Risk from Trident missiles in Devonport

If the majority of people in Scotland vote for independence in Autumn 2014 then it is likely that London will be told that Trident cannot remain on the Clyde. In January 2012 Scottish CND published a report which argues that this would result in nuclear disarmament for Britain, because there is nowhere for Trident to go.

The site which is most often mentioned as an alternative is Devonport. Scottish CND has recently established that Devonport does not have clearance to berth an armed Vanguard class submarine -

> "neither the Devonport Naval Base nor the Devonport Dockyard, which is owned and operated by Babcock, safety case permit the berthing of an armed Vanguard class submarine."[1]

The Navy only has two operational submarine bases and it is surprising that one of them is unable to berth armed Trident submarines. A possible explanation is the obvious risk from introducing nuclear missiles into the centre of Plymouth, a city with a population of over 250,000.

The Defence Nuclear Safety Regulator (DNSR) has not provided any advice on the potential to base armed Trident submarines at Devonport and no assessment of this risk has been carried out.[2] This paper is an attempt to address this omission by providing an initial estimate of the risk and consequences of a missile accident on a Trident submarine at Devonport.

The explosion of 8 Trident missiles on a submarine in Devonport would break windows across 23 % of Plymouth. There would be damage to property and a significant number of casualties, including fatalities, from blast damage. Plutonium from 40 nuclear warheads would be dispersed across the city. In a light breeze this could result in 800 long-term cancer deaths. In very calm conditions the death toll could be as high as 11,000, mostly short-term fatalities from Acute Radiation Syndrome. The MOD's Regulations for the Nuclear Weapons programme (JSP 538) also suggests that radiation could be at a level where there would be a significant number of fatalities from Acute Radiation Syndrome.

A large proportion of the city would be contaminated with plutonium. The MOD assumes that economic activity would be disrupted if the ground is contaminated with plutonium at levels exceeding 200 kbq/m^2. In a light breeze from the South West 16% of the city would be contaminated to this level. In very calm conditions 54% of the urban area would be contaminated to 200 kbq/m^2 and large parts of the city would experience far higher radiation levels. This would constitute a long-term hazard because of the long half-lives of plutonium isotopes. Large parts of the city would be abandoned. In addition to the direct health effects, the accident would have a major economic impact.

<u>Implications of basing Trident at Devonport</u>

The MOD have two main Trident sites in Scotland, the base at Faslane and the nuclear store at Coulport. It would not be feasible to build a replacement for Coulport in Devonport because of the

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[1] Letter from DE&S Policy Secretariat to Scottish CND, 27 November 2012.

[2] "We can confirm that the DNSR has not provided any advice on the feasibility of docking of an armed Vanguard class submarine in Devonport Dockyard." Letter from DE&S Policy Secretariat to Scottish CND, 27 November 2012.

large area required and the safety implications.[3] This paper looks only at the implications of using Devonport as an operational base for the Trident fleet.

There are currently two facilities where Vanguard class submarines can be docked. Major refits are carried out in 9 Dock at Devonport.[4] Additional work is done in the shiplift at Faslane. This carries out planned maintenance, such as Revalidation and Assisted Maintenance Periods (RAMPs), and emergency repairs, such as the work on HMS Vanguard following its collision with Le Triomphante.

Devonport Management Limited (DML) are licenced by the Office of Nuclear Regulation (ONR) to carry out nuclear work in 9 Dock. There is no civil licence for the Faslane shiplift which is only regulated by the Defence Nuclear Safety Regulator (DNSR).

The MOD might either use 9 Dock at Devonport, or provide a new facility. Moving the RAMPs and other repair tasks into 9 Dock would not be easy. It is unlikely that the Navy would be able to maintain Continuous At Sea Deterrence (CASD) without a second dock. 14 and 15 Docks carry out refits on conventionally-armed nuclear-powered submarines. But they are not large enough to accommodate a Vanguard class submarine. If the MOD wanted to maintain the same operational availability as at present, they would need to provide a new facility. A possible choice would be 10 Dock. This was repaired in the 1990s. It was then temporarily used for nuclear work while the new Submarine Refit Complex (14 and 15 Dock) was under construction. 10 Dock does not currently have clearance for nuclear work. It is likely that additional structural repairs would be required before it could be used for Vanguard class submarines. An alternative might be to build a new shiplift somewhere in the Devonport area, possibly on the West side of the river.

Current practice is that Trident missiles are not removed before Vanguard class submarines dock in the Faslane shiplift. Removing missiles prior to maintenance work would increase the risk wherever nuclear warheads were stored. It would also make it difficult to sustain current operational availability. Even if missiles were removed prior to a maintenance docking, basing Trident at Devonport would still mean that there was a risk of a missile accident on an armed submarine berthed in the Naval Base.

ONR would not normally permit a major nuclear facility to function in the middle of a city. They have made an exception for Devonport. However the trend is to reduce the range of nuclear activities carried out on the site. Nuclear refuelling will cease within a few years. Devonport will stop being a base for operational submarines in 2018. After this the site will only carry out non-refuelling refits on nuclear submarines. Basing Trident in Plymouth would reverse this trend and introduce an unacceptably hazardous new risk.

<u>Missile explosion sequence</u>

In 2000 the MOD produced studies into the likelihood and consequences of a missile accident in the Faslane shiplift.[5] These assume that if one part of one Trident missile detonates, then all of the missiles on the submarine will explode and all of the plutonium in all of the warheads will be dispersed into the atmosphere. Each missile has an explosive power equivalent to 70 tonnes of TNT.

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[3] Trident Nowhere to Go, Scottish CND, January 2012.

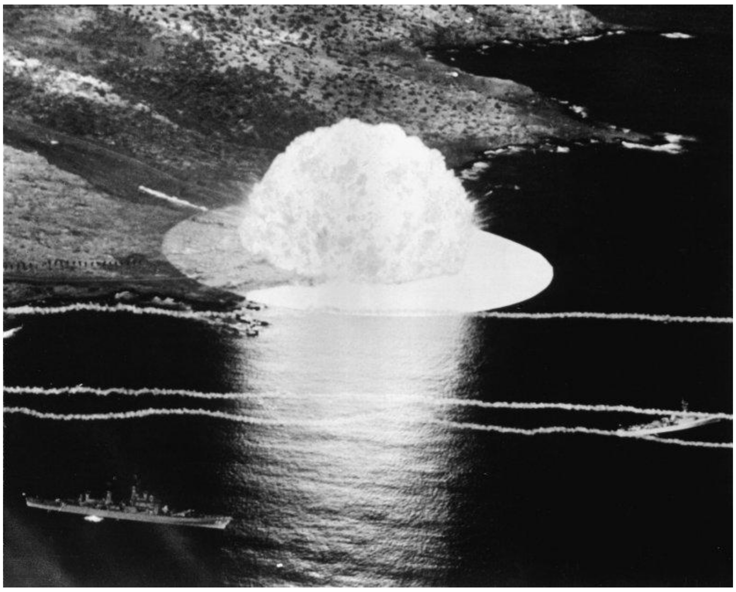
[4] The initial refits have involved refuelling. After the current work on HMS Vengeance is completed, future refits will not include refuelling due to the increased lifespan of the nuclear fuel cores.

[5] A Radiological Probabilistic Risk Assessment of the Faslane shiplift for Vanguard Class Submarines with Strategic Weapon System Embarked, AWE, 2000, and Accident Probaility Assessment of Faslane Shiplift for Vanguard Class Submarines with Strategic Weapon System Embarked, 2000. Both were released to Scottish CND under the Freedom of Information Act. After an internal review, most of the figures in these documents were released, but a few remain redacted.

Today British submarines carry 8 missiles. So, in an accident, there would be an explosion equivalent to 560 tonnes of TNT.

It is assumed that each submarine carries 40 nuclear warheads and that each contains 4 kilograms of plutonium. This means that a total of 160 kilograms of plutonium would be dispersed into the atmosphere.

In 1965 the US Navy conducted a test in which they detonated conventional explosives with a power of 500 tonnes of TNT. The experiment was to simulate the effect of a small nuclear explosion. Two redundant ships anchored nearby were severely damaged. The video of the test gives a graphic illustration of the type of explosion which could take place in Plymouth if Trident missiles were based at Devonport.[6]



500 tonne HE detonation Operation Sailor Hat 1965

Blast damage

A 560 tonne explosion would cause severe damage to houses with 1 kilometre of the dockyard. There are around 4,800 residents within this area.[7] There would be some damage to houses up to 2 kilometres from the blast. Windows would be broken up across 23 % of the city (within 3.5 kilometres of the dockyard).[8]

If the explosion was on a submarine at the Power Range Testing Berth in 5 Basin then the blast effects could be greater than this because the dock wall might deflect energy towards the city. On the other hand, if the explosion was on a submarine in dry dock the blast effect could be less, because it would be constrained by the dock walls.

Blast damage would result in a significant number of direct casualties. In addition it would complicate exposure to radiation. Normal advice in a nuclear emergency is that the public should close their windows. This would be rendered redundant if the windows had all been blown out. Much of the area which was subject to the greatest blast damage would also receive the highest levels of radiation.

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[6] Operation Sailor Hat 1965 US Navy video http://www.youtube.com/watch?v=ZVM9_attO1Q
[7] Calculation carried out from house density (Google Earth) and size of households in St Budeaux and Devonport wards.
[8] Blast calculations carried out using the Lawrence Livermore National Laboratory nuclear weapons programme Weapons Effects.

MOD Regulations (JSP 538)

The MOD's Regulations for the Nuclear Weapons Programme (JSP 538), 2005 edition, includes the following examples of the most serious categories of accident:

Event Category	Example	Effective dose at 1 km
e	Uncontained detonation of 4-30 warheads	1-10 Sv
f	Detonation of one or more missiles in a submarine with subsequent release of radioactive material from warheads.	10-100 Sv

Around one third of the through-life dose will be received within the first 24 hours.[9] So a category e incident is likely to result in an effective dose between 300 mSv and 3 Sv at 1 kilometre within 24 hours. A category f incident (missile explosion) is likely to result in an effective dose between 3 Sv and 30 Sv at 1 kilometre within 24 hours.

Exposure to radiation at levels higher than 500-700 mSv results in Acute Radiation Syndrome. This is where there is not just a risk of long-term cancer, but there are immediate and often life-threatening consequences. Up to 10 % of those who received a dose of 1-2 Sv might die. The mortality rate rises to 50% for doses of between 3.5 and 5.5 Sv. Where the dose is higher than 10 Sv, death is almost certain.[10]

The figures in JSP 538 show that a Trident missile explosion could result in levels of radiation which would be lethal in the short term to a significant proportion of the population living within 1 kilometre of the accident. There are no civilian residents living within 1 kilometre of the Trident berths at Faslane. However, there are around 4,000 people living within 1 kilometre of Devonport dockyard and thousands more living between 1 and 2 kilometres of the site.[11]

The dose estimates in JSP 538 indicate that a Trident missile explosion in Devonport would expose thousands of people to radiation at levels which would in many cases be lethal in the short term.

Modelling of plutonium dispersal

Radiation calculations were carried out using Hotspots 2.07.2 (August 2011).[12] This is a publicly available programme from Lawrence Livermore National Laboratory, one of the main nuclear weapons facilities in the US. Hotspots is designed to model the effects of a nuclear weapon accident. Hotspots can produce kml files which can be plotted on Google Earth. The areas affected were calculated with Easy Acreage and this was combined with census data from Plymouth City Council.

One limitation of Hotspots is that it is only able to simulate an explosion up to 227 tonnes TNT equivalent, which is half of the explosive power of the rocket motors in 8 Trident missiles. The areas affected would therefore be larger than the examples indicate.

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[9] Calculations carried out using Hotspots.
[10] http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1237362785677
[11] Population estimate based on housing density from Google Earth and household size in Plymouth wards from census statistics.
[12] Hotspots was set up with Weather Correction Factor from Likhtarev (2002) and Resuspension Factor from Maxwell and Anspaugh (2010).

The dispersal of radioactive material is dependent on meteorological conditions. Hotspots was run with a variety of different wind speeds and wind stability factors. This paper focuses on two distinct examples. The first is for a light breeze from the Southwest. In this case much of radioactive material is dispersed beyond the city boundary. The second example assumes calm conditions. This results in high concentrations of plutonium across a large part of the city.

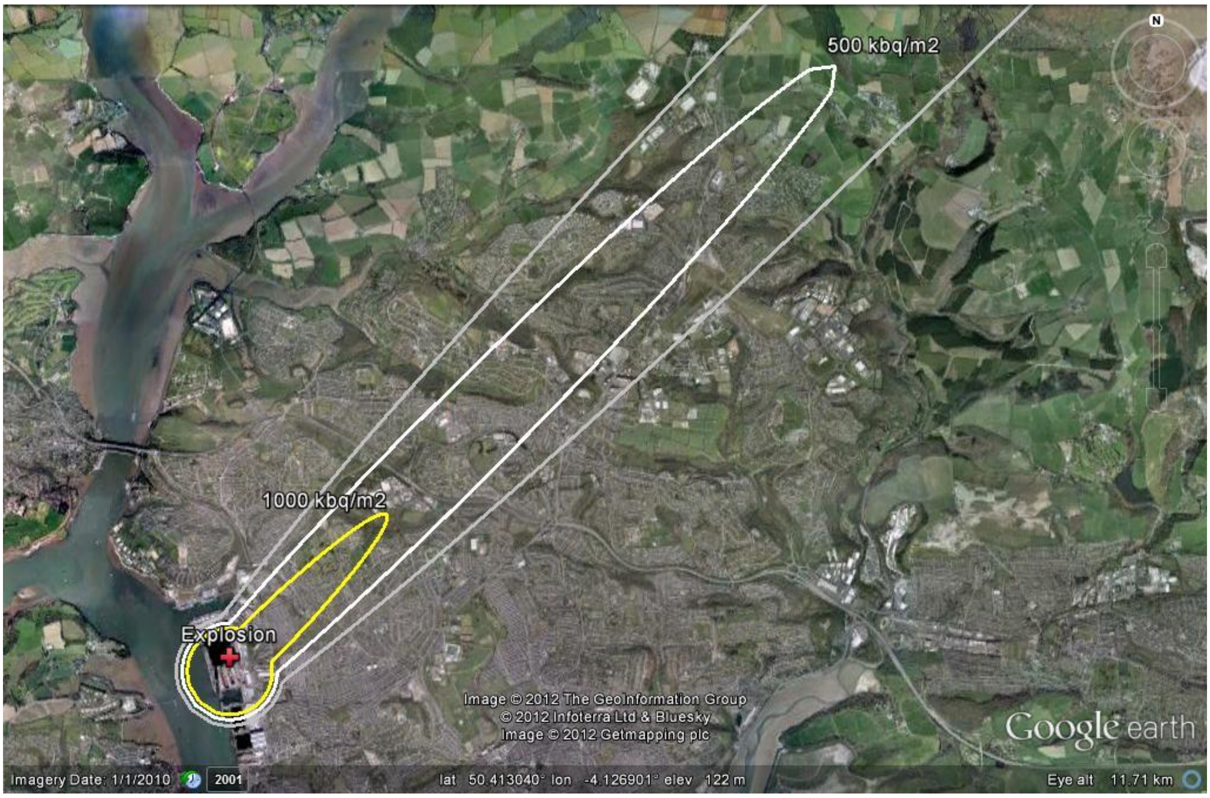
Multiple runs with Hotspots indicate that, in most meteorological conditions, a 227 tonne explosion dispersing plutonium from 40 nuclear warheads would result in a 50 year effective dose of less than 1 Sv at 1 kilometre. This is less than suggested in JSP 538. However, in very calm weather (Example 2) the dose at 1 kilometre would be 7 Sv after 24 hours, and the 50 year dose would be 23 Sv (chart 6). This is consistent with JSP 538.

Example 1

Wind direction: from the Southwest
Wind speed: 5 metres/second (light breeze)
Wind stability: neutral (D)

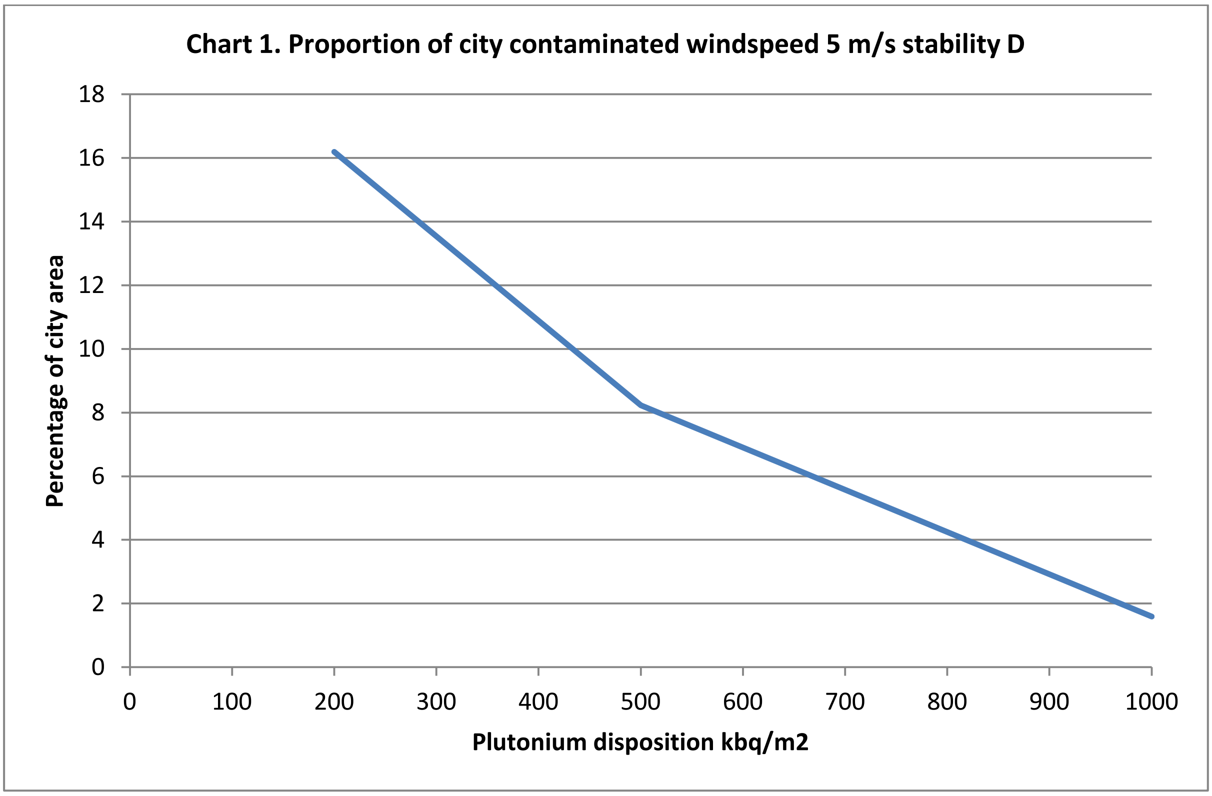
Hotpots can estimate the level of radioactivity from plutonium which is deposited on the ground following an accident. The Faslane assessment shows that the MOD use a criteria of 200 kbq/m^2 as a measure of the area within which there will be a significant economic impact. They assess the number of people living in the area which might be subject to this level of contamination.

Map 1. Plutonium disposition windspeed 5 m/s stability D from Southwest

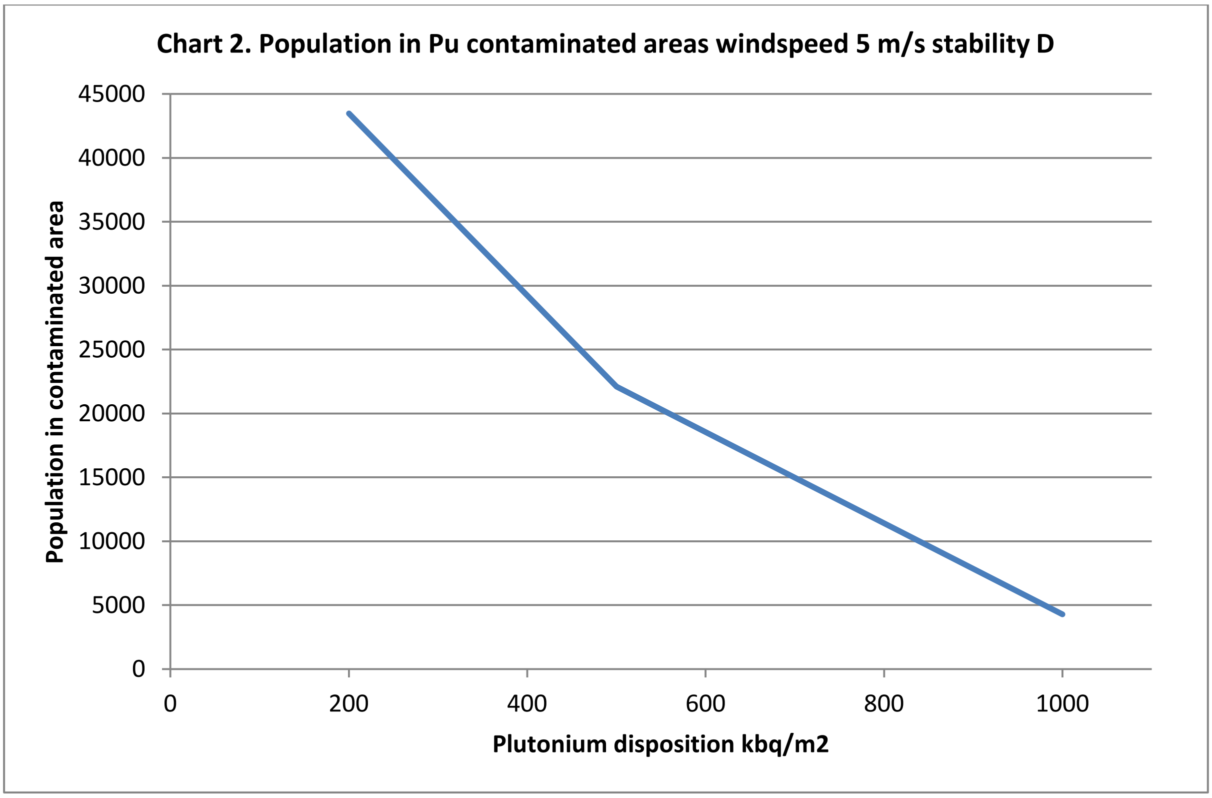


The contours are 1000 kbq/m^2 (yellow), 500 kbq/m^2 (white) and 200 kbq/m^2 (gray).

Chart 1 shows that 16% of the city of Plymouth would be contaminated to levels higher than 200 kbq/m^2.

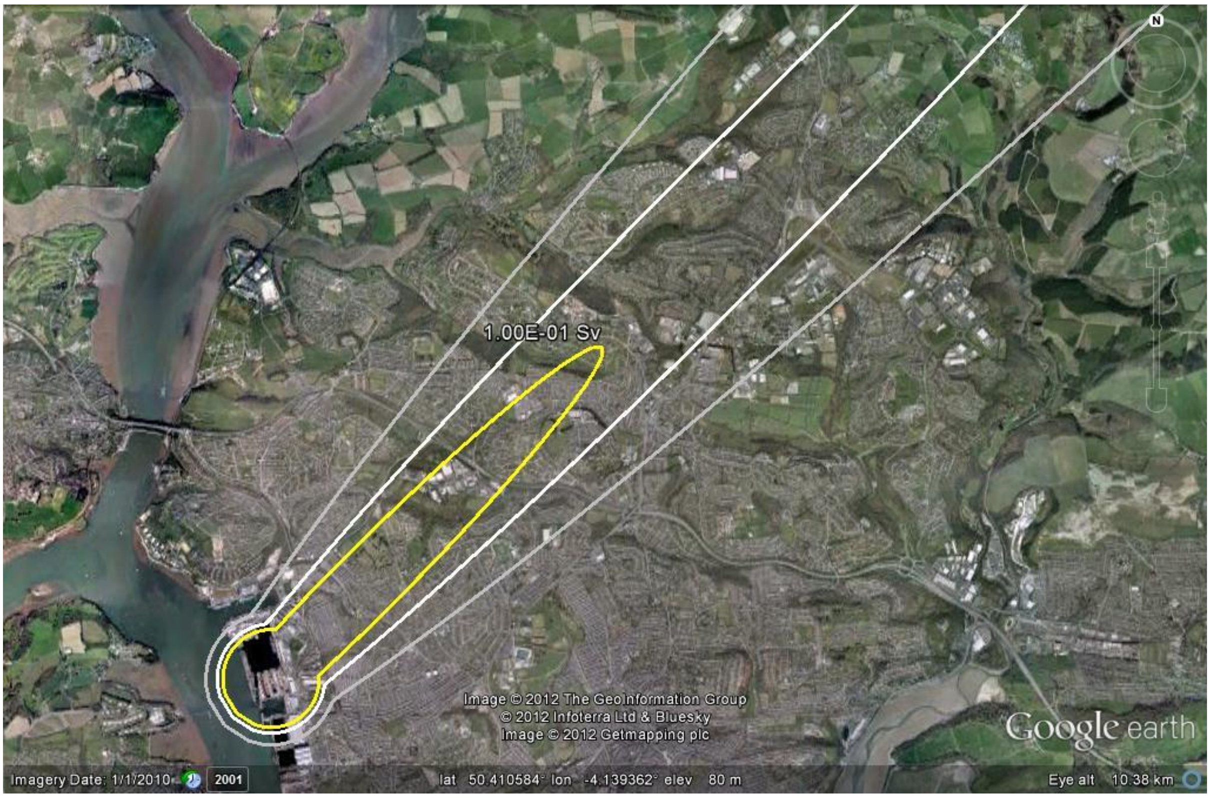


The number of people residing in these areas was calculated, based on an average population density of 3,175 people per square kilometre. There were 43,484 people living in the area contaminated to over 200 kbq/m^2 and 4,272 people in the area contaminated to over 1,000 kbq/m^2 (Chart 2).



The resulting dose to members of the public was calculated. Map 2 shows the dose received within the first 24 hours.

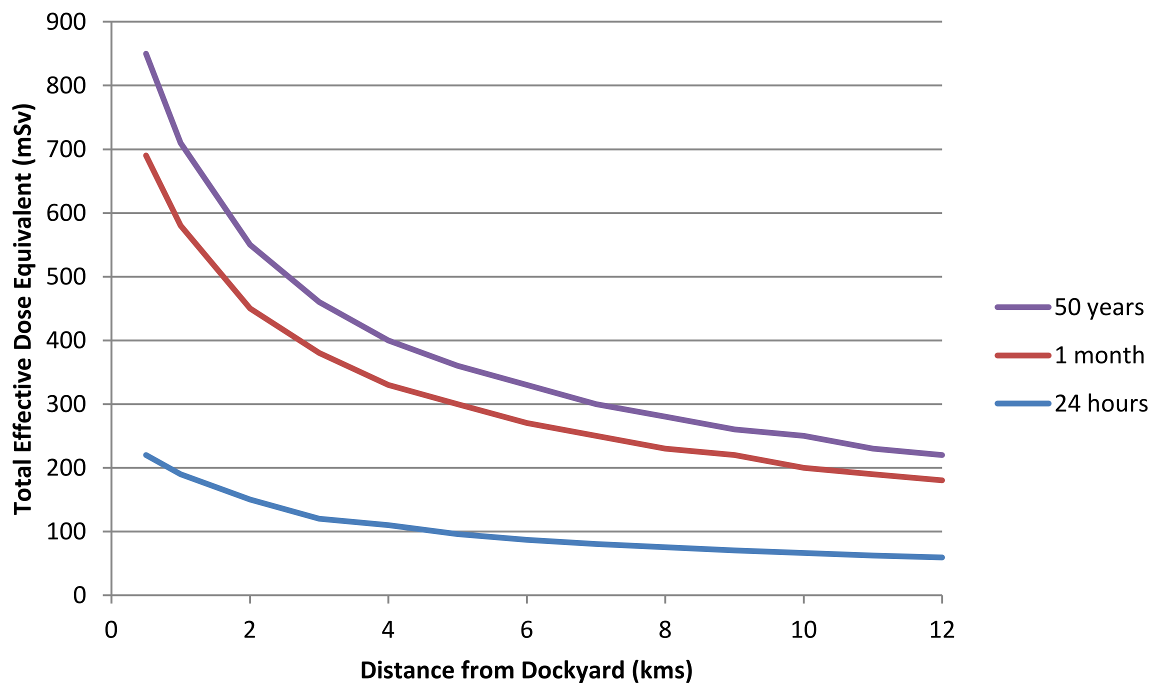
Map 2. Total Effective Dose Equivalent after 24 hours windspeed 5 m/s stability D from Southwest



The contours are 100 mSv (yellow), 50 mSv (white) and 10 mSv (gray).

The effect of exposure to the released plutonium was plotted over three timescales – 24 hours, 1 month and 50 years (Chart 3).

Chart 3. Total Effective Dose Equivalent windspeed 5 m/s stability D



Fatalities were estimated, based on the figures illustrated in chart 3. This was done by calculating the area of each plot, the dose and likely fatalities.[13] There were projected to be 178 long-term cancer fatalities as a result of the dose received within the first 24 hours. If the area continued to be inhabited for 50 years, then this would rise to 581 long-term fatalities.

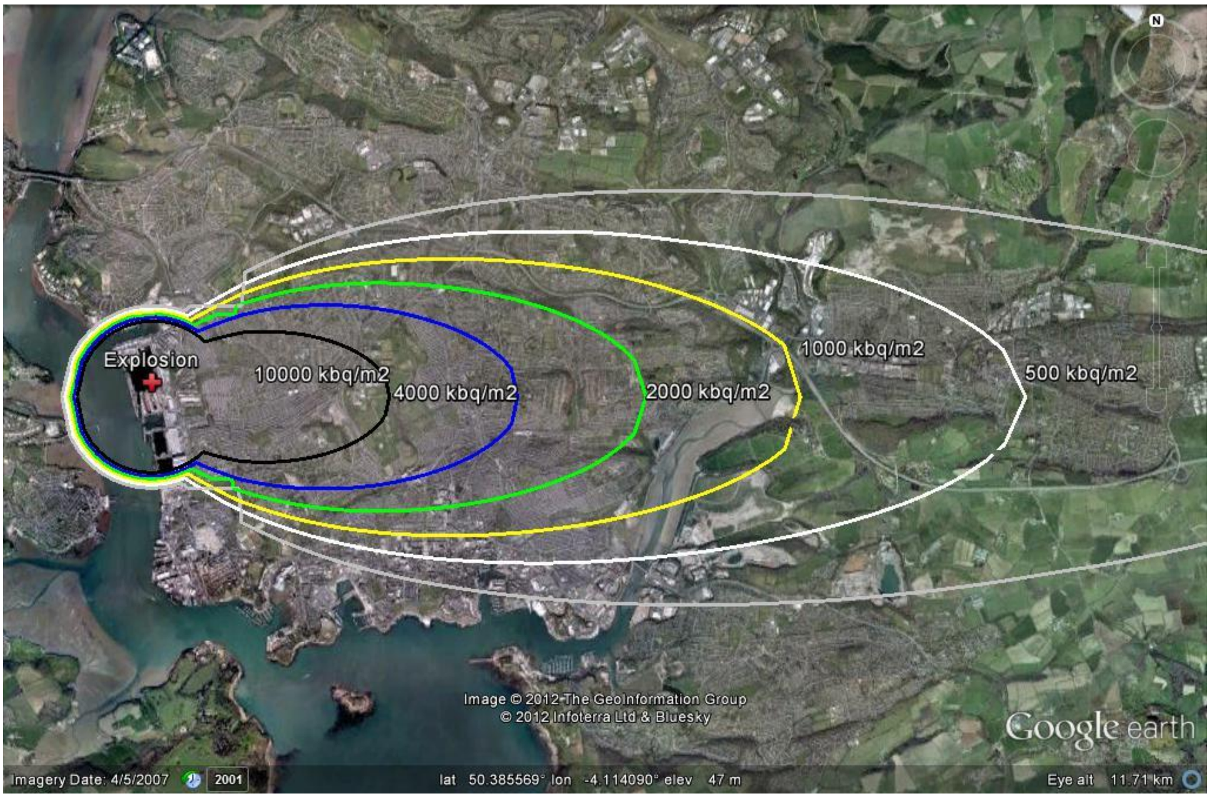
These figures were based on a 227 tonne TNT explosion, the maximum which can be calculated using the Hotspots programme. A 560 tonne explosion would disperse plutonium over a wider area. This could increase the long-term fatal cancers from the 24-hour dose to around 250, and the equivalent from the 50-year dose to around 800.

<u>Example 2</u>

Wind Direction: from the West
Wind Speed: 0.1 metres/second (calm)
Wind Stability: Very Unstable (A)

The disposition of plutonium is illustrated in Map 3.

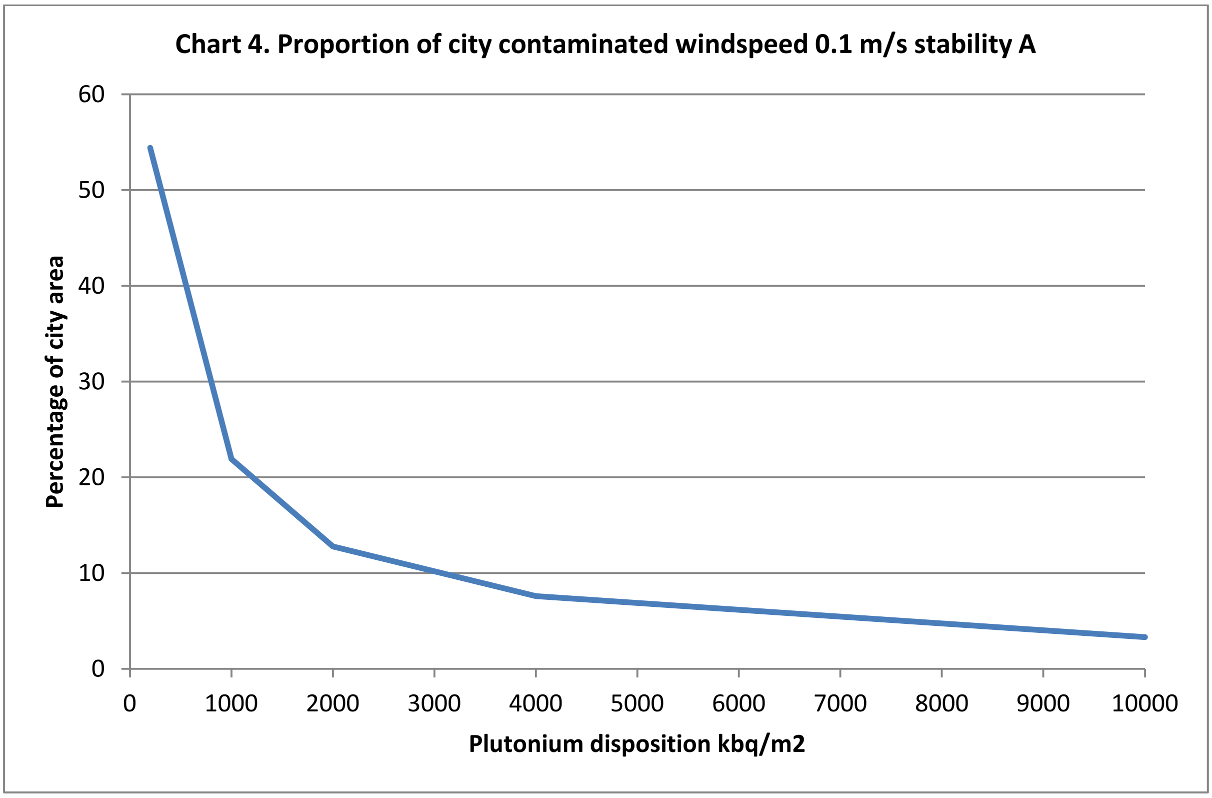
Map 3. Plutonium disposition windspeed 0.1 m/s stability A from West



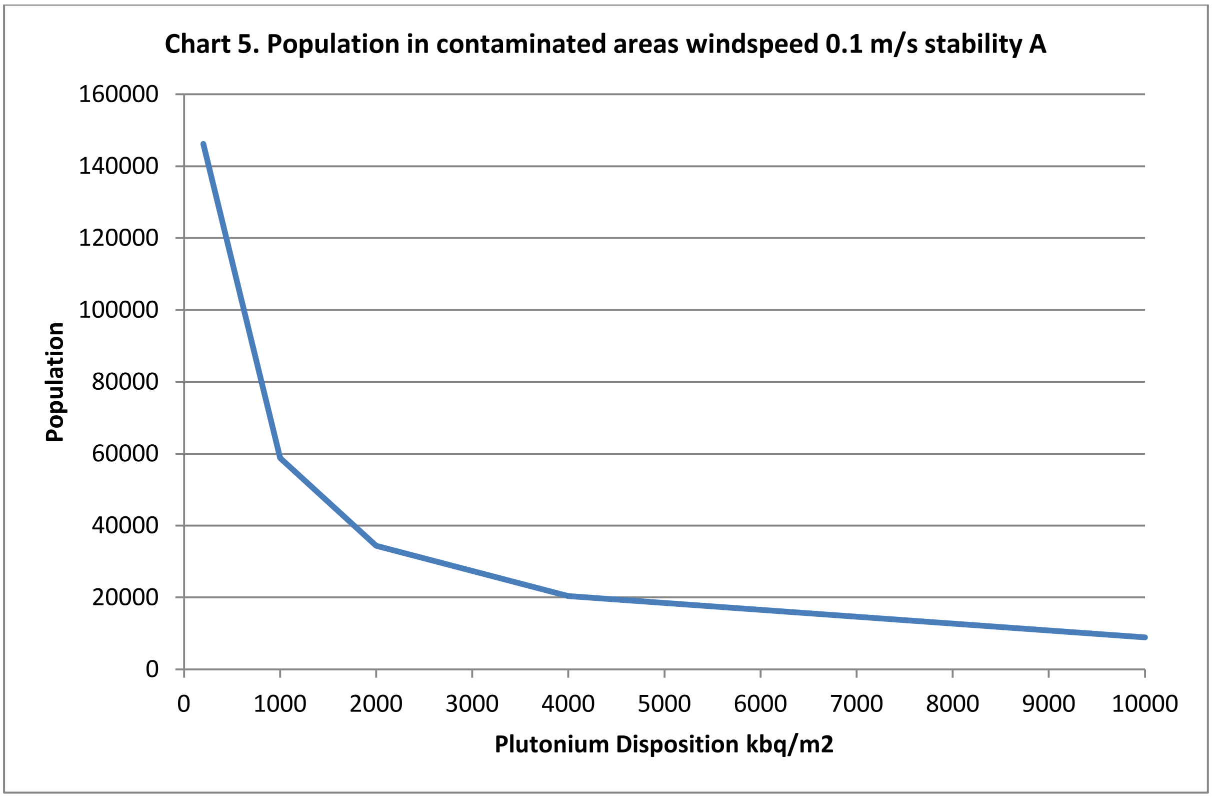
The contours are 10,000 kbq/m^2 (black), 4000 kbq/m^2 (blue) 2000 kbq/m^2 (green), 1000 kbq/m^2 (yellow), 500 kbq/m^2 (white) and is 200 kbq/m^2(gray).

[13] Long term cancer fatalities were calculated on the basis of 5 x 10^{-2} per Sievert. 1 Sv was taken as the threshold for short-term mortaility. 5 Sv was assumed to be lethal in 50 % of cases and 7 Sv in 95 % of cases.

Chart 4 shows the proportion of city of Plymouth which would be contaminated. 200 kbq/m^2 is the criteria adopted by the MOD. Contamination would be above this level in 54% of the city.

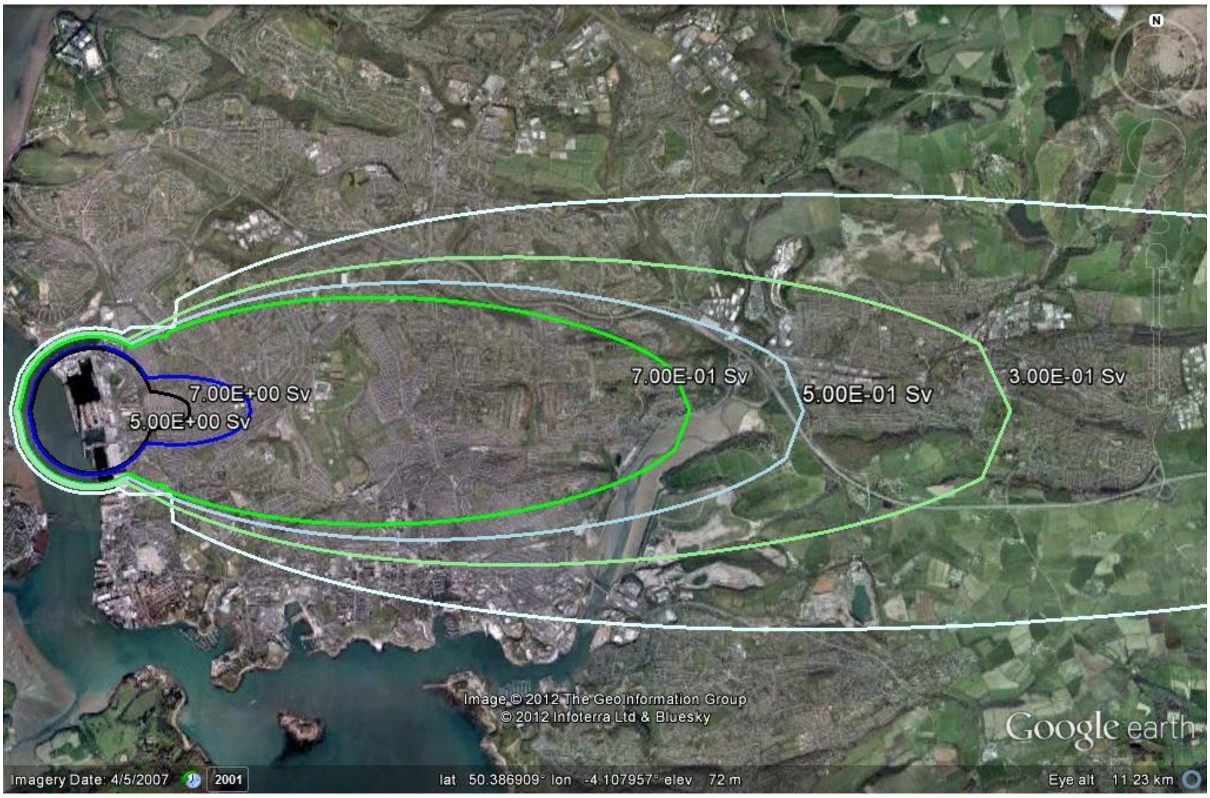


There were 146,202 in the area with over 200 kbq/m^2, 58,819 living where there was over 1,000 kbq/m^2 and 8,863 living in an area with over 10,000 kbq/m^2 (Chart 5)

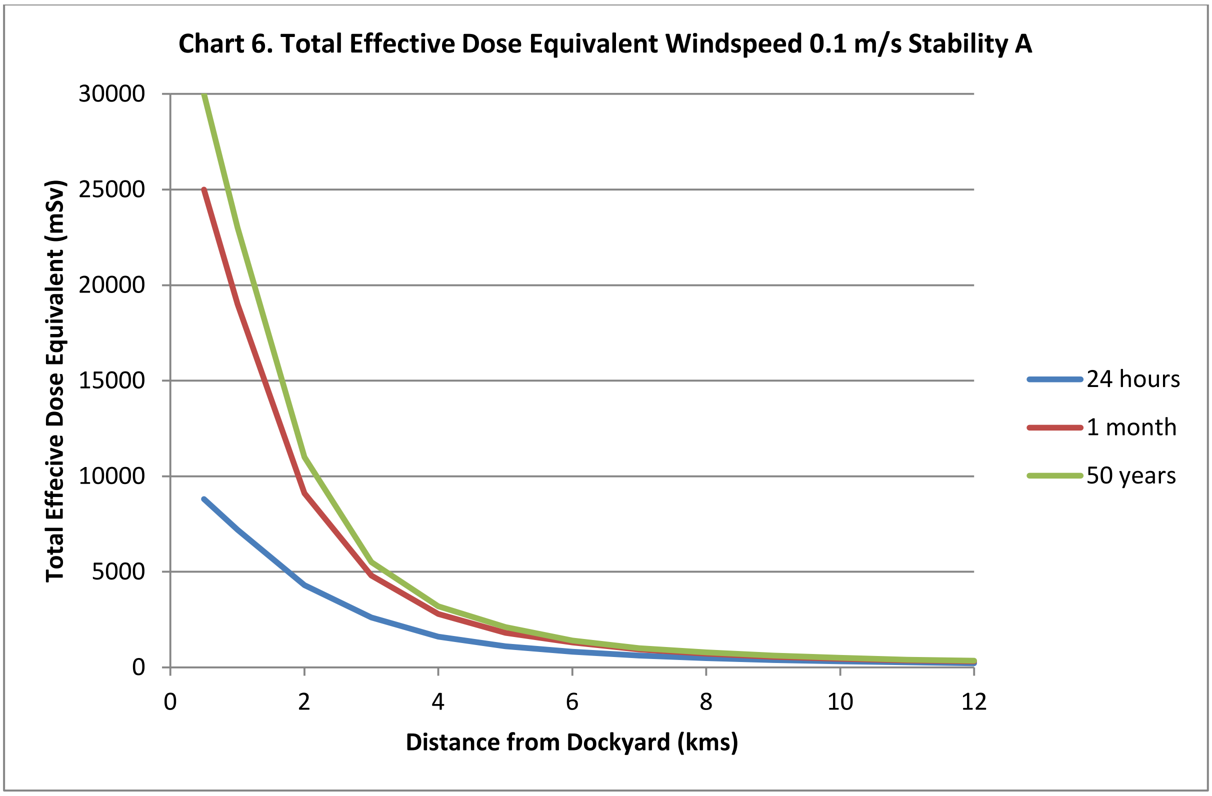


The resulting 24 hour dose is illustrated in Map 4.

Map 4. Total Effective Dose Equivalent after 24 hours windspeed 0.1 m/s stability A from West



The contours are 7 Sv (black), 5 Sv (blue), 700 mSv (green), 500 mSv (light blue), 300 mSv (light green) and 100 mSv (white).



In this case the 24 hour dose could result in 8,186 short-term fatalities from Acute Radiation Syndrome, plus 3,317 long-term cancer fatalities, giving a total death toll of 11,503.

The through-life dose of 23 Sv at 1 kilometre is consistent with the 10-100 Sv estimate in the MOD's regulations, JSP 538.

The high casualty level can be compared with a study into the explosion of a small dirty bomb in an urban area. The detonation of 0.45 kg of High Explosive, dispersing 1 kg of plutonium in calm weather, could result in 80 long-term cancer fatalities.[14] If this was scaled up for 160 kg of plutonium, then the number of long-term fatalities would be 12,800.

Response to accident

The actual number casualties would be affected by the way the population behaved after the explosion. The blast would be so loud that many people would assume that it was a nuclear explosion. While taking shelter would reduce initial exposure this would have limited effect where houses were damaged by blast. In addition, the shock of the explosion may lead people to go outside and to attempt to leave the city by car. Some who were in areas not directly affected could travel across contaminated parts of the city.

In most weather conditions plutonium would be rapidly dispersed across the city. However, in calm conditions radioactivity would be dispersed slowly.

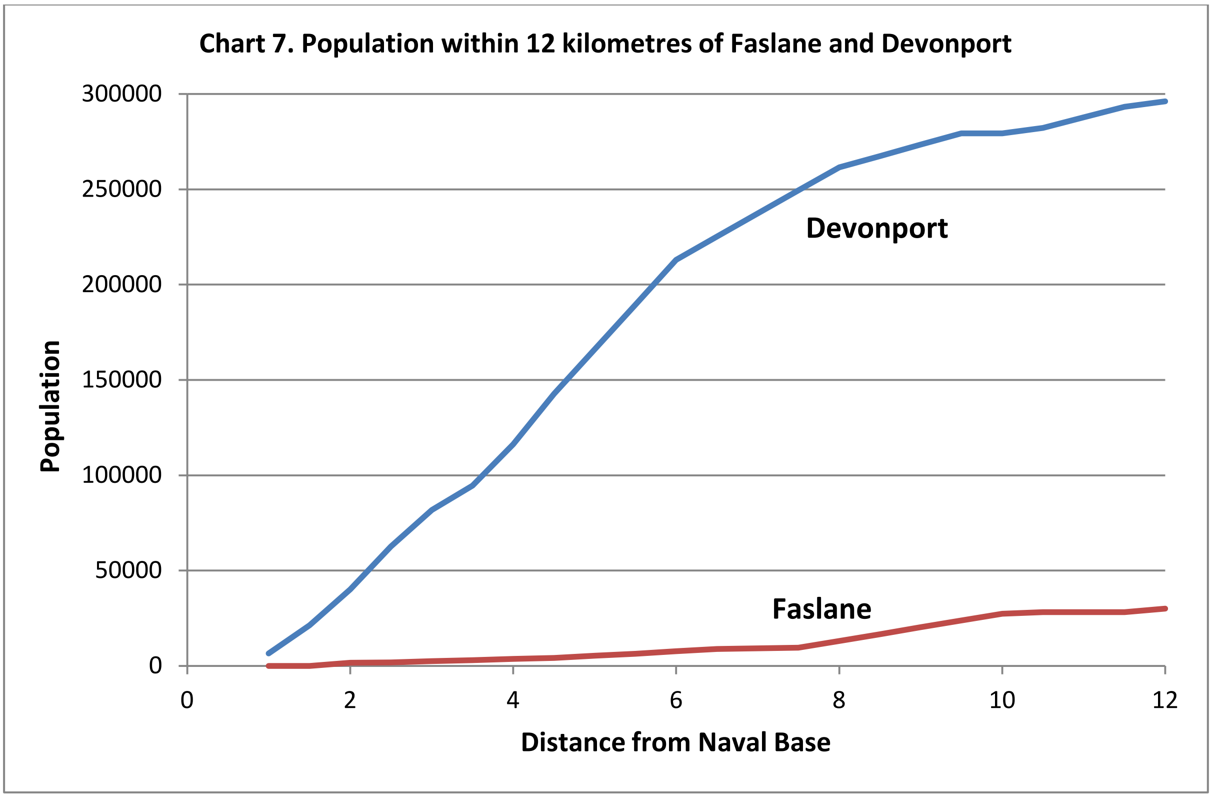
There would be a need at some point to evacuate large parts of Plymouth. Because of the difficulty in effectively monitoring the radiation from plutonium it would be hard to quickly and accurately access the area affected. As a result evacuation would probably be ordered over a wider area. There could also be a need for relocation from areas which did not require immediate evacuation but where the long-term exposure to radiation would be unacceptable.

Population density compared with Faslane

The risk to Scotland from Trident Faslane and Coulport is itself unacceptable. The risk at Devonport would be different from that at Faslane. The population close to the base is much higher in Devonport. Chart 7 illustrates the population within 12 kilometres of the two sites. However, at greater distances the population becomes similar. The centre of Glasgow is 40 kilometres from Faslane and at this distance the population is higher than at Devonport.

The MOD are likely to focus on the population closest to the bases. For example, their emergency plans only provide a pre-planned countermeasures zone of 2 kilometres and an extendibility zone out to 10 kilometres.

[14] Estimates of radiological risk from a terrorist attack using plutonium, M Durante and L Manti, Radiat Environ Biophys (2002), This study used an earlier version of Hotspots (1.06). Calm conditions were simulated with a wind speed of 1 m/s and stability F. The assumed population density was 4,500 / sq km.
http://www1.na.infn.it/wnucl/lines/radi/English/documentazione/pubblicazioni/p-modelli/reb2002.pdf



MOD estimate of the likelihood of a missile accident

In 2000 the MOD assessed the risk and consequences of a missile explosion on a Trident submarine in the shiplift at Faslane. Their reports reveal one of the principle concerns about the safety of Trident missiles. The nuclear warheads are fitted in a circle around the third stage motor on the top of each missile. The fault tree shows the consequences of one warhead colliding with the third stage motor of the missile:

> Probability of penetration of Third Stage Motor:
> Optimistic estimate: 10^{-3} Best estimate: 0.5 Pessimistic estimate: 1

This means, if one nuclear warhead collides with the third stage motor, the best estimate is that there is a one in two chance that it will penetrate the motor. The fault tree then shows that if a warhead penetrates the third stage motor then there is a probability of 1 (ie it is assumed) that all the missiles on the submarine will explode and will disperse the plutonium in all of the nuclear weapons onboard. The fault trees also show that the same sequence will be initiated if the explosive in the nuclear warhead detonates by accident.

The Faslane assessment argued that the chance of this sequence being initiated was remote. It concluded that the best estimate of the overall probability of an accident in the shiplift, where all the Trident missiles on a submarine exploded and all the plutonium was dispersed, was 6.4×10^{-6} per year. The optimistic estimate was 7.7×10^{-7} and the pessimistic estimate was 2.4×10^{-5}.

Some aspects of a fault tree for Devonport would be the same as for the Faslane Shiplift, but others would be different. For example, a major hazard at Faslane is shiplift collapse. The equivalent hazard in a dry dock at Devonport would be caisson collapse, leading to dock flood and boat roll. In addition to the hazards associated with docking a submarine there would also be risks from Trident submarines berthed in the base. The Faslane assessment says that if a crane collapses or drops a load then the best estimate is that the likelihood of this resulting in a missile explosion is 10^{-2}.[15] If an aircraft crashes onto an armed Trident submarine then it is assumed that this will result in a missile explosion (likelihood of 1).

MOD calculation of tolerable risk

The MOD's Regulations for the Nuclear Weapons Programme (JSP 538) sets down the acceptable frequency for various types of accident:

Event Category	Example	Basic Safety Limit (BSL) (Frequency/Year)	Basic Safety Objective (BSO) (Frequency/Year)
e	Uncontained detonation of 4-30 warheads	10^{-5}	10^{-8}
f	Detonation of one or more missiles in a submarine with subsequent release of radioactive material from warheads.	10^{-6}	10^{-9}

The BSL is the level which must be complied with. The BSO is a higher standard which DNSR should seek to meet. The BSL for a category f event is 10^{-6}. This means the probability of this kind of incident should be less than one in a million in a year.

The best estimate of the annual risk for Faslane shiplift (6.4×10^{-6}) is only slightly above the category f BSL (10^{-6}). The pessimistic estimate (2.4×10^{-5}) is below the BSL.

The MOD carried out a further study to model the effects of an accident of this kind in the shiflift. On this basis they argued that the probabilities were acceptable, but not by a wide margin. The three criteria adopted were individual fatality, societal fatality (long-term fatal cancers) and societal contamination (higher than 200 KBq/m^2). The compliance margin was smallest for the third criterion.

The compliance margin for societal contamination, based on the pessimistic assessment, was 2.1. The equivalent figures for the best and optimistic estimates were redacted. If they are proportional to the assessed risk, then the compliance margins are likely to be 7.9 (best) and 65 (optimistic). The compliance factor must be higher than 1. Values of between 1 and 100 are" tolerable". Values above 100 are "acceptable".

The MOD assessment says: "The low values of the Compliance Factors (Societal Contamination) for the CESO(N) pessimistic case indicate that the risks are close to the tolerability criterion level."

So the MOD's own assessment is that the risk of a missile explosion in the Faslane Shiplift is only just tolerable. The real risk is greater, because there were a number of major omissions in the way the MOD carried out this assessment.

Application of MOD criteria to Devonport

If the MOD were to repeat the same calculations for Devonport then the Compliance Factors would be below 1, and unacceptable, because the population density within 12 kilometres of Devonport is much greater than at Faslane. The Hotspots calculations suggest that they MOD would fall far below their own standard with regard to societal contamination. They would also fail the individual fatality and societal fatality criteria.

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[15] Optimistic estimate 10^{-3}, optimistic estimate 10^{-1}.

Weaknesses in MOD methodology

There are a number of serious omissions in the Faslane assessment.

The fault trees consider the possibility that an explosion in the submarine's reactor could trigger a missile explosion. But the analysis considered only the dispersal of plutonium from warheads and not the additional radioactive material from the reactor. In addition, the assessment ignores the significant possibility that a missile explosion, caused by an outside event, could rupture the integrity of the reactor circuit and so release the radioactive inventory in the reactor. The effects modelling only took account of the radioactive inventory from the nuclear warheads.

The likelihood of a torpedo explosion causing a missile explosion is considered. But the potential for a missile explosion to trigger a torpedo explosion, thus increasing the overall blast hazard, is ignored.

A massive explosion could trigger a fire, explosion or reactor accident on a second submarine berthed nearby. This is not considered in the Faslane shiplift assessment.

The Faslane assessment ignores the possibility of a nuclear yield. Because of a phenomenon called "popcorning" there is a significant chance that in a complex explosive situation a nuclear yield could be produced. This is likely to have less explosive power than the missile detonation, but would produce a different range of radioactive isotopes.

The assessment relies heavily on assumptions that the initiating event in each section of the fault tree is very unlikely to occur. In many cases, if the initiating event occurs then the likelihood that it will result in an explosion is considerable.

In the case of Devonport, if work on an armed Trident submarine was conducted within a dock licenced by ONR then the civil regulator is likely to require a more detailed investigation of the risk involved than was carried out for the Faslane shiplift. The risk of a Trident missile explosion in Devonport would be unacceptable under the MOD's regulations. It would be even less acceptable under ONR's standards.