

Plutonium which has been dispersed into the atmosphere will continue to be a significant radiation hazard for thousands of years. Studies have been carried out to assess likely ways in which plutonium which has been discharged can reach the human foodchain and these give some indication of the way in which plutonium behaves in the environment.
In sea water a large proportion of plutonium is expected to accumulate in sediments.
The levels of plutonium found in phyto plankton is likely to be high. From plankton the plutonium may then be passed along the food chain to zooplankton, plantiverous fish and pisciverous fish. Plutonium is also likely to be found in shrimps, crabs, lobsters, mussels and gastropod molluscs - algae have a particular ability to concentrate plutonium. Plutonium may also be taken in as food by sea mammals and birds feeding on sea life and feeding between the high and low water marks.
In the case of plutonium deposited on the soil the rate at which it is moved downward will

depend on the soil type, for example there is less downward migration in clay soil. Downward migration in soils varies between 0.1 and 1 cm per year. Plutonium may be moved upwards by mycelium and subsequently dispersed into the air in airborne spores. It may be absorbed by microorganisms which are food for protocoa and nematodes. These may then move the plutonium upwards towards the surface. While downward movement will be the main factor there are also a number of ways in which plutonium will move upwards in the soil.

The uptake of plutonium by plant roots is likely to be small, less than one ten thousandth per year, although the proportion will be higher for plutonium in soluble compounds. The proportion is greater if there are more organic ligands and micro organisms present. Plutonium can also be deposited on plants from the resuspension of material on the surface of the soil. A high proportion of material which is resuspended will be very close to the ground and so could be deposited on plants. Particular plants show greater ability to concentrate plutonium, eg the lichen which is eaten by reindeer in Northern Scandinavia.

Animals are likely to inhale some plutonium through inhalation of resuspended particles. The primary intake for herbivores is likely to be through food. Of the plutonium taken in as food, a proportion of 1 in 10,000 is likely to be subsequently deposited in the bones and liver. Relatively large amounts of plutonium will cause cancers in a range of animals which have been used in experiments.

Response of Emergency Services

Fire fighting

If there is a fire in the immediate vicinity of the warhead then fire crews could be in great danger. MoD guidelines indicate that if the weapon is jetting, hoses should be tied down onto the warhead before fire crews withdraw. Elsewhere the guidelines say that if the weapon is jetting the high explosive may be about to detonate. By remaining in the area to fix hoses fire crews may reduce the chance of a major nuclear accident, but they will be at great personal risk if the warhead was to explode, both from the explosion and from radiation. In addition fire crews may not be able to tell whether it is the high explosive or other materials which are on fire. Contrary to the information given in the guidelines to local authorities, training manuals used at the Naval College in Greenwich say that it will probably not be possible to distinguish between the flames from high explosives and those from other materials.

Detection of alpha radiation

Detection of alpha radiation would be a major problem. Local authorities would have to rely on detection equipment provided by the MoD much of which would not arrive until 24 hours after the incident. The immediate response would be based on computer predictions from Aldermaston rather than on readings taken on the ground. The actual dispersion would vary from the computer model. It would also be difficult to assess how much plutonium people have inhaled. It is not possible to detect a particle of plutonium from outside the body. Plutonium intake is normally assessed by measuring the amount of plutonium which is removed from the body in urine.

Immediate area

The MoD guidelines contain contradictory information about what should be done in the immediate area around a nuclear weapons accident. The explosives hazard and the immediate radiation hazard demand that the area be evacuated as quickly as possible. However there is also concern that people and vehicles leaving the area would be taking with them plutonium dust. Decontamination facilities would be set up to process everyone and all vehicles before they left the area. The demands of immediate evacuation and of contamination are not easily reconciled.

5.4 EXAMPLE OF A WARHEAD TRANSPORT ACCIDENT

Effect of a nuclear weapons accident in Glasgow city centre

If an accident took place while nuclear weapons were being transported through the centre of Glasgow, and there was a conventional explosion then plutonium would be dispersed downwind. Calculations have been carried out to determine the effect that a nuclear weapons accident on a naval vessel could have on the city of New York[24]. This has been used as the basis for this example with some modifications. It is assumed that the wind is from the South West, the prevailing direction, with a wind speed of 4 m/s, around 9 mph, and average air stability, Category D. It is assumed that a total of 2 kg of the plutonium is dispersed in particles small enough that they are likely to be retained in the body.

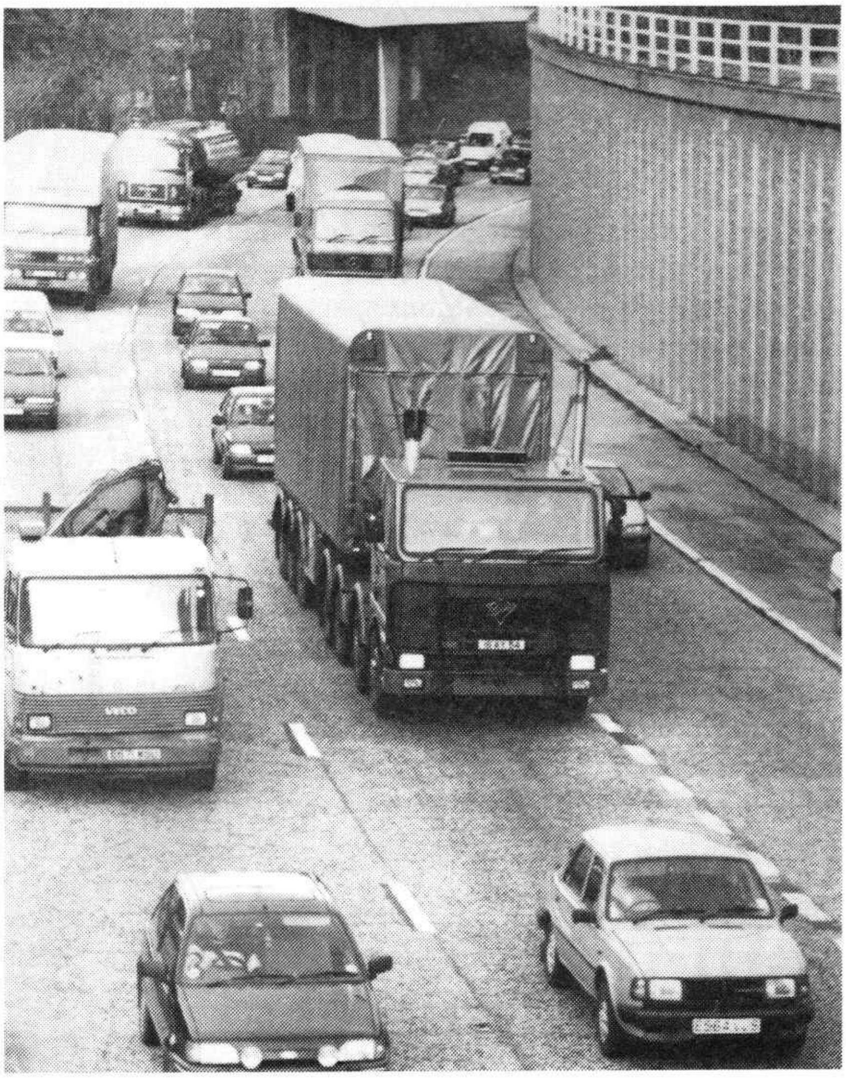
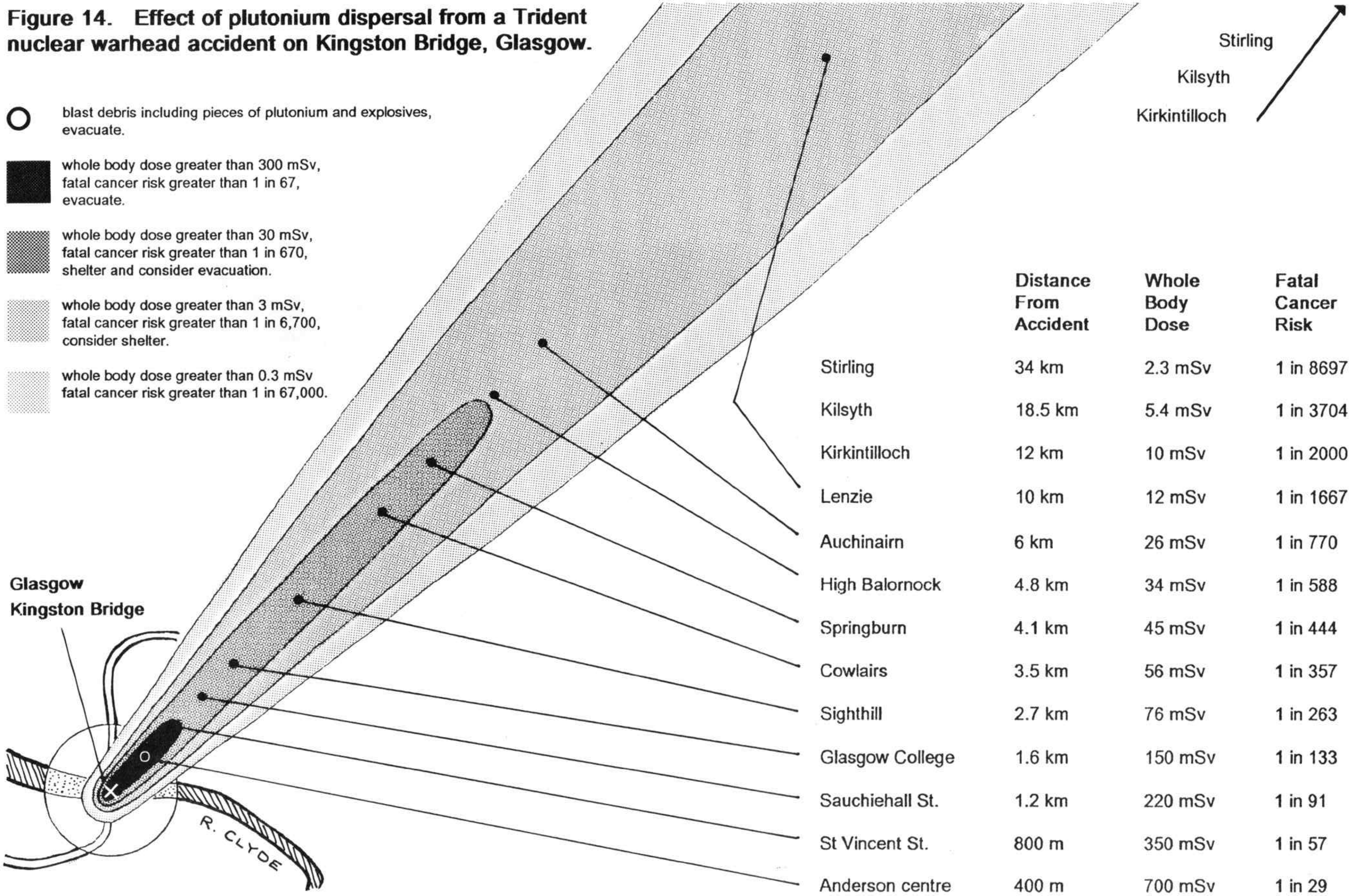


Figure 13.

This vehicle was transporting nuclear warheads on the M8 through the centre of Glasgow on 19th February 1993. 30 minutes earlier there was an accident here involving a police car escorting the convoy.

Figure 14. Effect of plutonium dispersal from a Trident nuclear warhead accident on Kingston Bridge, Glasgow.



	Distance From Accident	Whole Body Dose	Fatal Cancer Risk
Stirling	34 km	2.3 mSv	1 in 8697
Kilsyth	18.5 km	5.4 mSv	1 in 3704
Kirkintilloch	12 km	10 mSv	1 in 2000
Lenzie	10 km	12 mSv	1 in 1667
Auchinairn	6 km	26 mSv	1 in 770
High Balornock	4.8 km	34 mSv	1 in 588
Springburn	4.1 km	45 mSv	1 in 444
Cowlairs	3.5 km	56 mSv	1 in 357
Sighthill	2.7 km	76 mSv	1 in 263
Glasgow College	1.6 km	150 mSv	1 in 133
Sauchiehall St.	1.2 km	220 mSv	1 in 91
St Vincent St.	800 m	350 mSv	1 in 57
Anderson centre	400 m	700 mSv	1 in 29

The map in figure 14 shows the effect of the passage of the cloud of plutonium dust. The shaded areas show estimated whole body radiation doses. 300 mSv is the NRPB upper ERL above which evacuation is recommended. 30 mSv is the lower ERL at which evacuation should be considered and the upper ERL at which sheltering is recommended. 3 mSv is the lower ERL at which sheltering should be considered. The risk of fatal cancer in particular places is shown, estimated on the basis of the ICRP risk factor. From the map it can be seen that sheltering should be considered at 28 km from the accident and evacuation should be considered at 5 km.

Other accident models

An example of the effect of an accident is contained in an official US model (NARP). The dose levels and response at given distances are shown in figure 15.

Figure 15. US nuclear weapons accident scenario (NARP)

Distance	**Dose (mSv)**	**Response**
0 - 2 kms	250 - 750	Evacuate
2 - 10 kms	50 - 250	Shelter & consider evacuation
10 - 35 kms	5 - 50	Consider shelter

Further information is available from details of Exercise Pantograph which was carried out by the MoD from 9th to 13th May 1988. The exercise simulated the response to a nuclear weapons accident involving an air crash[25]. Evacuation was recommended 3.5 km from the scene on a 180 ° arc; the MoD EAGL for evacuation is 100 mSv. Sheltering was recommended 10 kms from the scene for 36 hours; the MoD EAGL for sheltering appears to be 30 mSv.

The dose levels estimated in the example of an accident in Glasgow city centre are less than those in the US model above. They also appear to be compatible with the calculations from Exercise Pantograph. All three examples, the US model, the MoD exercise and the one used for this report, show that the effects of a nuclear weapons accident could be more serious than indicated in guidelines issued by the MoD to local authorities. These guidelines suggested that evacuation would only be required up to 600 m from the site and sheltering up to 5 km.

Ground concentrations of plutonium

The map in figure 14 gives radiation dose estimates from inhalation of plutonium dust in the initial cloud. The dust in the cloud will settle, in decreasing concentrations from the site. This presents a hazard as a proportion of the dust will be resuspended and could be inhaled. The resuspension factor is measured as air concentration (Bq/m^3) / ground concentration (Bq/m^2). An average factor for newly deposited material is around 10^{-6} however this can be 10^{-5} on hard surfaces and higher where there is traffic. Naval manuals recommend evacuation within 12 hours if ground concentration is higher than 2×10^7 Bq/m^2 and evacuation within 7 days if ground concentration is higher than 2×10^6 Bq/m^2. While these levels might only be exceeded generally within 1 km of the site and at hot spots further afield, lower levels would present a long term hazard over a wide area.

5.5 NUCLEAR WARHEAD ACCIDENT ON A SUBMARINE

There is the potential for a very major nuclear warhead accident on a submarine. One Trident submarine could be armed with as many as 96 nuclear warheads in a small area without adequate blast protection between the warheads or from the missiles. In the event of a series of explosions there could be two very serious effects.

Nuclear explosion. The risk of a nuclear yield becomes significant in a complex explosion on a submarine. Blast fragments could impact on warheads from a variety of directions which would substantially increase the chance that a detonation might produce a nuclear yield. Even a very small nuclear yield, equivalent to a few kg of TNT would present a serious problem because of the generation of fission products and the effects of the intense heat on other radioactive substances and explosives.

Plutonium dispersal. The second risk is the dispersal of a very large amount of plutonium. If each warhead contains 4 kg of plutonium and there are 96 warheads on a submarine then the total amount of plutonium carried is around 0.4 tonnes. This is equivalent to 4,800 million lethal doses. Patterns of dispersal would be determined by the weather. The size of particles dispersed would affect the degree of risk to the general public. Plutonium would be dispersed over a wide area which would lead to long term agricultural restrictions and also to the relocation the local population.

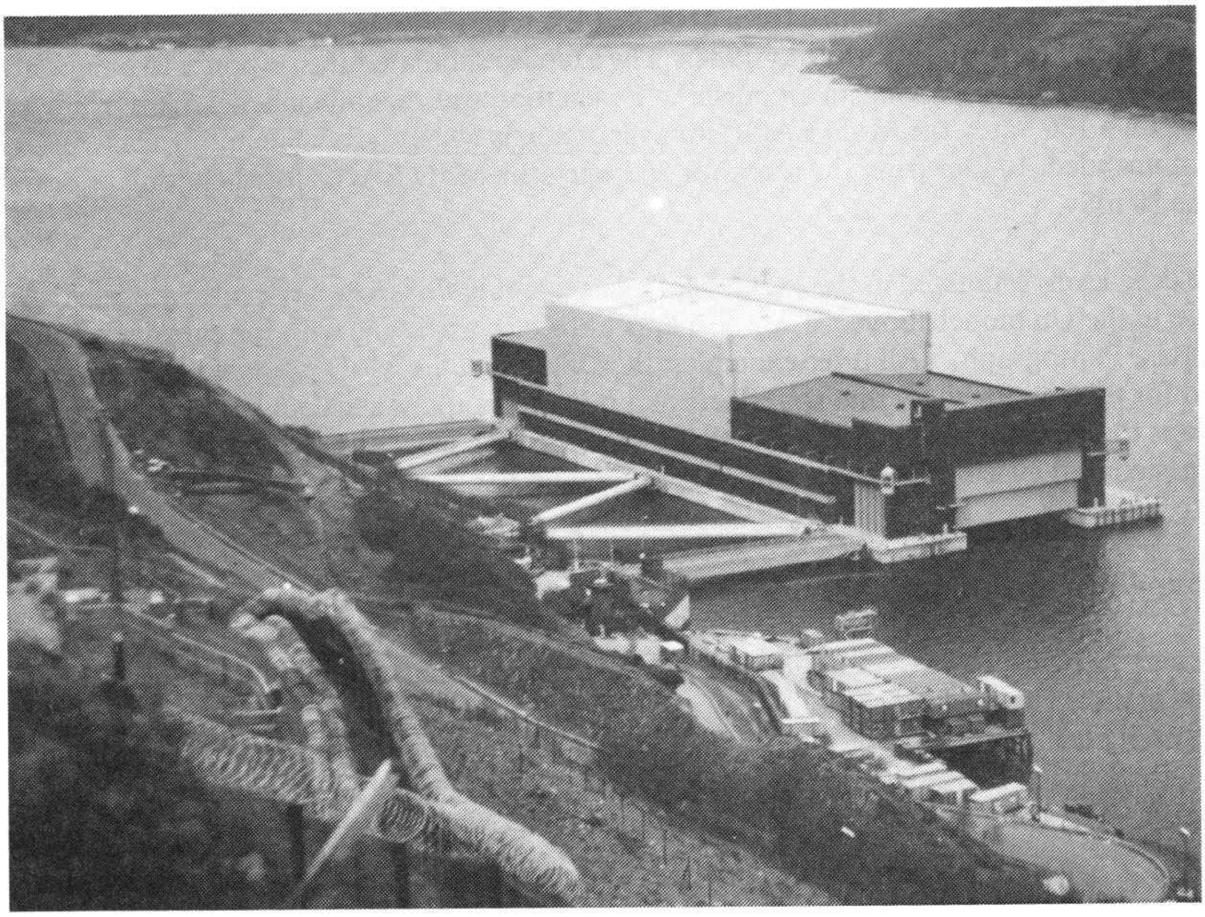


Figure 16. This is the Explosives Handling Jetty at Coulport where nuclear warheads will be placed on Trident submarines. This is the most likely scene of a major accident which could involve both a large number of warheads and the submarine's reactor. Strong winds blowing up Loch Long caused problems when HMS Vanguard berthed here for the first time on 22nd January 1994.

5.6 COMBINED REACTOR AND NUCLEAR WARHEAD ACCIDENT

The worst form of accident would be one in which not only was there a major release of fission products from the reactor, but also the dispersal of plutonium from nuclear warheads, possibly from the detonation of one or more missiles. Detailed information is not available on the effects which such an accident would have, however the result could combine the worst of a containment failure accident and a multiple warhead accident. In addition to the immediate risk to the general public from the reactor fission products and from inhaling plutonium dust, there would be long term risks from plutonium dispersal.

1 *Design information given by the US for the W76 but not fort he larger W88.*

2 *T Cochran et al op cit Vol 1 p74, 27; The W76 is not a full hydrogen or fussion bomb - the fussion elements, tritium and deuterium provide neutrons to make the fission process more complete.*

3 *Drell report p8*

4 *N Whitney, DNPS, 10/3/93, Report on the Progress of the Trident Programme, HC 549, 9203 p9*

5 *Mr Beaver, Deputy Controller (Nuclear) MoD, HC 549 92-3 p 12 10/3/93*

6 *1 kt released by complete fission of 0.057 kg Pu; T Cochran et al op cit Vol 1 p 22*

7 *based on stockpile figures in T Cochran et al op cit Vol 2 p 180, and 1 p 15*

8 *New Statesman 27/11/81, Guardian 24/11/81*

9 *MoD guidelines for local authorities on nuclear weapons accidents*

10 *T Cochran et al op cit & R Sutton op cit.*

11 *Encyclopedia Britannica*

12 *Drell report p23*

13 *T Cochran et al op cit Vol 1 p 70*

14 *Aldermaston -inside the citadel p 18*

15 *J Large Transportation of nuclear weapons through urban areas in the UK, 3-3.3f*

16 *Drell report p23*

17 *Hansard 17/12/92 c363*

18 *Drell report p12*

19 *The safety of UK Nuclear Weapons, CSA, MoD, Jul 92, (Oxburgh report)*

20 *Information taken from D Sumner et al op cit; J Large op cit; Manuals from Greenwich Naval College; International Physicians for the prevention of nuclear war, Plutonium Deadly Gold of the Nuclear Age, International Physicians Press, 1992*

21 *Plutonium Deadly Gold p14*

22 *It has been suggested that in the case of alpha radiation, the risk from very small doses may be greater than a straight line interpretation from high doses would indicate.*

23 *Information taken from: NEA, Environmental behaviour of transuranic elements, OECD, 1981*

24 *Jackson Davis, Nuclear accident aboard a naval vessel homeported at Staten Island, New York, Environmental Studies Institute, 1988. Additional use made of F Pasquill (ed) Atmospheric diffusion, Ellis Horwood, 1983; GT Csanady, Turbulent Diffusions in the environment, D Reidel, 1973.*

25 *J Large op cit pt6 p6*

6. NUCLEAR WASTE

The used fuel cores from submarine reactors are high level nuclear waste and are transported across Britain. The Trident programme produces large quantities of low and intermediate level nuclear waste and there are problems with disposal and storage.

6.1 HIGH LEVEL WASTE

Used Fuel Cores

After the fuel cores have been used in submarine reactors they cannot be reprocessed. Although there is one facility in the US which can do this work there is none in the UK and it is unlikely that the US would take used fuel from British submarines. All used fuel cores which have been in service in naval reactors to date are stored at Sellafield. Although they are classified as used fuel for reprocessing they should be considered as high level waste.

Used Fuel Core Transport

Used fuel cores have been assessed in the US as the most hazardous form of material which is transported. There have been delays in defuelling US submarines because transport and storage arrangements may be inadequate[1].

On the planned Trident programme there will be 12 used cores which will have to be transported from Devonport to Sellafield and 3 used cores from Dounreay to Sellafield. It is anticipated that these will be carried by rail with 2 containers used to transport each core . Parts of cores, modules, from submarine reactors have in the past been taken to Dounreay for post operation inspection. From Dounreay the modules should be returned to Sellafield. These modules have been moved using the same containers as for half cores. This may continue with the PWR 2 reactors.

There are serious grounds for concern about the safety of this part of the programme. From the late 1960s until 1991 used fuel from submarines was carried in Used Core Transport Packages (UCTPs). In October 1991 the Department of Transport refused to renew the special arrangement with the MoD which covered UCTPs. This was in compliance with IAEA guidelines published in 1985. Replacement containers were expected to take several years to be designed, produced and approved. A large team is currently working within the Department of Transport to resolve the issue[2].

There could be a major disaster, not unlike that described in Section 4.3, if there was a used core transport accident. This could occur anywhere on the rail routes from Devonport to Sellafield and from Dounreay to Sellafield. Privatisation of British Rail could reduce maintenance and could lead to closure of part of the rail link to Dounreay. Rail routes go through major towns and cities. UCTPs were derailed on several occasions and the problem of vandalism suggests that this is likely to occur again[3].

Processing residues

During the reprocessing of used fuel at Sellafield high level waste is produced. Some of this reprocessing has been to process plutonium for weapons purposes. High level waste will also be produced during the removal of decay products from weapons grade plutonium which is being recycled from old nuclear weapons - the MoD state that over 90% of this material is recovered but does not say what happens to the remainder.

The high level waste from reprocessing is in a liquid form. If a major accident occurred in the storage tanks at Sellafield then large amounts of long lived radionuclides could be dispersed over a wide area. If 10% of the caesium ^{137} was dispersed with the wind blowing towards Glasgow then there could be 14,000 deaths and 25,000 cases of cancer over a 30 year period, even assuming evacuation and relocation took place. There would be restrictions on agricultural produce from Dumfries to the Highlands for 20 - 30 years and severe economic disruption[4].

Dismantled nuclear weapons

After nuclear weapons are scrapped there will be substantial volumes of plutonium and HEU which result. Possibly 1.6 tonnes of plutonium and twice as much HEU. This could be considered as high level waste resulting from the Trident programme.

6.2 LOW AND INTERMEDIATE LEVEL WASTE

Total waste associated with Trident

NIREX has said that nuclear waste from defence sources could be equivalent to one sixth of all the waste in Britain[5]. The volume of low level waste which is expected to come from defence sources from 1988 to 2030 would be around 3×10^5 m^3. The volume of intermediate level waste from defence sources in the same period would be around 4×10^4 m^3. These figures would include waste from hunter killer and Polaris submarines, but not waste produced at Springfields, Capenhurst, Chapelcross, Calder Hall and Sellafield when BNF is carrying out work for the MoD. If these factors balance each other out, then around one sixth of all the nuclear waste produced in Britain can be related to the Trident programme.

Low level waste is likely to consist of clothing, wrapping materials and worn out or damaged plant, tools and equipment. Waste of this type, related to Trident, has been or will be produced at Dounreay, Faslane, Coulport, Chapelcross, Sellafield, Calder Hall, Cardiff, Aldermaston, Burghfield, Devonport, Capenhurst and Springfields. Low level waste from MoD and other establishments is transported to the BNF site at Drigg near Sellafield. In the case of Devonport, low level waste is transported to Drigg up to 8 times a year. Most low level waste is transported by road. Some low level waste from Dounreay may be transported by sea from Thurso to Barrow and then by road to Drigg. Rail transport is used to take waste from Sellafield to Drigg.

Intermediate level waste has an activity higher than low level waste. It is likely to consist of reactor fuel cladding, reactor components, chemical process residues, ion exchange resins and filters. At the moment intermediate level waste is stored on site. Intermediate waste generated from the PWR 2 prototype reactor at HMS Vulcan will be stored at Dounreay. Intermediate waste from the refuelling and refitting of Trident submarines at Devonport will be stored in a new facility. Some intermediate waste from submarines is stored at Faslane.

The Advisory Committee on the Safety of Nuclear Installations, part of the Health and

Safety Commission, have expressed concern that delays in the NIREX proposal for a deep depository for waste could compromise safety. There could be risks to workers at nuclear installations and the risk of accidental releases could be increased. There are two grounds for the Committees concern. One is that waste is being stored on site for a longer period than previously envisaged and "some of the waste storage facilities are unsuitable for long term storage, they are deteriorating ...."[6]. The other is that delays in agreeing on what type of packaging is required has created problems.

Aldermaston

The Pochin inquiry in 1978 found that there were fundamental problems with the design of plants for handling nuclear waste. Contamination was building up within these facilities and the health of workers was being put at risk. There was also poor management with containers of waste lying abandoned at various parts of the site. The Pochin inquiry recommended that new plants be built for liquid waste and solid waste as well as a waste compaction facility. The solid waste and compaction plants have not been built. The liquid waste facility, A91, has been built, however there are serious corrosion problems in the pipework. This has been attributed to the use of tap water rather than demineralised water during tests. No date has been set for the commissioning of A91. There would need to be major replacement work before it could be brought into service. The old facilities which were severely criticised in the Pochin report in 1978 are still in use 15 years later and are likely to continue to be used for years to come.

Delays in the NIREX deep storage plans have been used to justify the lack of progress at Aldermaston. It is argued that the new solid waste compaction and storage facilities have been delayed because NIREX has not yet defined the type of packaging required.

Devonport

In the early stages of a submarine refit work is carried out to reduce the levels of radiation in the reactor pipework. This MODIX process creates 10 containers of of resin per year at Devonport. Some resin is low level waste and some is intermediate level waste. The resin also has chemical contamination, due to the MODIX process. Most of the resin is stored in Resin Catch Tanks (RCTs) which were designed to be used to dump waste at sea. In July 1992, Devonport was storing 12 full RCTs in the storage building plus 7 full Magnox flasks outside the building, each holding the equivalent of 2 RCTs.

Because of the volume of intermediate level waste produced by MODIX, the MoD expect that the current storage facilities will be full by 1995. Devonport has been named in association with concerns about the how nuclear safety may be compromised by delays in the NIREX deep repository proposal[7]. There are plans to enlarge the current intermediate level waste storage facility. Storage vessels will be built from stainless steel and stored in 3 new pits[8]. The design of this facility has been criticised because it may not provide adequate shielding and because it is being built below ground level. There is also concern about the establishment of a long term nuclear waste store in the middle of a large town.

There will be space for 210 vessels in the proposed storage area. The MoD anticipate that 180 full vessels would be stored by 2010. Assuming a fleet of 4 Trident submarines and 12 hunter killer submarines, Trident would be responsible for one third of the total. This would be equivalent to 60 vessels of intermediate waste stored at Devonport in 2010. The actual number may be more due to the increased power and size of the PWR 2 reactor.

Some liquid waste is deliberately discharged into the River Tamar after treatment. There have also been a number of occasions in the past when coolant has been spilt accidentally at Devonport.

Faslane

There will be discharges into the sea of low level liquid waste from Trident submarines at Faslane. Water in the primary circuit is removed from the submarine into tanks and transferred to an Effluent Disposal Plant. The coolant is then conditioned to reduce the level of activity. At the end of this process the coolant is discharged into the sea[9]. Intermediate level waste, including ion exchange resins, will be stored at the Northern end of the base.

Chapelcross

At Chapelcross methods used for the discharge of liquid effluent in past years have been unsatisfactory. In 1992 particles of uranium were discovered near the end of the outflow pipe into the Solway Firth. This was explained as the result of earlier practice which allowed liquid effluent to be discharged before adequate time had been allowed for particles to settle so they could be removed.

Sellafield

Discharges from Sellafield are the largest source of radioactive isotopes released into the environment in the UK. The material discharged is dispersed by tidal currents to the North around the coast of Britain and to the South in the Irish Sea. Routine analysis of patients from North Uist in the Outer Hebrides showed that they had caesium ^{134} in their blood. This analysis was carried out in Glasgow and the radioactive isotope was not found in the blood of patients resident in Glasgow. It was established that caesium ^{134} was being discharged from Sellafield and carried on tidal currents to the Outer Hebrides. The isotope may have found its way into the human food chain through the consumption of local sheep which graze on the foreshore. Traces of plutonium and americium have also been found at a number of sites on the shore of North Uist. These too are believed to have come from Sellafield. It had previously been argued that while lighter elements, such as caesium, would travel long distances, this would not apply to heavy metals[10].

In addition to the widespread distribution of radioactive discharges there is a high concentration in areas near the site, in particular on coast in West Cumbria and the Solway Firth. A survey conducted by the Scottish Universities Reactor and Research Centre is reported as having found that there are radioactive hot spots in the Cree, Nith, Dee, Urr and Fleet estuaries in the Solway Firth. Fishermen, nature wardens, bird watchers and children playing in the banks of the rivers could be particularly at risk. Around a dozen coastal Sites of Special Scientific Interest may be polluted with caesium ^{137} beyond the accepted NRPB limits. The Royal Society for the Protection of Birds (RSPB) is concerned about the effect on birdlife in the estuary which has 120,000 visiting birds in Winter including the world population of Scalbard barnacle geese and half of the British population of Scaup duck. Chris Rollie of the RSPB has said "the Solway Firth ... is undoubtedly the most radioactively polluted in Scotland"[11].

Discharges from Sellafield have included substantial quantities of plutonium. A BNF report written in 1992 showed that levels of Pu ^{239} in the 1950s and early 1960s were more than 200 times the figures which had previously been revealed[12].

Submarine decommissioning

When Trident submarines are withdrawn from service there will be a considerable problem with what to do with them. The initial part of decommissioning is similar to defuelling during refit. However this leaves the long term problem of what to do with the reactor itself and the surrounding hull. It is possible to reduce substantially the levels of radiation in components of the reactor. This can partly be done by time and partly by chemical processes. The chemical processes produce nuclear waste. At the end of this there will be a large volume of low level waste and a smaller volume of intermediate waste. Large parts of the submarine hull will remain radioactive. A number of solutions have been proposed. The MoD would like to fill the submarines with concrete and sink them in the Atlantic but future monitoring would be difficult, recovery virtually impossible and there would be international objections. Shallow burial on land is another option, a number of American submarines have been dumped this way. Cutting the submarine up into small sections could be carried out and the sections then packaged and dumped in the NIREX deep depository. Cutting work would expose workers to higher levels of radiation than the other options. There is no easy answer to the question of what to do with a decommissioned submarine. When the Royal Navy first introduced nuclear powered submarines they did not even consider this issue. Almost 30 years later, they have still not been able to find a solution.

1 *Washington Post*

2 *UCTP information from Hansard 27/11/92, 14/12/92, 17/12/92, 21/20/92, 27/1/93, 5/2/93, Scotsman 19/2/92, 29/6/92, 27/11/92 and Plymouth DIG.*

3 *M Bond, Nuclear Juggernaut, Earthscan, 1992. p42*

4 *Preliminary report for Nuclear Free Local Authorities, Peter Taylor, 12/12/93*

5 *Defence waste equal to 20% of civil, NIREX, The Way Forward, p6*

6 *Observer Oct 93*

7 *ibid.*

8 *Plymouth DIG - minutes of meeting with MoD, Plymouth Civic Centre, 1/7/93.*

9 *Faslane Features, Spring 1993, p12*

10 *Scotland on Sunday 1/12/91*

11 *Scotland on Sunday 8/8/93*

12 *Guardian 10 /11/93*

7. EXPOSURE OF WORKERS AND SAILORS

Radiation records are kept for a large number of servicemen and workers who are involved in nuclear work for the MoD[1]. The number who would be exposed to radiation in the normal course of work related to the Trident programme is difficult to assess. In 1989 radiation records were kept for 377 personnel at HMS Vulcan, Dounreay. The PWR 2 prototype reactor is only for use on Trident submarines so all these can be considered as Trident related posts. The number in Trident related radiation posts at Faslane and Devonport from 1998 onwards is probably around half the 1989 totals which were 316 at Faslane and 2,394 at Devonport. Of the 3,842 monitored at Aldermaston a high proportion would have been involved in Trident work in 1989. The number of monitored personnel involved in Trident work at Coulport in the future could be higher than the total figure of 188 monitored in 1989, because of the increased number of warheads and changes to procedures in 1990.

The average collective exposure in one year at the Atomic Weapons Establishments between 1985 and 1989 was 2.34 man Sv. If Trident warhead production is continued from 1988 to 1998 then the total collective exposure during this period would be expected to be around 23.4 man Sv. The average annual collective exposure for the Naval Nuclear Propulsion Programme from 1985 to 1989 was 11.63 man Sv. If the Trident programme accounted for one third of similar work over a 25 year period this would be expected to result in a total collective dose of around 96.92 man Sv.

The accumulated doses which had been received by workers employed in 1989 in the Naval Nuclear Propulsion Programme (NNPP), at the AWEs and at RNAD Coulport are shown in figure 17.

Figure 17. Accumulated dose for workers in the NNPP, AWE & Coulport 1989
[Component figures have been deduced from percentages]

Accumulated Dose (mSv)	Personnel
0 - 50	9617
50 - 100	553
100 - 200	278
200 - 300	95
300 - 400	28
400 - 500	9
> 500	1
Total monitored employees	10587

There have been reports associating children's health with their father's exposure to radiation at work. There is speculation that submariners who served as sentries outside the reactor compartment while welding work was carried out on submarines in refit may have been particularly at risk. There may have been a particular problem with regard to the first refit of HMS Resolution in 1971-72 which could explain the 7 or more cases of deformities amongst children of the crew. The cases include several of children born with hare lip and cleft palate and one of brain damage[2].

There has been speculation for several years about the existence of clusters of leukaemia and other specific cancers around nuclear establishments. These include Capenhurst, Springfields and Aldermaston. In Scotland this phenomena is noted for particular years, for 1979-83 at Dounreay, for 1979-83 at Chapelcross and for 1974-78 for Rosyth[3]. A recent 15,000 case study has concluded that the chance of cancer occurring in the children of men who would have inhaled radioactive dust in their work was 2.7 times greater than normal[4].

The number of cases of childhood leukaemia around Sellafield was the subject of an extensive study, the Gardner report. Since this was published alternative explanations have been presented. In a detailed follow up to the Gardner report the HSE found that there was a significant association between leukaemia and the offspring of workers from Sellafield who were resident in the village of Seascale. The report examined where and when the father worked in Sellafield. There were found to be significant associations with father working in the Calder Hall part of the site and also with exposure to Tritium. The HSE report does not make any connections with military work, however Calder Hall was built to produce plutonium for nuclear weapons and Tritium is produced at Chapelcross for nuclear weapons[5].

Exposure to plutonium dust may be a major factor in problems amongst children. Dr Tom Sorahan of the Oxford Study of Childhood Cancers has said: "My own feeling is that alpha emitters like plutonium are going to prove an important pathway through fathers to their unborn children"[6].

The effect of radiation on workers themselves is illustrated by the case of Rudi Molinari who contracted leukemia after working on nuclear submarines. In December 1993 he was awarded £167,000 damages by the MoD.

1 *Figures published in Radiological protection of service and civilian personnel, House of Commons Defence Committee, HC 479 1989-90*
2 *Evening Times 16/2/88, also reported as 10 cases Sunday Mail 22/3/92*
3 *Letter from Scottish Office to SCND 23/12/86*
4 *Safe Energy*
5 *Sellafield and Leukemia, HSE Oct 93.*
6 *Safe Energy Apr/May 93 p5*

8. GEOGRAPHICAL ASSESSMENT

The transport of radioactive materials for Trident across Britain, the potential deployment of submarines around the Atlantic and the worldwide effects of the Chernobyl disaster all suggest that the hazards of the Trident programme are very far reaching. The dangers are everywhere, but are particularly great in a few key areas.

The most dangerous stage in the handling of nuclear weapons is their final assembly at Burghfield. Tritium replacement in the RBPB at Coulport is also hazardous. During the transport of nuclear weapons the chance of a release of radioactive material may be less, but the consequences could be greater if the accident occurred in a built up area.

The chance of a missile handling accident is probably greatest during missile test firing in the US Eastern Test Range and during missile loading at Kings Bay. The dangers of a reactor incident are particularly high during defuelling which will be carried out at Devonport, within a major built up area.

The conditions for a worst case accident involving both the nuclear reactor, missiles and nuclear warheads exist while Trident submarines are fully operational. During trials and patrols the submarines will operate in the North Atlantic and other areas. Submarine movements are most frequent in the Clyde estuary. There are also significant movements in the North of the Irish Sea and along the West coast of Scotland, especially in the Inner Sound.

The dangers inherent in the Faslane shiplift and in warhead loading procedures at the EHJ at Coulport suggest that there is a particular risk of a combined reactor - missile - nuclear warhead accident at these two locations. The range of other tasks carried out at Faslane and Coulport and the total length of time which vessels would spend there increases the possibility of an accident in Gareloch or Loch Long.

Particular types of accident present a high risk to Burghfield, Devonport and Kings Bay. The greatest risk is at Faslane, Coulport and the Clyde estuary due to the frequency of Trident submarine operations and the possibility of an accident involving nuclear weapons, missiles and/or the nuclear reactor.

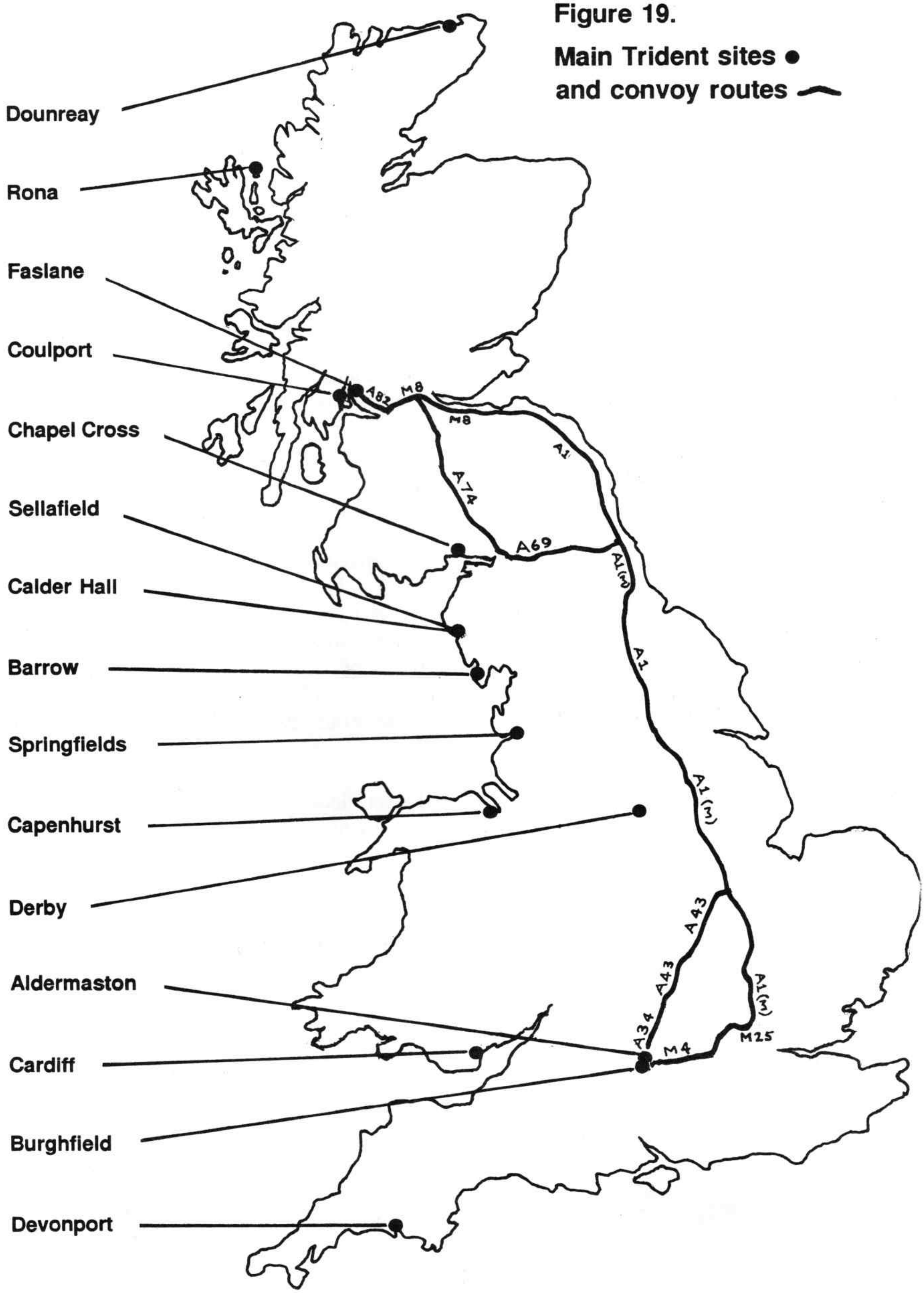
Figure 18 illustrates the locations associated with key parts of the Trident programme. The number of times operations are likely to be carried out has been estimated. The map in Figure 19 shows the main locations in Britain associated with Trident.

FIGURE 18 TRIDENT PROGRAMME - ACCIDENT POTENTIAL

Stage	Risk	Location (frequency)
uranium mining	U	Canada, US, Australia
uranium conversion	U	Springfields
HEU enrichment	H	Capenhurst
HEU transport	H	Capenhurst - Portsmouth US; Capenhurst - Aldermaston
HEU final enrichment	H	Portsmouth US
reactor HEU transport	H	Portsmouth US - Aldermaston
plutonium production	C	Windscale, Calder Hall, Chapelcross,
used core transport	C	Chapelcross - Sellafield
reprocessing	CP	Sellafield
plutonium transport	P	Sellafield - Aldermaston
tritium production	T	Chapelcross
tritium transprort	T	Chapelcross - Aldermaston - Coulport
nuclear tests	W	Nevada test site US
warhead manufacture	HPT	Aldermaston (400)
warhead assembly	W	Burghfield (400)
warhead delivery	W	Burghfield - Coulport (200 vehicles)
warhead storage	W	Burghfield, Coulport RBM
replace warhead tritium	TW	Coulport RBPB (1600)
reactor HEU transport	H	Aldermaston - Derby
new core contruction	H	Derby (15)
new core transport	H	Derby - Barrow (4); Derby-Dounreay (3); Derby-Devonport (8)
new core load	R	Barrow (4) Dounreay (3) Devonport (8)
initial power range tests	R	Barrow (4) Dounreay (3) Devonport (8)
initial sea trials	R	Faslane, L. Goil, Clyde, Skye, sea (4)
post refit sea trials	R	Faslane, L. Goil, Clyde, Skye, sea (8)
missile transport	M	Salt Lake City - Kings Bay US
missile load for tests	RM	Kings Bay US (4 x 4)
full missile load	RM	Kings Bay US (12 x 16)
missile unload	RM	Kings Bay US (12 x 16)
missile test firing	RM	Eastern Test Range US (4 x 4)
warhead/missile mating	RMW	Coulport EHJ (1200 - 2400)
unload armed missiles	RMW	Coulport EHJ
load armed missiles	RMW	Coulport EHJ
store armed missiles	MW	Coulport RIMs
routine maintenance	RMW	FaslaneFinger Jetty
maintenance docking	RMW	Faslane Shiplift (150)
reactor start up	RMW	Faslane / Coulport (300)
pre patrol trials	RMW	Clyde / sea (150)
noise ranging	RMW	Loch Goil (150)
torpedo loading	RMW	Faslane finger jetty
sonar range	RMW	Rona, Skye
torpedo firing	RMW	Inner Sound, Applecross; Bahamas
patrol	RMW	Clyde - sea (150)
defuel reactor	R	Devonport (12) Dounreay (3)
used core transport	R	Dounreay -Sellafield (3); Devonport - Sellafield (12)
used core inspection	R	Sellafield - Dounreay - Sellafield
used core storage	R	Sellafield (15)
warhead return	W	Burghfield - Coulport (200 vehicles)
warhead dismantling	W	Burghfield (400)

	MATERIALS		MAJOR RISKS
U	Natural Uranium	C	Magnox / Graphite reactor core
H	Highly Enriched Uranium	R	Submarine reactor core
P	Plutonium	M	Missile
T	Tritium	W	Nuclear Warhead

Figure 19.
Main Trident sites • and convoy routes



9. CHRONOLOGICAL ASSESSMENT

Some work related to Trident was done several decades ago. The construction work was at a peak around 1992. However a large proportion of the overall risk lies in the future, as the number of warheads and the number of irradiated fuel cores steadily increases. The hazards associated with submarines carrying nuclear missiles will be from 1994 to 2022.

Materials Production

Britain has had facilities to produce weapons grade plutonium at Windscale from 1950 to 1957, at Calder Hall since 1956 and at Chapelcross since 1958. Weapons grade plutonium could also be produced at other magnox reactors. Plutonium produced in the earlier years, which was not used in bombs exploded in nuclear tests, will have been recycled for use in future weapons. Some Trident warheads will contain plutonium produced in the 1950s and 1960s and other warheads will contain plutonium produced more recently. Likewise the HEU will be from a stockpile which includes recently enriched HEU as well as some enriched many years ago. The HEU for PWR 2 reactors should be delivered 5 - 7 years before the fuel core is loaded and so would be delivered from 1981 to 2010. It is possible that less than half of the enrichment work for this has been completed so far.

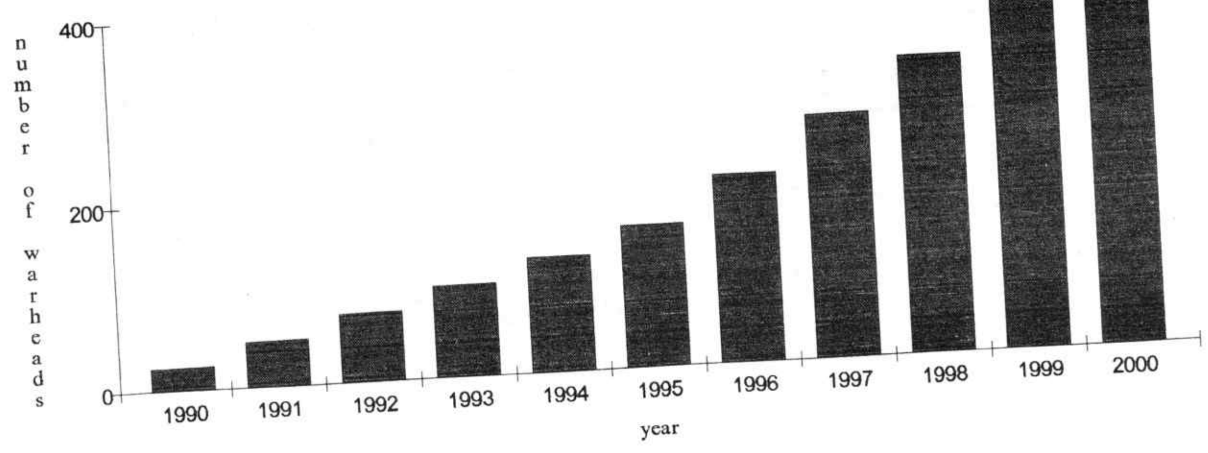
Weapons Production

There are two indications of the warhead production capacity.

a. It was originally planned to produce all the nuclear warheads for Trident in the A90 facility at Aldermaston within 8 to 10 years. Assuming a stockpile target of 400 warheads this suggests that A90 would have a production capacity of between 40 and 50 warhead pits per year. The A45 facility has a production capacity less than half that of A45 - "the rate within the current facilities is under half the initial rate for the new facilities"[1]. This suggest that A45 could produce 20 to 30 warheads per year.

b. The production programme was altered and it was decided to produce all the warheads for HMS Vanguard and a proportion of the warheads for HMS Victorious in

FIGURE 20. STOCKPILE OF TRIDENT WARHEADS



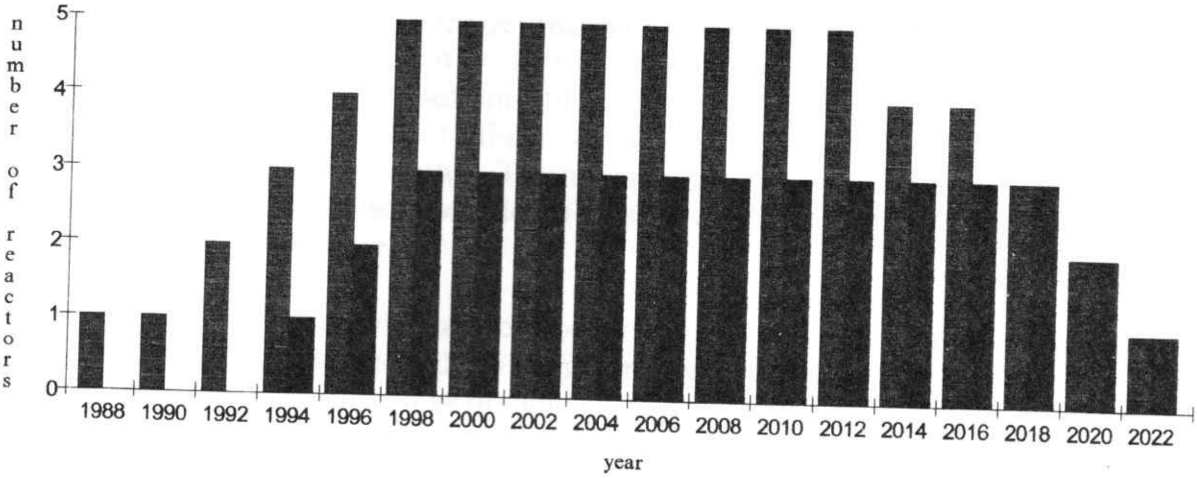
45. The first Trident warhead pit was produced from A45 in December 1988. At the time it was assumed that A45 would be replaced by A90 during 1992, which implies that it was planned to produce around 100 in A45 during a 4 year period. This suggest that A45 could produce around 25 warheads per year.

Combining these two approaches, it would appear that A45 has a production capacity of around 25 warheads per year and A90 of around 50 warheads per year. There will be a gap of several months between pit production and when the warhead is completely assembled. Figure 20 shows an estimate of total stockpile of fully assembled Trident nuclear warheads.

Nuclear Weapons Transport

If each vehicle carries 2 Trident warheads then 50 vehicle movements would be required to deliver warheads whose pits were produced in A45 between 1989 and the end of 1992. All nuclear weapons convoys visiting the Trident area from July 1992 to January1994 have been recorded. Taking account of the need to rotate Chevaline warheads the number of vehicles delivering Trident warheads was between 38 and 51, which could have been carrying between 76 and 102 warheads. Delivery of the warheads which have still to be built would require a further 150 vehicle movements between 1994 and 2000.

FIGURE 21. REACTORS IN SERVICE

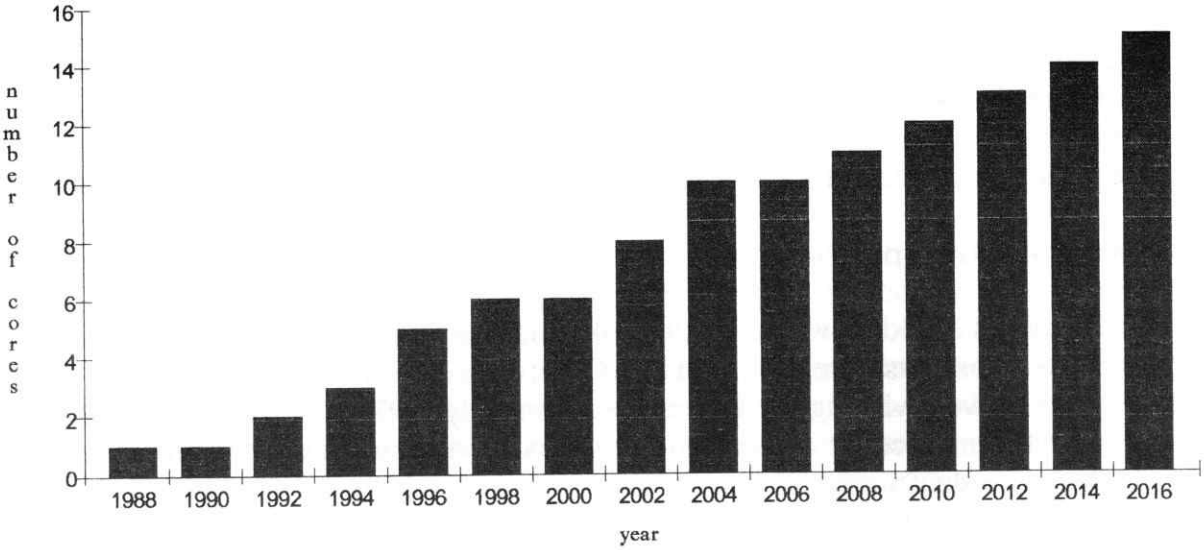


Naval Reactor life cycles

Each PWR 2 reactor is due to be refuelled twice, ie to use up 3 cores. The prototype at Dounreay was the first reactor to be made critical in July 1987, followed by HMS Vanguard in 1992 and HMS Victorious in 1993/94. The remaining two Trident submarines reactors will be made critical around 1995 and 1997. Figure 21 shows the total number of PWR 2 reactors in service between 1988 and 2022 (shaded). It also indicates how many reactors are in submarines which are armed, ie carrying missiles and nuclear warheads (black). It is anticipated that this will rise to three and remain at that level.

The fuel core in a reactor is irradiated when it is made critical for the first time and it remains irradiated after the reactor has been defuelled and for many years to come. So the total number of irradiated fuel cores will rise steadily throughout the period Trident is in service. These irradiated fuel cores represent one of the main hazards of the system. Figure 22 shows the cumulative total of irradiated fuel cores from Trident submarines and Dounreay.

FIGURE 22. IRRADIATED FUEL CORES (CUMULATIVE)



1 *Mr Mabberley, 21/3/89 Progress of the Trident Programme, House of Commons Defence Committee; HC374 88-89 p4.*

10. EFFECTS OF THE USE OF TRIDENT IN WAR

The bomb dropped on Hiroshima on 6 August 1945 was estimated to have a yield of 12.5 kilotons[1]. It has been calculated that 130,000 people died immediately or within 3 months. A further 70,000 died in the following 5 years. The bomb dropped on Nagasaki was estimated to have a yield of 22 kilotons. It has been calculated that between 60,000 and 70,000 died immediately or soon after and a further 50,000 died in the following 5 years. In both cases over 80% of those living within 1 km of the site of the explosion died and over 50 % of those living within 1.5 kms. There were also a wide range of health problems found in survivors.

One British Trident warhead is estimated to have a yield of 100 kilotons. This is 8 times the yield of the bomb dropped on Hiroshima and 4.5 times the yield of the bomb dropped on Nagasaki. The number of deaths which would result from the use of one Trident warhead would depend on where it was detonated and at what altitude. The explosion of one Trident warhead in a large built up area would result in fatalities several times more than recorded for Hiroshima and Nagasaki.

The use of one Trident warhead against a specific military target would be likely to result in significant civilian casualties, given that there would be at least small centres of population close to the explosion. Many military bases are not in isolated situations but are near large towns and cities.

The warhead mixture on a Trident submarine could consist of 4 missiles each with 1 nuclear warhead, 2 missiles with 6 warheads and 10 missiles with 8 warheads, giving a total of 96 warheads. It is likely that Trident submarines will carry targeting data to enable missiles to be fired against the city of Moscow. Taking into account the use of decoy RVs and the effect of Moscow's Anti Ballistic Missile defences, it would only need 3 or 4 Trident missiles to destroy the city of Moscow.

The independently targeted warheads can be used against separate targets, so long as the targets are all relatively close together - within an area of around 150 km by 500 km. If 96 warheads were used against a range of military targets it is likely that hundreds of thousands of civilians of all ages would be killed. Deliberate use against civilian targets could result in the destruction of 96 large towns and cities.

The operational cycle for Trident submarines is likely to mean that in addition to the submarine on patrol, a second vessel would be in reserve. If all the missiles on both were used this would give a total of 192 warheads.

The total impact from the explosion of nuclear weapons is much greater than the initial damage and fatalities. There would be long term radiation hazards, social disruption and widespread ecological damage.

1 Information on Hiroshima and Nagasaki is from the official report by the Committtee for the compilation of materials on damage caused by the atomic bombs in Hiroshima & Nagasaki, translated by Ishikawa and Swan, Hutchinson, 1981

CONCLUSIONS

1. Production and development.

The mining of Uranium puts miners and the general public at risk from radioactive dust. There are toxic risks associated with the conversion of natural uranium and there are criticality and fire risks associated with the enrichment of uranium.

Plutonium may be used in Trident which was produced at Windscale, scene of an accident in 1957. Plutonium produced at Chapelcross around the time of a serious incident in 1967 may also be used. The embrittlement of pressure vessels could cause a major accident at one of the plutonium production reactors at Chapelcross and Calder Hall. Plutonium is processed at Sellafield where an HSE inspection in 1986 found many facilities substandard. The production of tritium at Chapelcross may lead to birth defects and health problems. Warhead components are machined in facilities at Aldermaston which were criticised by the Pochin inquiry in 1978 and also by a former Director of the establishment.

2. Warhead assembly, transport and storage.

An explosion resulting in the release of plutonium to the atmosphere could occur during the joining of fissile and high explosive components at Burghfield.

A number of factors contribute to the dangers associated with the transport of nuclear warheads. Procedures for tying down containers within vehicles may not be sufficiently rigorous. There have been brake problems with the vehicles and on three occassions tractor units of the articulated lorries have been replaced on major public roads. The fact that vehicles travel in convoys may in itself increase the likelihood of an accident. Between 1982 and 1992 transporters were involved in an off-road accident, a collision between 2 transporters, a fatal accident and an incident where a gas main exploded. The transport of explosives and nuclear material together is illegal on safety grounds for everyone except the MoD.

An accident could occur while tritium is replaced on nuclear warheads at Coulport or during the transport and handling of warheads and missiles in the depot. There is the potential for one detonation to trigger other explosions with a domino effect.

3. Submarine

There are two main concerns on a Trident submarine, the reactor and the missiles. An accident may be initiated in the reactor compartment or the reactor may be involved in an incident initiated elsewhere. Missiles may detonate as a result of heat, shock, pressure, electromagnetic radiation or the detonation of explosive components. A missile explosion could affect the reactor and vice versa.

Submariners are under stress because of their unusual circumstances. There are particular problems with missiles submarine patrols whose duration may be extended at the last minute. The stress on family life can lead to a loss of experienced personnel. Ultimate control is in the hands of the Captain who is not primarily a nuclear reactor officer. Strict discipline may be a disadvantage if reactor operators are ordered to carry out unsafe procedures. In the event of an accident the Captain on a submarine has to consider a wider range of concerns than his counterparts in charge of a land based reactor.

The limitations of computer software could compromise the safety of land structures and of the handling of a Trident submarine at sea.

It is likely that Trident submarines will collide with other vessels and this is most likely near Faslane. A collision with another submarine could be particularly dangerous. There are likely to be fires which could be both a direct danger and an indirect danger if fumes prevent crew members from carrying out essential safety procedures. Torpedoes are a serious danger because both the fuel and the explosives can detonate. There are many new systems on Trident submarines which could go wrong.

There are particular hazards associated with loading and unloading missiles, with fixing and removing nuclear warheads, with using the Faslane shiplift and with defuelling the reactor at Devonport.

4. Reactor accidents

In a core damage accident submariners and workers could be exposed to radiation. Defuelling would be problematic. According to the Navy, in a Loss of Coolant Accident there would be radiation problems in the immediate area.

A containment failure accident would be more serious. In the 10,000 reactor years worldwide, to date there has been one such incident on a Soviet submarine. Estimates based on Navy training manuals show that evacuation of the general public should be considered at 30 kms downwind of the site, iodate tablets issued within 80 kms and sheltering considered within 100 kms. This type of accident could be on a scale comparable with Chernobyl. There is no guarantee that local authorities would be informed soon enough.

If a Trident submarine sank there would be long term hazards when fission products from the reactor and plutonium from warheads were dispersed into the sea

5. Warhead accident.

The warhead is probably based on a US design. A US report criticised the lack of priority given to safety in warhead design. The combination of plutonium and high explosives is dangerous, warheads can explode because of the effects of heat, shock or pressure.

The main result of a nuclear weapons accident would be the dispersal of plutonium - a nuclear explosion is possible but less likely. The risk from plutonium dispersal comes from very small particles which can be inhaled and remain in the body for 40 years. Alpha radiation can cause cancer or genetic problems. One warhead may contain 50 million lethal doses of plutonium. Plutonium remains a radiation hazard for thousands of years and during this time it will move around the environment. Emergency services would face dilemmas because of the risk to fire crews, the difficulty of monitoring alpha radiation and the conflicting requirements of evacuation and decontamination. It is estimated that in an accident involving one warhead, evacuation of the local population should be considered at 5 kms downwind and sheltering at 28 kms. An accident could occur on a submarine or at Coulport involving many warheads and the risk of a nuclear explosion would be more significant. If there was a containment failure reactor accident combined with the dispersal of plutonium from warheads then there would be major problems of long term contamination in addition to the dangers to the general public at the time.

6. Nuclear Waste

The used fuel from Trident reactors will present a long term hazard as high level nuclear waste. It is a particular danger when it is being transported. The Trident programme may account for around a sixth of all nuclear waste produced in Britain. The storage of intermediate level waste on site is a growing problem as facilities are not adequate for the long term storage which is required. Old inadequate waste treatment and storage facilities are still in use at Aldermaston, 15 years after they were criticised by the Pochin inquiry. The design of a new store at Devonport may be unsatisfactory. Sellafield is a major source of radiation in many areas including the Solway Firth and Western Isles. When Trident submarines are scrapped this will create large volumes of nuclear waste. The MoD has not yet produced any reasonable proposals on what to do with scrapped submarines.

7. Exposure of workers and military personnel to radiation

Several thousand workers and submariners will be exposed to radiation in the normal course of their work because of Trident. There is evidence which links radiation exposure with a number of health problems, including inherited problems in children.

8. Geographical assessment

The hazards of Trident affect all of Britain and beyond. The risks of particular types of accidents are highest at Burghfield, Kings Bay and Devonport. The overall risk is greatest on the West coast of Scotland in particular near Faslane and Coulport where a combined reactor / missile / warhead accident is most likely.

9. Chronological assessment

The number of irradiated fuel cores from Trident will increase in future years. The production of warheads is still at an early stage in 1994. It will be around 1997 before there are 3 submarines carrying Trident missiles. The dangers of Trident are largely in the future. The operational hazards would be for 30 years but the dangers from used cores and plutonium would be around for thousands of years.

10. Effects of the use of Trident in war

Each of the 400 Trident nuclear warheads will be 8 times the power of the bomb dropped on Hiroshima. There would be massive civilian casualties and environmental damage if they were ever used.

11. Overview

The environment has been, is being and will be put at risk from radiation associated with the Trident programme. While the dangers are greatest at a few key sites and in particular on the Clyde, there are many places within the UK and beyond which are being or could be affected. As well as the risk of a major accident there are also the hazards associated with the routine production, handling and disposal of radioactive material.

Trident is designed only in order to threaten and effect massive devastation and so there is no public benefit against which the risks can be balanced. A price has already been paid in damage to the environment and will continue to be paid over thousands of years. However the dangers are increasing and it is in the future that we will have to face the risks associated with operating fully armed Trident submarines and using shore facilities and practices which are unsafe. The hazards cannot be eliminated, but can be substantially reduced if the decision is made now to halt the Trident programme.

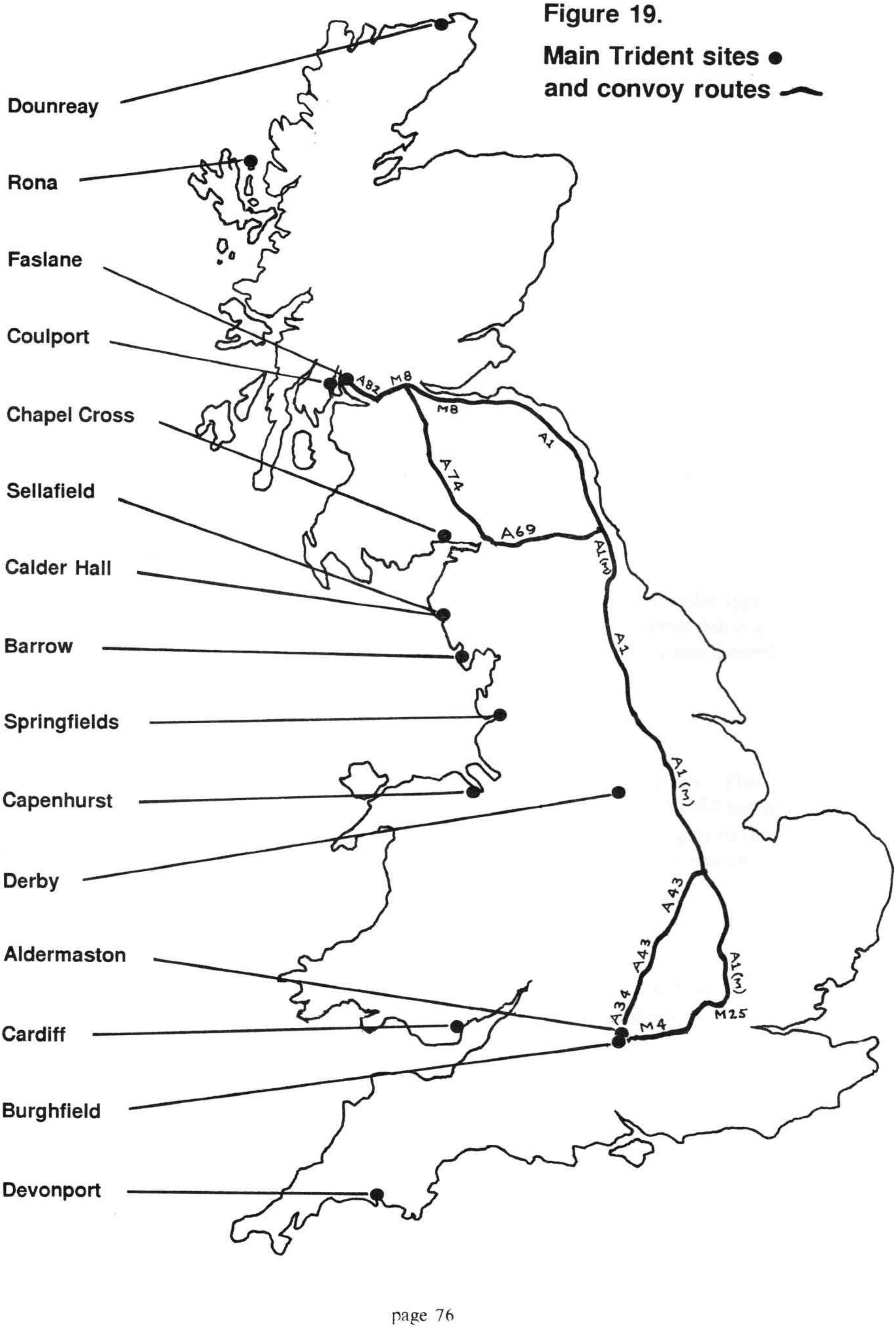


Figure 19.
Main Trident sites ● and convoy routes ⁓

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