# If Britain fired Trident

## The humanitarian consequences of a nuclear attack by a Trident submarine on Moscow

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John Ainslie, Scottish CND, February 2013

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**Summary**

Deputy Prime Minister Nick Clegg has questioned the traditional rationale for British nuclear weapons and said that the UK does not need to be able to flatten the city of Moscow. Destruction of the Russian capital has been at the centre of British nuclear planning for 50 years. The current plan for a like-for-like replacement for Trident suggests that the Ministry of Defence still regards this as the key damage criteria. This report explains what "flattening Moscow" would mean for the 11.5 million residents of Europe's second largest city.[1]

This study gives an illustration of the catastrophic humanitarian consequences of an attack on a large urban area with multiple nuclear weapons. It also shows that the devastation would be on such a scale that humanitarian and emergency response agencies would be unable to provide an adequate response.[2]

The targeting policy for Trident was established in the early 1980s. The primary aim-points were to be specific locations within the city of Moscow and command bunkers in the surrounding area. Today an attack on these

1 The only city in Europe which is larger than Moscow is Istanbul.
2 The Red Cross have highlighted the "lack of any adequate humanitarian response capacity" to a nuclear explosion. Working towards the elimination of nuclear weapons, Council of delegates of the international red cross and red crescent movement, 26 November 2011, http://www.redcross.com.fj/pdf/NW-Resol-1.pdf

targets with 40 nuclear warheads, the normal complement on a Trident submarine, would result in 5.4 million deaths, 4.5 million inside the city and a further 870,000 in Moscow Region. This is an estimate of casualties within the first few months and does not take account of long-term effects.[3]

In estimating the number of casualties, the starting point was to consider the effect of blast damage from each explosion. Blast alone would kill almost everyone within 1 kilometre of each target, plus a large proportion of residents who were between 1 and 2 kilometres of each site. Heat and immediate nuclear radiation would be additional risks to residents within 2.2 kilometres of each explosion. Those with severe burns or blast injuries would be less likely to survive large doses of radiation. This would result in high mortality rates within these areas. Some residents would be shielded from heat and gamma radiation by adjacent buildings, but those in skyscrapers would be particularly vulnerable. Today Moscow has many of the tallest buildings in Europe.

Fire would be a major killer in any nuclear attack on an urban area. The intense heat from the fireball would start fires near each explosion. Beyond 3 kilometres from each Ground Zero, fires would be triggered by blast damage to gas and electrical fittings rather than heat. The blast wave can extinguish flames, but it can also cause fire to spread more rapidly between buildings. Within 3 kilometres of each explosion it is unlikely that residents would be able to prevent fires from expanding. Many of the city's power stations would be set alight. Individual fires would grow and could combine into a destructive firestorm which would create hurricane-force winds, burn up almost all combustible material and asphyxiate large numbers of residents.

The nuclear weapons would be detonated as ground-burst rather than air-burst explosions, in order to destroy underground command centres. Ground-burst explosions create vast quantities of radioactive fallout. Fallout from the explosions within Moscow would be lethal to many residents of the city and its suburbs. The attacks on command bunkers outside the city would spread more radiation over a wide area. Many houses in the suburbs would provide little protection from nuclear fallout. Most buildings in the city could reduce the dose from fallout, if intact. But in many cases they would be badly damaged and would provide little protection. The interaction between fire and fallout would increase the number of fatalities within Moscow. Fires would force residents to flee from shelter and to move in the open, where they would be more exposed to radiation from fallout. In some cases people would flee into areas where the radiation levels were higher.

Fatality rates would be around 95% within 1.6 kilometres of each explosion and at greater distances directly downwind, due to fallout. There would be extensive fires within 3 kilometres of each Ground Zero. Fires would be a particular problem in areas which lay between two or more explosions. Most of the city and large parts of Moscow Region would be affected by high levels of radiation from fallout.

The casualties would include doctors, nurses and patients in hospitals across the city. Several of Moscow's largest hospitals would be completely destroyed and others would be seriously damaged. It would be difficult to bring aid and assistance to a city contaminated with radioactive fallout. The scope for providing humanitarian assistance to the huge number of victims would be very limited. Schools across the city would be flattened or torn apart. Over 788,000 of those who were killed would be under 18 years old.

If there was warning and residents took shelter in underground bunkers and the subway then the number of fatalities would be lower. However, it is likely that thousands of people would try to flee the city. If the attack took place while they were travelling or sheltering in the suburbs, then the reduction in casualties would be less significant. If there was a firestorm then many of those in shelters would die from carbon monoxide poisoning. In 1978 the UK government concluded that if warheads were detonated as groundburst explosions, the resulting fallout would reduce the effectiveness of Russian civil defence plans.

There would be more fatalities in an attack from two submarines and fewer if some warheads were intercepted by Russian Anti Ballistic Missiles. The scenario assumes average wind speed and direction. In some weather conditions casualty numbers would be higher.

3 Philip Webber outlines the potential long-term environmental impact of a UK Trident attack in "Could One Trident Submarine Cause Nuclear Winter", SGR, 2008, http://www.sgr.org.uk/climate/NuclearWinterTrident_NL35.pdf

## 1. Attack scenario

### British nuclear targeting

The essence of British nuclear targeting today has been revealed in a number of comments from the Liberal Democrats, as they open up the possibility of alternatives to a like-for-like replacement for Trident. In October 2012 Deputy Prime Minister Nick Clegg said:

> "The idea of a like-for-like entirely unchanged replacement of Trident is basically saying we will spend billions and billions and billions of pounds on a nuclear missile system designed with the sole strategic purpose of flattening Moscow at the press of a button".[5]

This followed an earlier comment from Nick Harvey, former Armed Forces minister, that the Ministry of Defence (MOD) was locked in a 1980s' mindset of having nuclear weapons to "flatten Moscow". Harvey had been leading a major review of nuclear alternatives, which included a fresh look at the rationale behind the British nuclear force.

When Sir Menzies Campbell wrote in the Financial Times that it was time for Britain to abandon the "Moscow Criterion", there was a reply from three men who had been closely involved in the Trident programme at the highest level. Sir David Omand, Sir Kevin Tebbit and Franklin Miller KBE argued that a serious confrontation with Russia was not unthinkable. They said that Britain's possession of nuclear weapons was based on "holding at risk what any potential adversary's leadership would value most" and added "in the Russian case, Moscow has, of course always represented the very centre of state power".[6]

It is reasonable to conclude that the primary targeting of the British Trident force today is against Moscow. Declassified papers in The National Archive provide an insight into what this means.[7] The term "Moscow criterion" was initially used, in 1962, for the targeting of the capital and the next four largest cities in the Soviet Union. Polaris missiles were to cause "breakdown" level damage in each city. Until 1979 breakdown was defined as causing severe structural damage to 50% of the buildings in a city, resulting in around 50% fatalities. In 1979 the threshold was lowered to 40%.

A review of nuclear policy in 1972 had noted that the Soviets had built underground command centres outside the capital. But there was no serious attempt to target the bunkers at this time, because this was beyond the capability of Polaris. In 1978 the Callaghan government considered replacing Polaris. Officials drew up the Duff -Mason report. This presented 3 damage criteria. One account says that Option 1 was "to destroy the command centres of the Soviet political and military systems (both above and below ground) inside the Moscow ring road and extra ones in the wider Moscow area".[8] However the emphasis was probably on disrupting rather than destroying the command system.[9]

British intelligence calculated that there were 27 ex-urban national command bunkers, concentrated at 8 sites.[10] The Duff-Mason report was adopted and amended by the Thatcher government who decided, in December 1979, to acquire the Trident C4 missile system. In a presentation to the MISC 7 committee, Defence

4 http://www.bbc.co.uk/news/uk-politics-20116648
5 http://www.guardian.co.uk/uk/2012/sep/26/trident-nuclear-missiles-review-downgrading
6 UK cannot afford to be complacent. Letter from Sir David Omand, Sir Kevin Tebbit and Mr Franklin Miller to the Financial Times, 22 May 2012. http://www.ft.com/cms/s/0/553053ec-a34f-11e1-ab98-00144feabdc0.html#axzz2ILeqhmDB
7 This archive evidence is explored in detail in Unacceptable Damage, John Ainslie, Scottish CND, February 2013. http://www.banthebomb.org/images/stories/pdfs/UnacceptableDamage.pdf
8 Cabinets and the Bomb, Peter Hennessey, OUP, 2007, page 324.
9 "disruption of the main governmental organs of the Soviet state" Factors Relating to Further Consideration of the Future of the United Kingdom Nuclear Deterrent (Duff-Mason report), Part II Criteria for Deterrence, Summary, The National Archive (TNA) DEFE 19-275 e1 para 2
10 Duff-Mason report, Part II Annex A: Unacceptable Damage, 30 November 1978, TNA DEFE 25-335.

Minister Francis Pym argued that the primary focus should be on Moscow, but he added that the force should also have some capability to attack some of the command bunkers.[11] In January 1982 the MISC 7 committee decided that Britain should acquire Trident D5 rather than Trident C4. While this change was largely to retain compatibility with the US Navy, a secondary advantage was that D5 would be more effective against command bunkers.[12]

In 1981 the MOD carried out a review of Strategic Targeting Policy, looking ahead to Trident. This reaffirmed that Moscow was the main focus. While the report itself remains classified, comments on the draft policy suggest what it may have said. Group Captain Miller prepared a briefing for the Chief or Air Staff in which he noted: “With the improved accuracy of the new system we should plan to attack specific key areas rather than built up areas as a whole.”[13] Admiral Leach, Chief of Naval Staff, used the term “Moscow plus hardened bunkers”.[14] There was a departure from the previous “breakdown” approach of achieving a prescribed level of destruction across a city. Targeting command bunkers was a feature of the new policy.

There was further confirmation of the focus on bunkers in 1995 when Field Marshall Nigel Bagnall, former Chief of General Staff was asked about the targeting of Trident. He said, “It is more than just the destruction of Moscow, it is the destruction of their command and control system”.[15]

It is possible to deduce that Britain’s primary nuclear policy today is to target Moscow. Warheads are probably targeted on particular facilities, including command centres, within the city and at that the main bunkers outside the capital. The MOD are currently upgrading the Trident warhead to a new Mk4A specification. The Mk4A will be substantially more effective than the original Mk4 against command bunkers.

Defence ministers are fond of saying that Trident missiles are now “de-targeted”, but the significance of this should not be exaggerated. In 1994 Britain, the US and Russia agreed that their missiles would not normally hold real target data. This was to reduce the risk that the accidental launch of a single missile could trigger nuclear war. It does not mean that Britain has no target plans. It is almost certain that the Trident submarine on patrol carries electronic plans which can be implemented if the Captain receives authorisation.

**Model target list**

A target list has been created in order to illustrate the effect of an attack by 40 warheads from one Trident submarine. The government of Russia is heavily concentrated in the central district of Moscow. This is also the location of several underground command bunkers. This list assumes that 10 warheads are targeted on facilities in the city centre, a further 10 elsewhere in the city and 20 at command bunkers outside the city, but within Moscow region. The centre of Moscow is likely to be completely destroyed, regardless of the precise targets in the central district. The identification of individual targets across the city may not be accurate, but the list provides a reasonable basis for estimating the overall effect on Moscow as a whole.

11 Speaking note for Secretary of State for MISC 7 meeting on 5 November 1979, TNA DEFE 13-752 e1. Due to a date error this paper was in a file covering 1970. If it had been in the correct file the document might have been redacted.
12 The MOD calculated that One warhead from a D5 missile would have a similar effect on a bunker as four warheads from a C4 missile, because D5 was more accurate.
13 “Brief for Chief of Air Staff for presentation to SofS on strategic nuclear targeting, Group Captain Miller, 23 October 1981, TNA AIR 8-2846 e67ii
14 In a critique of the new targeting policy, Leach said that “Moscow plus hardened bunkers” had not been the planning assumption when the initial Trident C4 decision had been taken. His comment implies that it was part of the new approach. British Strategic Nuclear Targeting Policy, Assistant Secretary CNS, 21 October 1981, TNA AIR8-2846 e66
15 Moscow Criterion, BBC, broadcast July 1995

*Table 1. Ten targets in Moscow city centre*

| Target | Location | Missile/Warhead |
|---|---|---|
| Special Communications HQ | Bolshoy Kiselni Lane | 2.1 |
| Presidential Administration | Old Square | 2.2 |
| Communications Ministry | Tverskaya Street | 2.3 |
| Kremlin | | 2.4 |
| Defence Ministry | Znamenka Street | 2.5 |
| Navy Headquarters | Bolshoy Koslowski Lane | 3.1 |
| Moscow District HQ | Kosmondamianskaya Embankment | 3.2 |
| Ground Forces HQ | Frunzenskaya Embankment | 3.3 |
| Rear/Logistics HQ | Bolshoya Pirogovskaya Street | 3.4 |
| White House | | 3.5 |

*Chart 1. Ten targets in Moscow city centre*


*Table 2. Ten targets in Moscow outside the city centre*

| Target | Location | Missile/Warhead |
|---|---|---|
| Ostankino Tower transmitter [16] | Academician Koroleva Street | 1.1 |
| Collective Security Treaty HQ | 41 Leningradski Avenue | 1.2 |
| Military Intelligence (GRU) HQ | Grizodubovoy Street | 1.3 |
| Space Intelligence Centre | Balokamskoy Highway | 1.4 |
| FSB Cryptology Centre | Molodogvardeyskaya Street | 1.5 |
| Interior Forces HQ | Energetiskaya Street | 4.1 |
| FSB complex | Vernadskogo Avenue | 4.2 |
| Space Forces HQ | Profsoyuznaya Street | 4.3 |
| General Staff Academy | Vernadskogo Avenue | 4.4 |
| Air Defence Bunker | Akademika Yangelya Street | 4.5 |

16 Ostankino Tower houses a transmitter, “Message”, for the Kavkaz-7 nuclear authorisation system.

*Chart 2. Ten targets in Moscow outside the city centre*


*Table 3. Targets outside Moscow (20 warheads)* [17]

| Area | Facility | No. of warheads |
|---|---|---|
| Gorki-25 | Navy Alternate Command Centre | 1 |
| Monino | Air Force Command Centre | 1 |
| Balashikha | Air Force Headquarters Command Centre | 1 |
| Odintsovo-10 | Strategic Rocket Forces Command Centre (facilities 315/1 & 315/221) | 2 |
| Balabanovo-1 | Strategic Rocket Forces Alternate Command Centre | 1 |
| Chekhov-3 | General Staff Central Command Centre (including facility 201) | 6 |
| Chekhov-4 | General Staff Central Command Centre | 1 |
| Chekhov-2 | Government Command Centre | 5 |
| Ilinskoe | Ground Forces Alternate Command Centre | 1 |
| Egorievsk | Rear/Logistics Alternate Command Centre | 1 |

*Chart 3. Targets outside Moscow*


17 Monino, Balashikha, Odintsovo-10, Chekhov-3 and Chekhov-2 were identified as potential targets in a key paper which influenced the UK's decision to buy Trident. Duff-Mason Report Part II, Appendix to Annex A, TNA DEFE 25-335.

**Assumptions**

The calculations below assume that the wind is from the Southwest, with a windspeed of 7 metres per second. These are typical wind conditions. Visibility is assumed to be 40 kms.[18] The population are at their normal place of residence and there is no notice of the attack. The potential for taking shelter in civil defence bunkers and the subway is considered towards the end of the report, as is the impact of different weather conditions. Calculations are based on the 2010 Russian census. The geographical boundaries of Moscow which were in place in 2010 are used throughout this report.

## 2. Effects

Three consequences of a nuclear explosion (blast, heat and initial radiation) are often grouped together as prompt effects, as distinct from radioactive fallout which is a long-term hazard. However, this grouping may not adequately address the issue of fire. Blast and initial radiation are effective within 1 minute of the explosion. Direct burns from thermal radiation are also experienced within this timescale. Fires can be initiated by heat from the fireball and as a result of blast damage. The intensity of fires is likely to increase over the first hour and the resulting conflagrations can remain a major hazard for several hours. Fires may have a critical effect in determining how people behave. In order to escape flames and smoke, residents may move away from shelter and into areas where they are at greater risk from fallout.

Two effects modelling programmes in the public domain are Weapons Effects (Version 2.1 December 1984) and Hotspot (Version 2.07.2 August 2011).[19] Weapon Effects was produced by Horizon Technology for the Defence Nuclear Agency and was originally classified. Hotspot was produced by Lawrence Livermore National Laboratory to model the effects of nuclear accidents. It includes a nuclear explosion model. A comparison of the programmes, Table 4, shows that Weapon Effects gives slightly higher estimates for blast, but significantly lower estimates for heat and initial radiation. Hotspot was used as the primary source for this paper.

*Table 4. Comparison of Hotspot and Weapon Effects*

| Distance (km) | Blast (psi) | | Heat (cal/cm$^2$) | | Initial Radiation (Gray) | |
|---|---|---|---|---|---|---|
| | Weapon Effects | Hotspot | Weapon Effects | Hotspot | Weapon Effects | Hotspot |
| 0.7 | 47 | 44 | 180 | 270 | >1300 | 3500 |
| 1 | 21 | 20 | 85 | 130 | 210 | 510 |
| 2 | 5.7 | 5.3 | 20 | 29 | 1.2 | 2.8 |
| 3 | 3 | 2.6 | 8.7 | 12 | | |
| 4 | 2 | 1.6 | 4.7 | 6 | | |

Hotspot shows the effective dose from fallout in rem and the absorbed dose from initial radiation in rads. This report uses the standard international equivalent measures. The effective dose from fallout is shown in Sieverts (1 Sv=100 Rem). The absorbed dose from initial radiation is shown in Gray (1 Gy=100 rads). For gamma and beta radiation the conversion factor between Sieverts (effective dose) and Gray (absorbed dose) is one. The casualty estimates in this paper assume the same mortality rates per Sievert and per Gray.

The fallout plots produced by Hotspot are available online in a kmz file which can be viewed on Google Earth. The kmz file also includes damage areas and the location of targets, hospitals and power stations.[20]

18 Hotspot provides three visibility options: 20, 40 and 80 kms.
19 Weapon Effects: http://nuclearweaponarchive.org/Library/Nukesims.html
Hotspot: https://narac.llnl.gov/HotSpot/HotSpot.html
20 Kmz file: http://banthebomb.org/images/stories/FlatteningMoscow.kmz Google Earth: http://earth.google.co.uk

**Blast effects within 3 kilometres of each Ground Zero**

Within 500 metres of each explosion the blast overpressure would be 97 psi. This would completely destroy all buildings. This effect would be particularly noticeable in the middle of Moscow, where there would be five explosions, 1 kilometre or less apart. At 500 metres, the direct blast effect on the body would be fatal for 100% of those who were exposed to it, before taking account of falling buildings, heat and radiation.

Between 500 metres and 1 kilometre, rubble would be thrown a considerable distance from each building. In the Mill Race experiment a building was subjected to 30 psi in a US nuclear test. Masonry from the front and side walls was discovered 60 metres from the site.[21] Within 1 kilometre of each explosion the blast overpressure would be 20 psi. This would destroy or severely damage even the most substantially built reinforced-concrete buildings in the city. Injuries sustained from collapsed buildings would result in a fatality level from blast alone of around 100%.[22]

At 1.5 kilometres the overpressure would be just under 10 psi. This would severely damage or destroy many reinforced-concrete buildings. One recent report indicates that most buildings would be destroyed by overpressure values of between 10 and 12 psi.[23] The percentage of fatalities from blast damage would decline from 100% at 1 kilometre to 58% at 1.5 kilometres. Almost all who survived in this area would be injured.

Reinforced concrete buildings would suffer significant damage at distances of between 1.5 and 1.8 kilometres (6‑9 psi). Steel framed buildings would be seriously damaged between 1.7 and 2.4 kilometres (4-7 psi).[24] Wood -framed buildings would collapse at just over 2 kilometres from Ground Zero (5 psi). At 2 kilometres, the effects of blast would kill 13% of residents and injure around 54%.

Someone standing up in a standard house 2.6 kilometres (3.5 psi) from Ground Zero would be at 50% risk of death from damage to the building.[25] If they were lying down then they would be at a similar risk of death from blast damage if they were 1.7 kilometres (7 psi) from Ground Zero. At 2.8 kilometres (3 psi) the wind speed would be 152 kph (95 mph).[26]

In 1979 the US Office of Technology Assessment (OTA) produced an indication of casualties at given overpressure values.[27] A graph consistent with these values was used to estimate casualties.

*Table 5. Blast casualties (OTA report 1979)*

| Overpressure (psi) | Fatalities (%) | Injuries (%) | Safe (%) |
|---|---|---|---|
| >12 | 98 | 2 | 0 |
| 5-12 | 50 | 40 | 10 |
| 2-5 | 5 | 45 | 50 |
| 1-2 | 0 | 25 | 75 |

21 Structural Debris Experiments at Operation Mill Race, JR Rempel et al. Asilomar conference 1983. http://www.dtic.mil/dtic/tr/fulltext/u2/a132780.pdf
22 Vulnerability of populations and the urban health care systems to nuclear weapon attack – examples for four American cities. WC Bell & CE Dallas, 2007, page 13.
23 A study on nuclear blast overpressure on buildings and other infrastructures using Geospatial Technology. C Vijayaraghavan et al. 2012
24 A study on nuclear blast overpressure on buildings and other infrastructures using Geospatial Technology.
25 The Effects of Nuclear War, Office of Technology Assessment, May 1979. p 19 http://www.princeton.edu/~ota/disk3/1979/7906/7906.PDF
26 The Effects of Nuclear War, Office of Technology Assessment, May 1979.
27 The Effects of Nuclear War, Office of Technology Assessment, May 1979.

**Effects of initial radiation and direct burns at between 1 and 2.2 kilometres from each Ground Zero**

Residents would be exposed to two forms of direct radiation. The main hazard would be gamma radiation, but neutron radiation would also contribute to the total dose. Initial radiation would affect residents before most buildings were destroyed by blast.

Many residents would not be within line-of-sight of the fireball because of shielding from buildings. Within the 1 second of the explosion, the fireball would expand and rise. As it rose, the gamma radiation would be emitted from higher above the ground. The shielding effect from buildings would decline. Meanwhile, the amount of gamma radiation emitted from the fireball would reduce. Between 0.1 seconds after the explosion and 1 second after the explosion it will have declined by a factor of 10.[28] The size and height of the fireball at this time would be similar to that described in Table 10.

Within 2.2 kilometres of Ground Zero the initial radiation could be fatal. The effect on three groups of people is considered. The first is those who would be directly exposed to heat from the explosion and gamma radiation. The second is those who would be exposed to the full effect of gamma radiation, but not to thermal radiation, due to shielding. The third is those who would receive 1/10th of the gamma radiation dose as a result of shielding from one external wall.

Between 1 and 2 kilometres from Ground Zero many people would be killed, and others would be injured, by blast damage. The radiation dose which would be fatal for injured residents would be lower than that for healthy adults. The combination of exposure to initial radiation and blast injury would have a significant effect on mortality between 1.4 and 2.2 kilometres from Ground Zero. Severe burns, combined with radiation exposure, category 1 above, would be fatal for all those exposed within these distances. The risk to residents in high-rise buildings would be higher, because the proportion in direct line-of-sight with the fireball would be greater. These are considered later.

Table 6 indicates the proportion exposed to each effect, taking account of fireball height and shielding from buildings in a typical section of Moscow. This also shows the absorbed dose from initial radiation.

*Table 6. Proportion exposed to direct heat and gamma radiation*

| | **1 km** | | **1.5 km** | | **2 km** | |
|---|---|---|---|---|---|---|
| | **Percent** | ***Absorbed dose (Gy)*** | **Percent** | ***Absorbed dose (Gy)*** | **Percent** | ***Absorbed dose (Gy)*** |
| 1. Direct heat and gamma radiation | 14 | *510* | 9 | *32* | 7 | *2.8* |
| 2. Full gamma radiation dose only | 6 | *510* | 4 | *32* | 3 | *2.8* |
| 3. 1/10th gamma radiation dose | 42 | *51* | 28 | *3.2* | 21 | *0.28* |

Table 7 is an estimate of mortality rates, when no medical aid is available, for those with only radiation exposure and for those with radiation exposure plus other injuries.[29]

28 Effects of Nuclear Weapons, Glassstone, p328.

29 There are several sources for uninjured mortality rates when no medical aid is available, eg http://www.epa.gov/rpdweb00/docs/er/planning-guidance-for-response-to-nuclear-detonation-2-edition-final.pdf p34. This report also indicates that the mortality rate for uninjured exposed to 4 Sv is equivalent to that for injured patients exposed to 2.5 Sv. The increased mortality rate for those who are injured is also described in Combined Radiation and Thermal Injury after Nuclear Attack, W Becker et al, 1991, and Medical Management of Radiological Casualties, 1999, http://www.seizeliberty.com/Documents/Radiological%20Casualty%20Handbook.pdf

*Table 7. Mortality rates associated with absorbed dose when no medical aid is available*

| Absorbed dose (Gray) | Mortality rate | |
|---|---|---|
| | Uninjured | Injured |
| 1 | 0 | 15 |
| 2 | 5 | 45 |
| 3 | 35 | 72 |
| 4 | 65 | 95 |
| 5 | 95 | 100 |

Table 8 shows how gamma radiation and direct exposure to thermal radiation increases the proportion of fatalities between 1.4 and 2.2 kilometres of Ground Zero.[30]

*Table 8. Fatalities from blast, initial radiation and direct thermal radiation (1.4- 2.2 kms)*

| | Blast | Blast, initial radiation and direct thermal radiation |
|---|---|---|
| 1.4 km | 70 | 83 |
| 1.6 km | 40 | 55 |
| 1.8 km | 23 | 33 |
| 2 km | 13 | 21 |
| 2.2 km | 7 | 14 |

**Fire**

The development of fires in the aftermath of a nuclear explosion is a key issue for several reasons. In some circumstances, such as at Hiroshima, fire can be the biggest killer. Fire can also have a major impact on how people behave, including their ability to remain in shelter and their exposure to radioactive fallout. Thirdly, extensive fire damage is an underlying assumption behind models which estimate the global impact of multiple nuclear explosions on the climate. Research into how fires develop after a nuclear explosion, including the relationship between fire and blast, was carried out in the United States in the late 1970s and early 1980s. Some of this work was to inform civil defence planning. The possibility of deliberately using fire from nuclear explosions as a way of inflicting maximum damage to cities was also explored.

Table 9 shows the distance at which materials may ignite if in line-of-sight of a 100 kiloton nuclear fireball.[31]

*Table 9. Ignition of material relative to distance from Ground Zero*

| Distance from Ground Zero (kms) | Thermal Radiation (cal/cm$^2$) | Material which ignites |
|---|---|---|
| 2.1 | 24 | 90% probability of igniting interior furnishing |
| 2.6 | 16 | 50% probability of igniting interior furnishing |
| 3.1 | 11 | Cotton |
| 3.4 | 9 | Some polyester fabrics |
| 3.5 | 8 | 10% probability of igniting interior furnishing |
| 4 - 4.8 | 4-6 | Newspaper |

30 Estimates of blast casualties are derived from the figures in The Effects of Nuclear War, Office of Technology Assessment, May 1979.
31 Effects of Nuclear Weapons, Glassstone, p289; Fire and Strategic Targeting, Brode, p13.

A paper written in 2007 examines the thermal effects of a groundburst 10 kiloton explosion in a city. It illustrates how heat is distributed in three dimensions.[32] Areas behind tall buildings would be less hot because they are shielded from thermal radiation. As the fireball rises, these cooler areas shrink. The illustrations in the paper show that the effect is similar to shadows which shorten as the sun rises in the sky.

For a 100-kiloton explosion, the peak emission of thermal radiation is 0.3 seconds after the weapon detonates. 50% of the heat is emitted by 0.5 seconds after detonation and 90% is emitted by 2.2 seconds after detonation.[33] During this period the fireball is expanding and rising. Table 10 shows the height of the centre of the fireball from a groundburst explosion at each stage. If the Mk4A Trident warhead is fused for near-surface-burst detonation, with a Height of Burst below 250 metres, then the Height of Burst should be added to these figures. In this case the shielding effect will be less.

*Table 10. Fireball height and thermal radiation in first seconds after detonation*

| **Time after detonation (seconds)** | **Height of centre of fireball (metres)** | **Thermal Radiation** |
|---|---|---|
| 0.3 | 232 | Peak heat emission |
| 0.5 | 322 | 50% of heat has been emitted |
| 2.2 | 516 | 90% of heat has been emitted |

Table 11 is an estimate of the proportion of indoor space exposed to direct heat from a groundburst 100 kiloton explosion.[34]

*Table 11. Effects of thermal radiation at1.5 – 3.5 kms from Ground Zero*

| **Distance from Ground Zero (kms)** | **Thermal Radiation ($cal/cm^2$)** | **Probability of igniting interior furnishing** | **Proportion of interior space exposed to direct heat (%)** |
|---|---|---|---|
| 1.5 | 68 | 1 | 9 |
| 2 | 29 | 0.99 | 7 |
| 2.5 | 17 | 0.55 | 5 |
| 3 | 12 | 0.3 | 5 |
| 3.5 | 8.3 | 0.12 | 4 |

The figures in table 11 show only fires which are initiated by thermal radiation. They do not include additional fires resulting from blast damage. The results can be compared with the OTA estimate that there would be sustained fires in 10 % of buildings where the overpressure was 5 psi (2.1 kms for 100 kt).[35] Another report indicates that fires would start in between one third and one half of properties in this area.[36]

Because of the effects of shielding, the upper floors of apartment blocks are more likely to be exposed to thermal radiation than lower floors.  Very tall buildings are particularly vulnerable. These are considered later.

32Thermal radiation from nuclear detonations in urban environments, RE Marrs, WC Moss & B Whitlock, Lawrence Livermore National Laboratory, June 2007. https://e-reports-ext.llnl.gov/pdf/348428.pdf
33 Thermal radiation from nuclear detonations in urban environments, p 3
34 Estimates of the probability of igniting interior furnishing are based on the figures in Fire and Strategic Targeting, Brode, p13. Estimates of the proportion of interior space exposed to thermal radiation are based on calculations taking account of the ratio of building height to space between buildings in Moscow, proportion of window space on exterior walls and the height of the fireball.
35  The Effects of Nuclear War, Office of Technology Assessment, May 1979, p 21.
36  Blast/Fire interactions, Program Formulation, Defense Civil Preparedness Agency, 1979, p A-8

Where a building 2-3 kilometres from Ground Zero is subjected to the effects of a single nuclear explosion, the sequence will be that parts of the structure will be exposed to thermal radiation for around 2 seconds, and then, a few seconds later, the blast wave will hit the building, causing extensive damage.

In the case of a 1 Megaton explosion, the blast wave is 800 metres from Ground Zero 1.8 seconds after detonation. It is 4.8 kilometres from Ground Zero after 11 seconds and 6.4 kilometres from Ground Zero after 16 seconds. So, at 6.4 kilometres, there would be a gap of 15 seconds between the pulse of thermal radiation and the arrival of the shock wave.[37] These figures suggest that the heat/blast interval at 2 kilometres would be 4 seconds and at 3 kilometres, 6 seconds, for a 1 Megaton explosion. The intervals for a 100 kiloton explosion would be longer. The intervals are unlikely to be long enough to allow a full-scale fire to develop, but, where thermal radiation is above 20 $cal/cm^2$, there could be almost instantaneous combustion of a significant proportion of the material in a room.

When the blast wave arrives it has a complex effect on the development of fires. The blast wave can extinguish flames. However, some US tests indicated that blast overpressures of 5 psi and less did not have this effect.[38] In addition, where the blast wave does suppress initial flames the material may later reignite.[39]

The blast wave would also eject combustible material from apartments into streets and gardens. There would be a substantial build up of debris, some of it readily combustible, in open areas. As a result, although the blast wave would reduce the number of buildings in which thermally-induced fires were developing, it would increase the ease with which fire would spread between buildings. Even Moscow’s widest thoroughfares would cease to provide effective firebreaks, because they would be filled with smouldering debris.

The blast wave would also initiate secondary fires. Gas pipes would be ruptured when heaters and cookers were blown away. Blast damage would also trigger electrical fires. Where overpressure was around 2 psi most fires would be caused by blast rather than thermal radiation.[40] This would result in sustained fires in 2 % of buildings which were 3.5 kilometres from a 100 kiloton explosion.[41] Some secondary fires would be ignited as far as 8.8 kilometres from the explosion, where the overpressure was greater than 0.5 psi.[42] Brode described how the risk of fire depends on the strength of the building and the flammability of its contents. Overpressure of 0.5 psi would cause fires in lightly constructed buildings containing highly flammable material.[43]

The interaction between blast and fire becomes even more complex when there are several nuclear explosions. A 1979 report into blast/fire interaction said, “The extension of fire-start (and fire spread) models to a multi-burst case appears to be a rather complex project involving many poorly defined phenomena”.[44]

The targeting scenario described assumes that there are only very small time intervals between each explosion. In many cases this would mean that a building was exposed to thermal radiation from several explosions and then the blast waves each of the detonations. The proportion of the building that was ignited would be increased, because it would be exposed to thermal radiation from several directions and the shielding effect would be reduced. However, the time interval between thermal radiation from later explosions and the first

37 Possible fatalities from superfires, T Postol, Medical Implications of Nuclear War, 1986, p 18f.
38 Blast/Fire interactions, Program Formulation, Defense Civil Preparedness Agency, 1979, http://www.dtic.mil/dtic/tr/fulltext/u2/a064316.pdf p A-1239
39 Fire and the related effects of nuclear explosions, Proceedings of the 1982 Asilomar Conference, Federal Emergency Management Agency. p VI-5 http://www.osti.gov/bridge/product.biblio.jsp?osti_id=6520265
40 Fire and the related effects of nuclear explosions, Proceedings of the 1982 Asilomar Conference, p III-11
41 Blast/Fire interactions, Program Formulation, Defense Civil Preparedness Agency, 1979, p A-4
42 Fire and the related effects of nuclear explosions, Proceedings of the 1982 Asilomar Conference, p VI-13
43 Fire damage and strategic targeting, Harold L Brode, Defence Nuclear Agency, 1984, p 24. http://www.dtic.mil/dtic/tr/fulltext/u2/a159280.pdf
44 Blast/Fire interactions, Program Formulation, Defense Civil Preparedness Agency, 1979, p 11

blast wave would be shorter, reducing the time that some fires would have to develop. The amount of debris that was ejected into the streets would be greater.

In some cases, buildings would be subjected to the blast wave from one explosion before they were exposed to thermal radiation from a second explosion. The interior space of buildings would be more exposed to heat because of blast damage. A higher proportion of fires would develop in this situation.[45]

In the immediate vicinity of the fireball a large amount of material is incinerated. Other combustible material may then be buried beneath piles of masonry. It has been suggested that, after the initial effects have subsided, there may be fewer fires in this central area, and more in a ring or doughnut around it.[46] There may be a higher risk of fire where buildings have been damaged rather than completely destroyed.[47]

Ten 100-kiloton explosions close together may have a similar effect, in terms of displacing the fire area, to a single one megaton explosion. This could mean that fire is likely to be concentrated in a doughnut around the edge of central district, rather than in the vicinity of the Kremlin. The fire risk may also be higher than otherwise expected in areas which lie between the devastated central district and individual explosions elsewhere in the city. For example, there might be extensive fires to the North of central district, as a result of the combined effect of a series of explosions.

The ability of the local population to bring fires under control would have a major effect on the spread and intensity of fires. The scale and extend of devastation resulting from a multi-warhead attack on Moscow would be such that fire-fighting efforts are likely to be very limited. Water supplies would be disrupted, roads blocked and fire engines damaged and destroyed. Within the 2 psi blast zone (3.5 kilometres) sporadic fires could develop if they were not tackled within 30 minutes and this could lead to extensive fires.[48]

Residents who were already injured by falling masonry and debris would be less likely to survive if they were also victims of fire.[49] In addition, those who were suffering from burns and smoke inhalation would succumb to lower levels of radiation than residents who were uninjured.

Where a large number of substantial fires take hold at the same time, there is a risk that a firestorm may develop. A firestorm develops its own momentum. Hurricane-force winds of 120 kph (75 mph) are created around the firestorm, sucking in air from all directions.[50] The temperature in the firestorm rises and a large proportion of combustible material is burnt. Residents above ground would not survive the intense heat. Those in shelters are likely to die from carbon monoxide poisoning, unless their shelter had a functioning independent air supply system.[51] They might also be exposed to extreme heat. One account of the bombing of Dresden describes the basements and shelter as "both crematoria and gas chambers combined".[52] Postol argued that the number of fatalities could increase by a factor of 2.5 where there was a firestorm.[53]

45 Assessment of combined effects of blast and fire on personnel survivability, Federal Emergency Management Agency, 1982. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA117958
46 If a firestorm is established it is expected to move into the heavily-destroyed centre of the doughnut after it takes hold. Proceedings of the 17th Asilomar Conference on Fire and Blast Effects of Nuclear Weapons, 1983, p 83.
47 Assessment of combined effects of blast and fire on personnel survivability, Federal Emergency Management Agency, 1982. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA117958
48 Evaluation of the nuclear fire threat to urban areas, SJ Wierama, Defense Civil Preparedness Agency, 1973, p 6. http://www.dtic.mil/dtic/tr/fulltext/u2/779340.pdf
49 Possible fatalities from superfires, T Postol, Medical Implications of Nuclear War, 1986, p 16 & 64.
50 Fire and the related effects of nuclear explosions, Proceedings of the 1982 Asilomar Conference, p VI-28
51 Problems of fire in nuclear warfare, JE Hill, RAND, 21 August 1961, http://www.dtic.mil/cgi-bin/GetTRDoc?AD=AD673703
52 Defending against allied bombing campaign: air raid shelters and gas protection in Germany 1939-1945, S Cromwell, Institute for historical review, http://www.ihr.org/jhr/v20/v20n4p15_Crowell.html
53 Possible fatalities from superfires, T Postol, Medical Implications of Nuclear War, 1986, p 64.

In a multiple-warhead attack on Moscow it is possible that two or more firestorms may develop. In this situation it is possible that two firestorms of different size may combine and consume an area which is up to 50% greater than the sum of the areas of the two firestorms.[54]

The development of firestorms and the combination of multiple firestorms are both dependent on weather conditions, including wind speed and stability. Analysis of Second World War fire raids suggests that rain and humidity has less effect than might be expected.

**Radioactive fallout**

The greatest problem from fallout will be from radioactive dust from the 10 nuclear explosions in the central district. This will be a major hazard downwind of this area. In addition there will be fallout from each of the other explosions in the city. Fallout from some of the explosions at bunkers outside Moscow is likely to reach the city. If the wind is from the Southwest the main problem would be fallout from Odintsovo-10. This would affect the North of the city. Fallout from bunkers would be a greater problem if the wind was from the South or South-Southwest, because this would blow fallout from the multiple explosions around Chekhov towards Moscow.

Table 12 shows how the effective radiation dose would increase over time in the case of someone who remained in the open directly downwind at 2, 5 and 10 kilometres from a 100 kiloton explosion.

*Table 12. Build up of effective dose over time*

| **Period of time** | **Effective dose (Sieverts)** | | |
|---|---|---|---|
| | **2 km** | **5 km** | **10 km** |
| 1 hour | 81 | 47 | 25 |
| 6 hours | 120 | 84 | 61 |
| 24 hours | 140 | 100 | 82 |
| 4 days | 150 | 120 | 97 |
| 1 year | 180 | 150 | 120 |

The number of casualties is affected by the degree of protection provided by buildings or other shelter. There is a significant difference between the design of buildings in Moscow and most of the structures outside the city. In the suburbs there are a large number of one and two storey houses, whereas most of the residential properties in the city are apartment blocks. There are also many dachas, summer cottages, outside the city.

Many of the buildings in Moscow would, if intact, provide significant protection from fallout. However, damage from blast and fire would greatly reduce the protection they would provide.[55] Most of the properties outside the capital would provide less protection. Although these houses would be far less affected by blast and heat, they would have little effect in reducing the dose from fallout. One storey houses have a Protective Factor of 2 or 3. The apartments in blocks of flats have Protective Factors between 10 and 50. Basements in houses have a

54 Interactions and spreading of adjacent large area fires, Defense Nuclear Agency, March 1986, http://www.dtic.mil/dtic/tr/fulltext/u2/a176338.pdf
55 Vulnerability of populations and the urban health care systems to nuclear weapon attack – examples for four American cities. WC Bell & CE Dallas, 2007, p 5.

Protective Factor of 10. Underground parts of large buildings can have a Protective Factor of 100 or more. The Protection Factor for those in the open is 1. Table 13 shows an estimate of the Protection Factors available to proportions of Moscow residents.

*Table 13. Estimate of the proportion of the population with varying degrees of protection from fallout*

| **Protective Factor** | **Urban area Damaged** | **Urban area Undamaged** | **Suburbs Undamaged** |
|---|---|---|---|
| 1 | 0.15 | 0.05 | 0.05 |
| 2 | 0.1 | 0.1 | 0.35 |
| 3 | 0 | 0 | 0.35 |
| 5 | 0.3 | 0.1 | 0.15 |
| 10 | 0.3 | 0.3 | 0.1 |
| 20 | 0.1 | 0.35 | 0 |
| 100 | 0.05 | 0.1 | 0 |

Table 14 shows short-term mortality rates, within two months, in specific fallout zones as shown in the Hot-spot/Googleearth charts. In the case of the most highly contaminated areas the criteria adopted were the effective dose over 1 and 6 hours. The casualty estimates are all based on the total effective dose over 4 days, taking account of the protection factors in Table 13 and the mortality rates in Table 7.

*Table 14. Mortality rates associated with fallout zones*

| **Fallout zone** | **Urban area Damaged** | **Urban area Undamaged** | **Suburbs Undamaged** |
|---|---|---|---|
| **1hr dose 30-50 Sv** | 0.94 | | |
| **1hr dose 5-30 Sv** | 0.63 | | |
| **6hr dose 10-50 Sv** | | 0.55 | 0.95 |
| **4 day dose 10-20 Sv** | 0.6 | 0.34 | 0.73 |
| **4 day dose 5-10 Sv** | 0.26 | 0.13 | 0.3 |
| **4 day dose 1-5 Sv** | 0.07 | 0.03 | 0.06 |

For those in damaged areas of Moscow where residents received an effective dose of 30-50 Sv within the first hour, this would itself result in a mortality rate of 0.75. This would rise to 0.94 with the total dose after 4 days. Where the one hour dose was 5-30 Sv, the one-hour mortality rate of 0.42 would rise to 0.63 with the 4-days dose. In suburbs where the dose was 10-50 Sv after six hours, the mortality rate from this dose would be 0.88 rising to 0.95 with the 4-day dose.

Some residents are likely to move location during this initial 4-day period. Where they are in a room which provided a Protective Factor of 10 or more, then their 4-day dose is likely to be higher if they have to spend up to 24 hours in the open in order to reach an area with significantly less radiation. Where they have limited shelter, Protective Factor of 1 or 2, then their 4-day dose may be lower if they take similar action. It is assumed that the overall effect on the whole population might remain the same as if everyone remained where they were.

One recent study concludes that residents should remain in the best available shelter for at least 12 hours when there is a single low-yield explosion in an urban area.[56] This issue will be more complex when there is extensive radioactive contamination over a wide area from 40 surface burst 100-kiloton explosions.

## Damage Areas

### Fire zone within Moscow

There are likely to be extensive fires within 3 kilometres of each explosion. Brode said there would be substantial fires where blast overpressure was greater than 3 psi.[57] This is equivalent to 2.8 kilometres from each explosion. Postol said that there would be simultaneous fires where blast overpressure was greater than 2 psi or thermal radiation was more than 10 cal/cm$^2$.[58] The 2 psi blast contour is 3.5 kilometres and the 10 cal/cm$^2$ contour is 3.2 kilometres, for a 100 kiloton explosion. Postol also said there was a large amount of uncertainty in calculating the radius within which there would be extensive fires. Chart 4 shows the 3 kilometre zone (orange) within which extensive fires could be expected. This 3 kilometre zone was broken down into a number of areas.

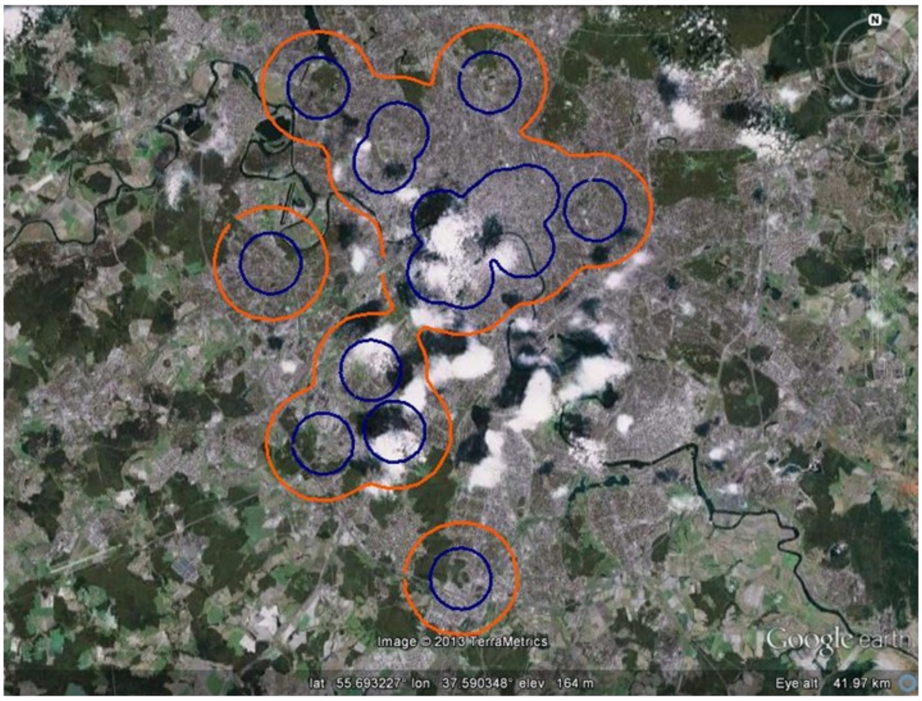
*Chart 4. Three kilometres fire zone*


### 1.6 Kilometre zones

Within 1.6 kilometres of each explosion, the combination of blast, heat, initial radiation and fallout would produce a very high mortality rate. Almost all of those who survived the initial physical damage would die within a few months from the effects of radiation. It is assumed that 95% of those in this area would be killed and the remaining 5% would be injured. The 1.6 kilometre zones are shown in blue in Chart 5.

56 Analyzine Evacuation Versus Shelter-in-Place Strategies After a Terrorist Nuclear Detonation, LM Wein, Y Choi & S Denuit, Risk Analysis, http://iis-db.stanford.edu/pubs/23053/Wein_-_Evacuation_vs_Shelter_in_Place_after_Terrorist_Nuclear_Attack.pdf
57 Fire damage and strategic targeting, Harold L Brode, Defence Nuclear Agency, 1984, p 30. http://www.dtic.mil/dtic/tr/fulltext/u2/a159280.pdf
58 Possible fatalities from superfires, T Postol, Medical Implications of Nuclear War, 1986.

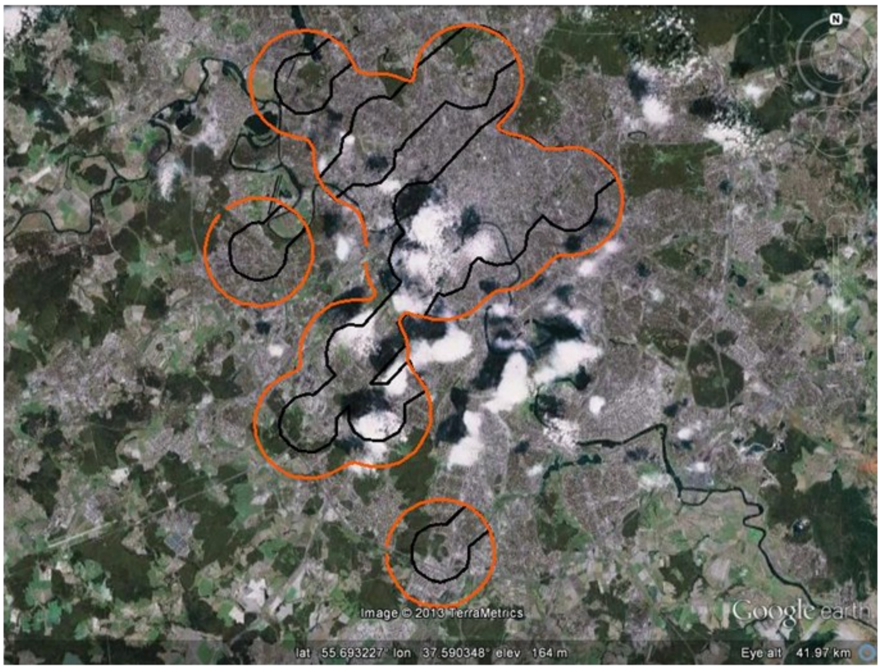
*Chart 5. 1.6 kilometre zones*




1 hour effective dose exceeding 30 Sv

Outside the 1.6 kilometre zone there are additional areas, within the fire zone, where the effective dose from fallout would exceed 30 Sv within the first hour. Severe damage would limit the protection from radiation provided by buildings. Where there was a Protection Factor of 5, the radiation dose would still be 6 Sv within the first hour. This would be fatal within a few months in around 100% of cases. The ability of residents to seek shelter would be limited by extensive fires in this area. Many residents would be injured from blast damage, thermal radiation and fires. For them the lethal radiation threshold would be lower. It is assumed that within these areas the mortality rate would be around 95% and that the remaining 5% of residents would be injured. The total area of these zones would be 53 square kilometres and the population 560,000. The black outline in Chart 6 shows the combined extent of these areas and the 1.6 kilometre zones.

*Chart 6. High mortality zones*



Specific Damage areas

*Chart 7. Specific damage areas*

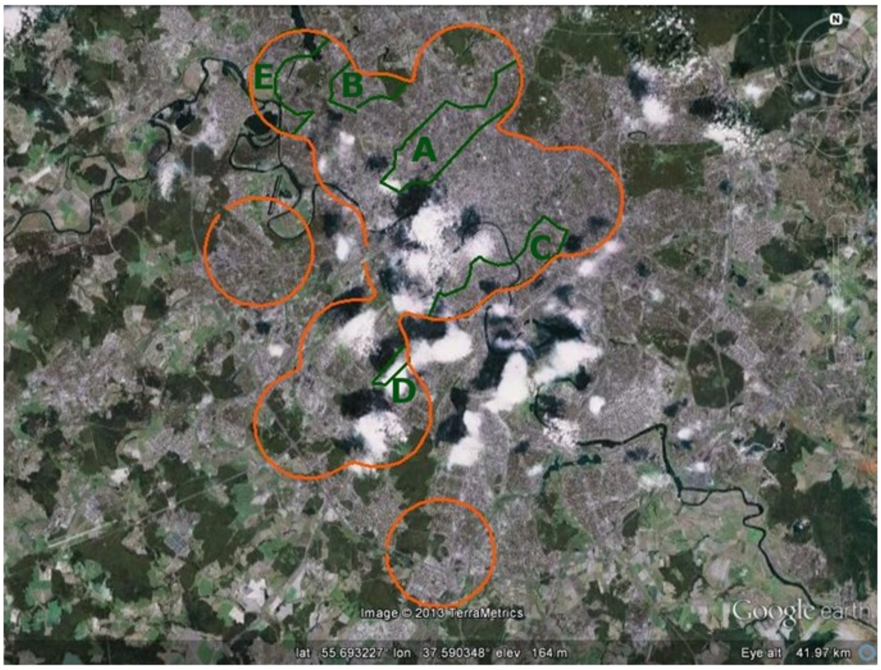



Chart 7 shows five specific areas within the fire zone. Area A is between the multiple explosions in Central District and three other explosions. There are likely to be extensive fires in this area and it could be part of a fire storm.  Survivors attempting to flee from this area would be likely to cross areas of extreme devastation, where progress would be slow and they would be exposed to high levels of radiation. Fatality rates could be 90% with 9% injured. There would be similar problems in areas B and D.

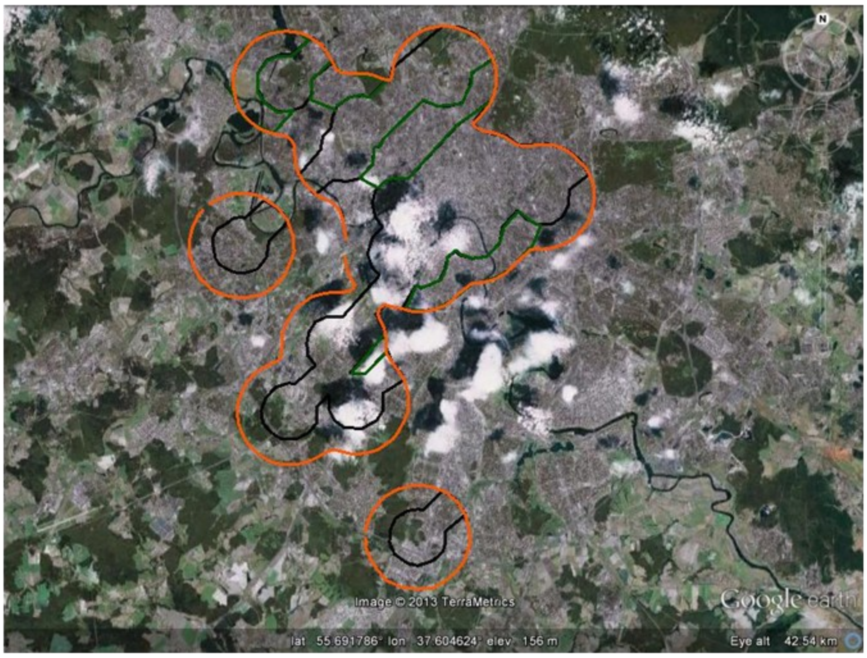
In area C there would be extensive fires and considerable damage because of the proximity to multiple explosions in the Central District. Surviving residents would be likely to attempt to flee to the South. While this would be possible, progress would be slow. Within one hour of the explosions, residents who were in the open in this area would receive a radiation dose exceeding 5 Sv, which would be fatal within a few months in 95% of cases.

Area E would be exposed to fallout from two explosions at Odintsovo-10, in addition to the direct effects of explosion 1.4. The four-day radiation dose from fallout from Odintsovo-10 would exceed 10 Sv.

Remainder of fire zone

The remainder of the fire zone is made up of areas which are between 1.6 and 3 kilometres of at least one explosion, but where fallout is less significant. This is predominantly the case in South-western parts of the fire zone. Here mortality and injury rates will relate to proximity to each explosion. The mortality rate would decline from 78% at the 1.6 kilometre contour to 15% at 3 kilometre contour.

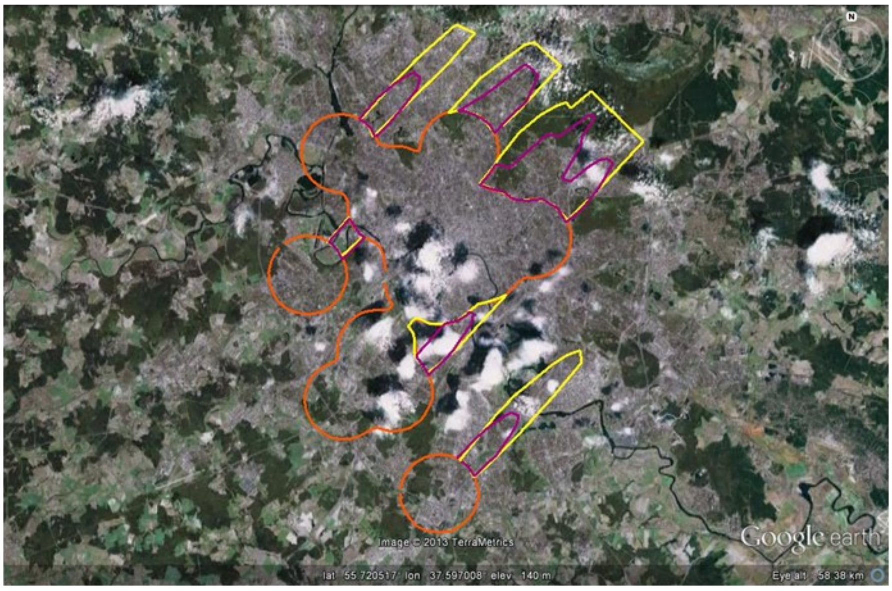
*Chart 8. Remainder of Fire Zone*




**Other areas within Moscow**

Potentially lethal radiation dose within one hour

*Chart 9. Effective dose within one hour of 5 Sv and 30 Sv*




Within the purple contours in Chart 9, residents in the open would receive an effective dose of more than 30 Sv in the first hour, rising to over 60 Sv within 6 hours, over 80 Sv in 24 hours and over 100 Sv in 4 days. Throughout these areas there would be some blast damage. In almost all buildings, windows would be in broken and in many cases internal walls and doors would be damaged or removed. This would limit the protection from fallout. Those who were under cover which provided a Protection Factor of 5 would still receive a fatal dose within one hour. Where there was a Protection factor of 10, the lethal dose for 100% would be reached within 6 hours. Survivors attempting to flee within the first few hours would be exposed to high levels of radiation as they moved in the open. 70% of residents in these areas might receive a lethal dose of radiation, with a further 20% injured.

The yellow contours indicate where the one hour radiation dose would exceed 5 Sv. Within six hours the radiation dose will have risen to over 10 Sv, within 24 hours to over 15 Sv, and within 4 days to over 20 Sv. The dose to those in the open after one hour would be fatal for 95% of people in the open. There would be a similar mortality rate for those in cover with a Protection Factor of 2 after 6 hours, and for those in cover with a Protection Factor of 4 after 4 days.

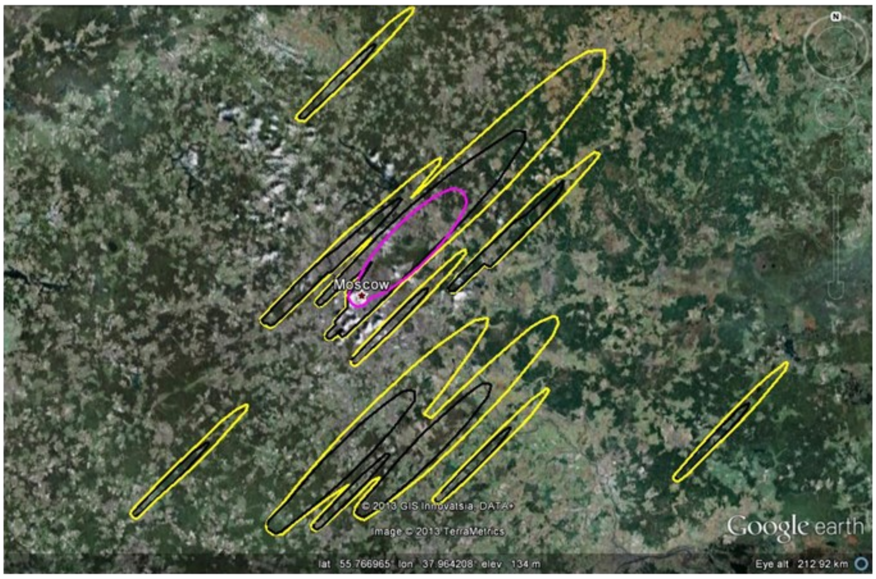
The blue contours in Chart 10 show additional areas, within Moscow, where the radiation dose for those in the open would exceed 10 Sv after four days. This includes fallout from Odinstovo-10 which would affect a strip in the North of the city.  Where the Protection Factor provided by buildings was 2, as in a basic wood-framed house, this dose would be fatal in 95% of cases. There are slightly bigger zones in which the four-day dose would be greater than 5 Sv.

*Chart 10. Effective dose within four days of 10 Sv*


**Fallout outside Moscow**

The purple contour in Chart 11 shows where the 6-hour radiation dose would exceed 10 Sv. This is only shown for the 10 warheads detonating in Moscow city centre. The black contour shows where the 4-day radiation dose would exceed 10 Sv and the yellow contour shows where the 4-day radiation dose would exceed 5 Sv. Outside the city, the heaviest concentration of radioactivity would be in the areas to the North East of Moscow, including the districts of Mytishchinsky, Pushkinsky and Schchyolkovsky. While most of the areas identified are within Moscow Region, the 4-day dose would also exceed 1 Sv in parts of Vladimir Region. Lower levels of radiation would be experienced over a far wider area.

*Chart 11. Effective dose within six hours of 10 Sv and effective dose within four days of 5 Sv and 10 Sv*




**Overall casualty estimate**

The area of each of the zones within Moscow was calculated using Google Earth and Easy Acreage. The population in each zone was estimated based on average population density for Moscow. Outside the city, the proportion of individual towns and rural areas within various fallout zones was estimated. The number of fatalities in each case was estimated based on the proportion of fatalities associated with each radiation band.

The total number of fatalities is estimated to be 5.37 million. A similar study by Scottish CND in 1998 concluded that there would be 3 million fatalities.[59] The 1998 study assumed an attack with 3 warheads on each of 5 targets in Moscow. The change to 20 warheads on separate targets explains most of the increase.

*Table 15. Casualties within the city of Moscow*

| | Area $km^2$ | Population | % Fatalities | % Injured | Fatalities | Injuries |
|---|---|---|---|---|---|---|
| *Within 3 km Fire Zone* | | | | | | |
| 1.6 km zone around GZs | 119 | 1270110 | 95 | 5 | 1206604 | 63505 |
| 1 hour dose >30 Sv | 53 | 560249 | 95 | 5 | 532236 | 28012 |
| Areas A, B & D | 37 | 392653 | 90 | 10 | 353388 | 39265 |
| Area C | 1.6 | 17345 | 80 | 20 | 13876 | 3469 |
| Area E | 11 | 116413 | 44 | 44 | 51222 | 51222 |
| Remainder of 3 km Fire Zone | 93 | 992805 | 33 | 44 | 327626 | 436834 |
| | 315 | *3349574* | | | *2484951* | *622308* |
| *Outside 3 km Fire Zone* | | | | | | |
| 1 hour dose >30 Sv | 76 | 808716 | 95 | 5 | 768280 | 40436 |
| 1 hour dose 5-30 Sv | 73 | 773175 | 62 | 38 | 479369 | 293807 |
| 4 day dose >10 Sv | 93 | 991209 | 60 | 10 | 594725 | 99121 |
| 4 day dose 5-10 Sv | 50 | 535881 | 26 | 5 | 139329 | 26794 |
| 4 day dose 1-5 Sv | 47 | 503745 | 7.5 | 2 | 37781 | 10075 |
| | 339 | *3612726* | | | *2019484* | *470232* |
| Total within Moscow | 630 | *6962300* | | | *4504435* | *1092540* |

59 http://www.banthebomb.org/archives/wmd/index.htm

*Table 16. Casualties outside the city of Moscow*

| Districts in Moscow Region | Fatalities | | Towns under Moscow Region jurisdiction | Fatalities |
|---|---|---|---|---|
| Dmitrovsky | 29865 | | Bronnitsy | 3208 |
| Sergiyevo Posadsky | 684 | | Zhukovsky | 5027 |
| Mytishchinsky | 151010 | | Ivanteevka | 21692 |
| Pushkinsky | 49396 | | Korolev | 67859 |
| Shchyolkovsky | 143628 | | Krasnoarmeysk | 3418 |
| Balashikhinsky | 65875 | | Losino Petrovsky | 7667 |
| Noginsky | 13021 | | Lytkarino | 7181 |
| Pavlovo-Posadsky | 5011 | | Zuyevo | 724 |
| Lyuberetsky | 535 | | Podolsk | 6015 |
| Leninsky | 8699 | | Reutov | 8382 |
| Ramensky | 86282 | | Khimki | 6223 |
| Orekhovo-Zuyevsky | 213 | | Electrostal | 4656 |
| Shatursky | 4546 | | Yubileynyy | 997 |
| Domodedovsky | 84717 | | Vlashka | 25041 |
| Podolsky | 12102 | | | |
| Chekhovsky | 21024 | | *Total in towns under regional jurisdiction* | *168090* |
| Yegoryevsky | 4309 | | | |
| Naro-Fominsky | 2048 | | *Total in Moscow Region* | *857955* |
| Odinstovsky | 2871 | | | |
| Krasnogorky | 4029 | | *Vladimir Region* | *12157* |
| | | | | |
| *Total in Districts* | *689865* | | *Total outside Moscow city* | *870112* |

*Table 17. Overall Casualty estimate*

| | Fatalities | Injuries |
|---|---|---|
| Within Moscow | 4504435 | 1092540 |
| Outside Moscow | 870112 | |
| Total | 5374547 | |

## 4. Specific effects

### Damage to high-rise buildings

Today there are a large number of very tall buildings in Moscow. Five of the ten highest skyscrapers in Europe are in the city. Skyscrapers and high tower blocks are particularly vulnerable to the direct effects of a nuclear explosion. Residents are more likely to be in direct line-of-sight with the fireball and so exposed to gamma radiation and thermal radiation. People in the higher floors of these structures are most at risk.

Where tall buildings are more than 3 kilometres from an explosion, the residents may be at less risk from radioactive fallout than those in other buildings. A key issue is the point at which windows and glass curtain walls will fail. In modern buildings the windows and curtain glass curtain walls are reinforced and will withstand overpressure values significantly higher than normal glass.

High-rise buildings within 1 kilometre of a nuclear explosion

Within 1 kilometre of an explosion the blast overpressure would be at least 20 psi. This would be sufficient to destroy even robustly-built modern skyscrapers.[60] The initial absorbed dose would be 510 Gray for those directly exposed. Even those who were behind solid shelter, which was able to reduce the dose by 100 times, would still receive a fatal dose of 5.1 Gray. With thermal radiation of 130 cal/cm$^2$ buildings would be engulfed in flames. The following is a list of some of the high-rise buildings which are within 1 kilometre of an explosion and which would be completely destroyed, with virtually no survivors. Building heights are in brackets.

*Table 18. Tall buildings with 1 km of a nuclear explosion*

| | |
|---|---|
| Kotelnika Apartments (136 m) | Hotel Leninsgradskaya (136 m) |
| Swissotel Krasnye Holmy (165 m) | Grand Park complex |
| Novyy Arbat Street (87 m) | (large residential development, towers 138 m) |
| Golden Ring Hotel (81 m) | Triumph Palace (264 m, 57 floors, 1,000 apartments) |
| Belgrade Hotel (81 m) | Skylight complex (109 m) |
| Foreign Ministry (172 m) | 4-10 Academika Koroleva St (69 m) |
| Radisson Royal Hotel (198 m, 34 floors) | 125-137 Leninsky Avenue (66 m) |
| World Trade Centre (123 m) | 143 Varshavaaskoye St (49 m) |
| Kudrinskaya Ploshchad 1 (101 m) | 152 Varshavskoye Shosse (50 m) |

*Grand Park complex*

*Moscow International Business Centre*

High rise buildings between 1 and 2 kilometres of a nuclear explosion

Modern high-rise buildings might remain standing within this distance, with the possible exception of those within 1.0 and 1.2 kilometres. However, the reinforced glass panels on the exterior of modern skyscrapers are likely to shatter and break from heat, blast and flying debris, as are reinforced windows.[61]

At 2 kilometres the blast overpressure would be 5 psi and the windspeed would be 260 kph (160 mph). Furniture and fittings would be ejected from offices and apartments. More horrifically, the force of the wind would throw people from the upper floors to their deaths.[62]

60 Martin Hellman suggests that modern skyscrapers would be destroyed by a blast of 15 psi from a nuclear explosion. http://ee.stanford.edu/~hellman/sts152_02/handout01.pdf
61 The Pilkington website provides information on the testing of some of the company's reinforced glass products. http://www.pilkington.com/international+products/planar/
In 2011 several glass panels on Shanghai skyscrapers broke during a heat wave. http://shanghaiist.com/2011/06/21/glass_bombs_falling_from_shanghai_s.php
62 Blast overpressures of between 2 and 3 psi could blow people out of a typical tall modern office building. he Effects of Nuclear War, Office of Technology Assessment, May 1979, p 19.
http://www.princeton.edu/~ota/disk3/1979/7906/7906.PDF

Where there are several tall buildings in close proximity to each other, the blast effects will be complex, particularly when the area is exposed to more than one explosion. Some debris will damage adjacent buildings. Many residents would be exposed to lethal levels of initial radiation. Fires would be started on many floors of each building. Firebrands scattered by the blast will spread fire between towers. All of these effects would be greater on upper floors than on lower floors.[63] In addition, there will be many cases where survivors on the higher floors will be unable to escape because of fires on floors below them. The combination of heat, blast and initial radiation would result in a high proportion of fatalities in tall buildings which were between 1 and 2 kilometres of a 100 kiloton nuclear explosion.

*Table 19. Tall buildings between 1 and 2 kilometres of a nuclear explosion*

| Distance (km) | Blast (psi) | Heat (cal/cm$^2$) | Absorbed dose from initial radiation (Gy) | Examples | Height (m) |
|---|---|---|---|---|---|
| 1.1 | 16.2 | 113 | 340 | Airbus residential complex | 123 |
| | | | | Moscow technical university of telecommunications | 76 |
| | | | | 17 Starobittsevskaya St | 65 |
| 1.2 | 14.2 | 100 | 188 | Former GIAP building | 81 |
| | | | | Volochaeveskaya St | 47 |
| 1.3 | 12.4 | 88 | 94 | Paveletskaya Tower | 114 |
| 1.4 | 10.8 | 77 | 53 | Kalushkaya Square 1 | 156 |
| | | | | Golden Gate | 109 |
| | | | | Gazoprovod St | 55 |
| 1.5 | 9 | 68 | 32 | Nikoloyamskaya Naberezhnaya | 43 |
| | | | | Gasprom Tower | 151 |
| | | | | Aliye Parusa | 184 |
| 1.6 | 8 | 58 | 20 | RIO complex | 139 |
| | | | | Wellhouse,  Leninsky Avenue | 162 |
| 1.7 | 7 | 50 | 14 | 25-27 Sheremetevskaya St | 65 |
| 1.8 | 6.3 | 43 | 7 | Rosneft Office | 98 |
| 1.9 | 5.8 | 35 | 4.6 | Nordstar Tower | 171 |
| 2 | 5.3 | 29 | 2.8 | Nikulinskaya St | 85 |

Moscow International Business Centre (2.1 – 2.4 kilometres)

Several of the tallest buildings in Europe are at the Moscow International Business Centre.  This complex includes the Mercury City Tower (339m), Moscow Tower (301m), St Petersburg Tower (257m), Naberezhnaya Tower (268 m), Federation Tower West (243m), Imperia Tower (239 m) and several smaller structures. Other skyscrapers, some of them even taller, are under construction. A large proportion of the floor space in the complex is for residential apartments.

Powerful blast waves would hit the towers from three directions within several seconds. The combination of heat and blast, particularly from the second and third explosions, could shatter the glass curtain walls on the

63 The higher probability of fires on upper floors is explained in Fire Spread in High Density High-Rise Buildings, Report for Office of Civil Defense, February 1971. http://www.dtic.mil/dtic/tr/fulltext/u2/719731.pdf

exposed sides of the skyscrapers. Other windows would be broken by flying debris. There would be a large number of fires on many floors. Most of these would be initiated by thermal energy. Others would be secondary fires, caused by blast. Blast damage would also disrupt fire fighting systems.

Before the blast wave hit the buildings, many occupants would receive a dose of 1.8 Gray from gamma and neutron radiation from the third explosion. For those who were uninjured this would result in a mortality rate of around 2%. However this could jump to around 40% mortality in the case of those who had serious blast or burn injuries. Many who were exposed to gamma radiation would also receive 3rd degree burns .

*Table 20. Effect of nuclear explosions on Moscow International Business Centre*

| **Missile/ Warhead** | **Distance (km)** | **Direction** | **Blast (psi)** | **Heat ($cal/cm^2$)** | **Immediate Radiation (Gy)** |
|---|---|---|---|---|---|
| 1.3 | 3.6 | N | 1.9 | 7.8 | 0 |
| 3.4 | 2.6 | SE | 3.5 | 16 | 0.2 |
| 3.5 | 2.1 | ENE | 4.9 | 25 | 1.8 |

<u>Other high rise buildings between 2 and 3.5 kilometres of a nuclear explosion</u>

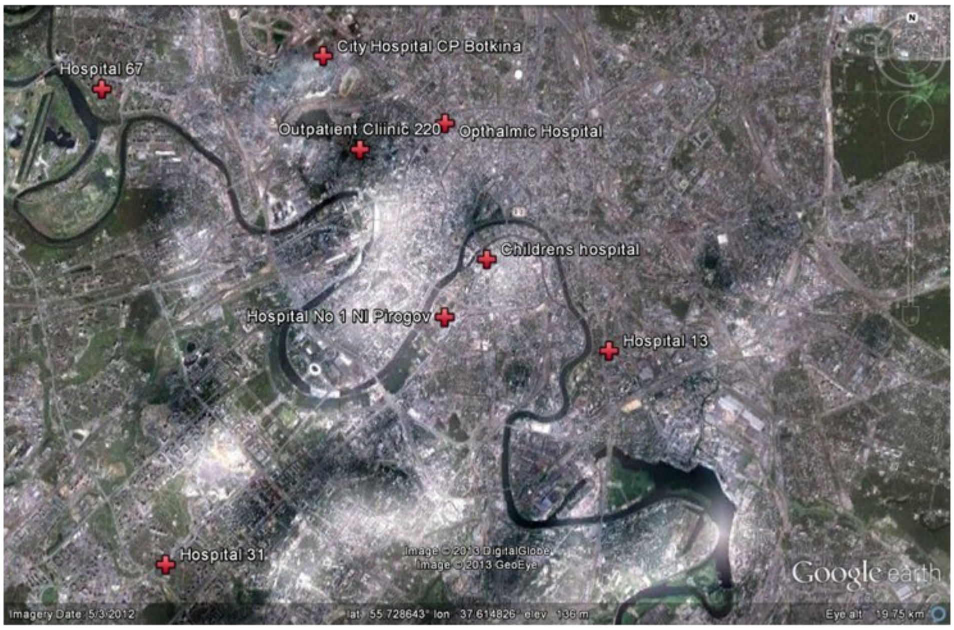
*Table 21. Tall buildings between 1 and 2 kilometres of a nuclear explosion*

| Distance (km) | Blast (psi) | Heat ($cal/cm^2$) | Absorbed dose from initial radiation (Gy) | Examples | Height (m) |
|---|---|---|---|---|---|
| 2.1 | 4.9 | 25 | 1.8 | Monarch Centre | 134 |
| | | | | Bibliotechnaya St | 47 |
| | | | | Hotel Cosmos | 96 |
| 2.2 | 4.6 | 22 | 1 | 35-41 Ostrovityanova St | 42 |
| | | | | 27 Tyoplyy Stan St | 51 |
| 2.3 | 4.3 | 20 | 0.7 | Moscow State University | 240 |
| 2.4 | 4.1 | 18.5 | 0.4 | 7 Nizhegorodskaya St | 79 |
| 2.5 | 3.8 | 17 | 0.3 | 15-25 Nizhegorodskaya St | 81 |
| | | | | Sminovskaya St | 47 |
| | | | | Shakovaya St | 51 |
| | | | | 22-34 Ostrovityanova St | 77 |
| 2.6 | 3.5 | 16 | 0.2 | House on Mosfilmovskaya | 201 |
| 2.7 | 3.2 | 15 | 0.1 | 16 Selsokhozyaystvehhaya St | 122 |
| | | | | White Square business complex | 91 |
| 2.8 | 3 | 14 | - | Monte Falcone | 135 |
| 2.9 | 2.8 | 13 | - | Sovetskoy Armii St | 51 |
| 3 | 2.6 | 12 | - | Statistics Centre | 108 |
| 3.1 | 2.5 | 11 | - | Sokolniki Complex | 147 |
| | | | | Minaevskiy Lane | 50 |
| 3.3 | 2.2 | 10 | - | Sparrow Hills | 188 |
| | | | | Edelweiss | 176 |
| 3.5 | 2 | 8.3 | - | Nezhinskaya St | 95 |

Initial radiation remains a problem for buildings within 2.4 kilometres, but not those further away. A key factor is the point at which reinforced windows and glass panel walls will fail. If these remain intact then they may reduce thermal radiation and the number of fires. In any case there are likely to be a significant number of fires in these buildings. There would also be internal disruption as a result of blast damage.

**Damage to hospitals**

*Chart 12. Hospitals affected by nuclear explosions*




*Outpatient Clinic 220*

This is Moscow's largest outpatient clinic. It has 220 doctors. It would be completely destroyed by explosion 3.5, only 750 metres away. There would be no survivors.

*Hospital 1, NI Pirogov*

This hospital has 1,328 beds and 2,000 staff. It would be completely destroyed by explosion 3.3, only 830 metres away. There would be virtually no survivors.

*Outpatient Clinics 1 and 3 and Ophthalmic hospital*

These two outpatient clinics and the ophthalmic hospital are 1.2 kilometres from explosion 2.3. There would be three other explosions within 1.8 kilometres. The combined effect would be to destroy these medical facilities. There would be very few survivors.

*Children's Hospital 20*

This is a major children's hospital which deals with surgery and trauma cases. It would be destroyed by the combined effects of five nuclear explosions to the North, East and South West (explosions 2.2, 2.4, 2.5, 3.2 and 3.3). Two of these would be within 1,400 metres, one within 1,600 metres and a further two within 2 kilometres.

*City Hospital CP Botkina*

This is the largest hospital in Moscow. It has 2092 beds and 2,100 staff, including 600 doctors. It treats 40,000 patients each year.

Staff and patients in upper floors of the hospital, in rooms facing West or North West, could receive a radiation dose of 14 Gray from explosion 1.3 and 4.6 Gray from explosion 1.2. These levels of radiation would be fatal in almost all cases. In many cases the doses would be lower, because of shielding from external walls, but still high enough to increase the risk of death.

Parts of the hospital would be exposed to 50 cal/cm$^2$ and 35 cal/cm$^2$ from the two explosions. This would rapidly create extensive fires throughout the hospital complex.

The hospital would be hit by two blast waves, with overpressures of 7 psi (from the West) and 5.8 psi (from the North West). This would cause massive damage inside the wards. Interior walls and windows would be ripped away and some buildings would be severely damaged. 42% of the occupants would be killed and 49% injured in an average building this distance from explosion 1.3, if there was only one nuclear blast. With two explosions, and the vulnerability of patients, the casualty levels, from these initial effects, would be higher.

Survivors would be exposed to lethal levels of radiation from fallout if they remained in the hospital grounds. However, escaping to a safer area would be very difficult because of fires, debris and radioactive fallout. Survivors might move into areas where the fire or radioactive risk was even greater than at the hospital.

*Hospital 31*

This hospital has 620 beds. It is 1.7 kilometres from explosion 4.2. It would be subjected to initial radiation of 14 Gray, thermal radiation of 50 cal/cm$^2$ and blast overpressure of 7 psi. As indicated above, this would result in at least 42% fatalities and 49% injuries. Survivors would be exposed to fallout from explosion 4.4 if they remained at the hospital. The only viable escape route would be to the West, and even then they would be exposed to fallout on the first part of this journey.

*Hospital 13*

This hospital has 807 beds and 1,200 staff. Those in North-facing rooms on upper floors could receive an initial radiation dose of 0.7 Gy from explosion 3.2. These parts of the building would also be subject to 14 cal/cm$^2$ from thermal radiation. This would create extensive fires. The overpressure from blast would be 3 psi. This would cause damage both inside and outside the hospital. Normal casualty rates at this distance from a 100 kiloton explosion would be 45% killed and 55% injured. In a hospital, the figures are likely to be higher. In addition, 26 minutes after the explosion, there will be fallout from explosion 4.3. The resulting dose would be 17 Sieverts in the first hour, rising to 46 Seiverts after four hours. These levels of radiation would be fatal to all of those in the open. Even where people were able to find shelter which was able to reduce the radiation dose by a factor of ten, the four hour level would still be fatal. Survivors would have to move at least 1 kilometre South East, to escape this fallout.

*Hospital 67*

This hospital has 1,680 beds and conducts 14,000 surgical operations per year. There would be some damage from two explosions (1.3 and 1.5) with blast overpressures of 1.8 and 1 from opposing directions. The heat from the nearest explosion, 7 cal/cm$^2$, and blast damage would ignite sporadic fires. The area would be exposed to fallout from explosion 1.5 after ten minutes. While it would be possible to flee to the East, this could expose patients and staff to fallout from the two explosions at Odintsovo-10.

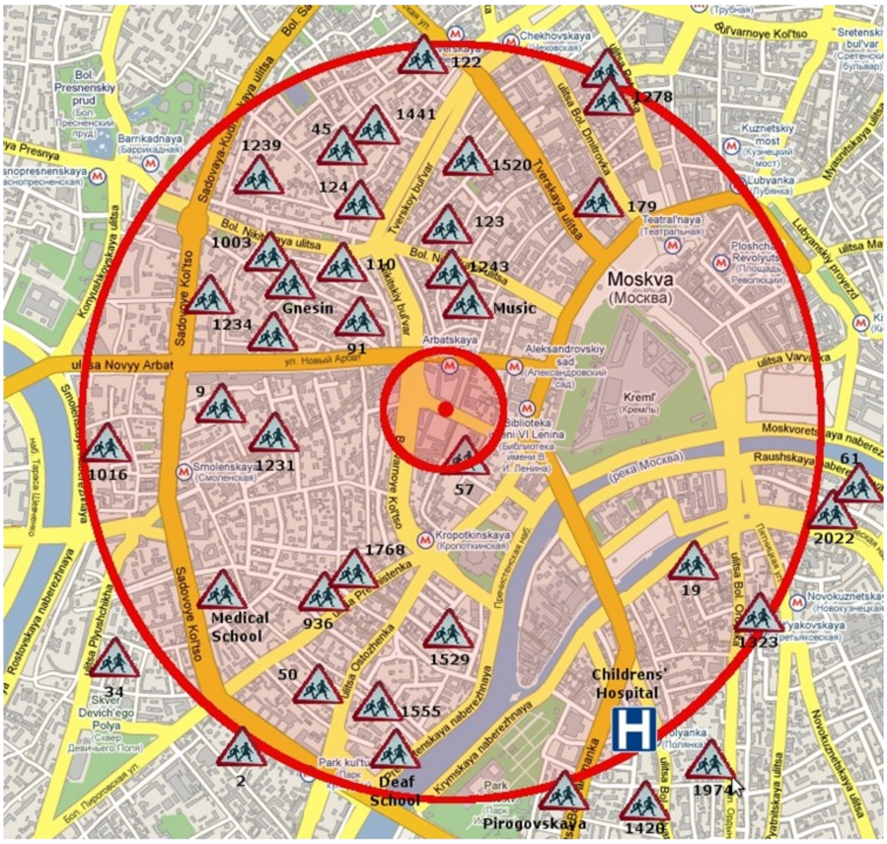
*Other medical facilities*

The Electro Magnetic Pulse from the nuclear explosions would destroy all electrical equipment which was plugged in, across the city. This could affect a significant amount of the equipment in medical facilities which were only slightly damaged by the blast effects of the explosions.

## Damage to schools

If they suffered the same mortality rate as adults, 788,271 children (under 18) would be killed.[64] Because they would be more vulnerable to radiation, the actual number would be higher. Across the city a high proportion of schools would be destroyed or seriously damaged. Chart 13 shows the schools which would be completely destroyed by just one nuclear warhead. The outer red circle marks the 1.6 kilometre zone around the explosion at the Defence Ministry. The schools shown include the Central Music School and schools which specialise in drama (schools number 123) and languages (school number 1555). There are also several large secondary schools and kindergarden (for example school 1016).

*Chart 13. Schools within 1.6 km of the nuclear explosion at the Defence Ministry*

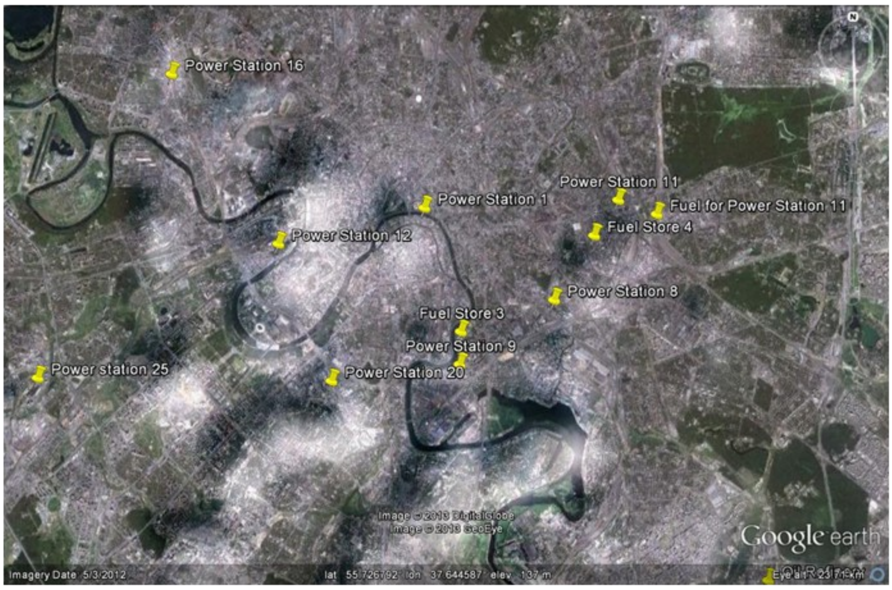



## Damage to power stations and fuel storage

Electricity in Moscow comes from a series of gas-fired power stations in the city (Chart 14). There are also two additional fuel stores. Fires and explosions at these sites would have a significant effect and would send a large amount of smoke and soot into the atmosphere.

64 There are 1,657,864 children, aged under 18, in Moscow. If they suffered the same mortality rate as adults then 649,171 would be killed. A further 139,100 would be killed outside the city, giving a total death toll of 788,271 children.

*Chart 14. Power Stations and Fuel Stores*




*Power station 1*

This 86 Megawatt power station has been functioning since 1897. It is in the centre of Moscow, 700 metres Southeast of the Kremlin. It would be completely destroyed by three nuclear explosions within 1 kilometre to the North, Northwest and Southeast. All fuel in the power station would be ignited.

*Power station 12*

This 408 Megawatt power station supplies power to central Moscow. Explosion 3.4 would be only 800 metres from here. The substantial main building would be destroyed. There would be numerous fires. Damage from flying debris and the very high heat levels would be likely to result in the explosion or ignition of the fuel store.

*Power station 16*

This is a 360 Megawatt power station. Explosion 1.3 would be 1.3 kilometres from the facility. The fuel tanks would be exposed to thermal radiation of 88 cal/cm$^2$. Blast overpressure across the site would be 12 psi. The three main fuel tanks, below ground, are likely to explode or ignite. There would be severe damage to the power station buildings and extensive fires.

*Power station 26*

This is a 1410 Megawatt power station. It supplies power to 2 million residents of Southern Moscow. Explosion 4.5 would be 2.6 kilometres from the main building and 2 kilometres from the fuel tanks. The nearest of the four above-ground fuel tanks would be exposed to thermal radiation of 29 cal/cm$^2$ and blast overpressure of 5.3 psi. Heat and flying debris could result in an explosion or ignition of the fuel tanks. There would also be fires across the site and some blast damage.

*Fuel Store 4*

This can store 12,500 cubic metres of fuel. Explosion 4.1 would be 2.1 kilometres from the site. The above-ground fuel tanks would be exposed to 25 cal/cm$^2$ thermal radiation and 4.9 psi overpressure. This could result in an explosion and there would be fires in and around the compound.

*Power station 11*

This is a 330 Megawatt power station. Explosion 4.1 would be 1.8 kilometres from the power station itself and 3 kilometres from the three above-ground fuel tanks. There would be severe damage to the power station and extensive fires. At the fuel tanks the heat would be 12 cal/cm$^2$ and the blast overpressure would be 2.6 psi.

*Fuel Store 3*

This can store 29,731 cubic metres of fuel. Explosion 3.2 would be 3 kilometres to the North. Thermal radiation would be 12 cal/cm$^2$ and blast overpressure would be 2.6 psi.

*Power station 20*

This is a 360 Megawatt power station. Explosion 3.3 would be 3 kilometres from the power station and 3.7 kilometres from the three above ground fuel tanks which support it. There would be some damage and fires at the power station. At the fuel tanks, thermal radiation would be 7 cal/cm$^2$ and blast would be 2 psi.

*Power station 25*

This is a 1370 Megawatt power station. The site would be between explosion 1.5 (4.3 kilometres to the North) and explosion 4.2 (4.4 kilometres to the Southeast). The nearest explosion would result in thermal radiation of 5 cal/cm$^2$ and blast overpressure of 1.5 psi. While this may not be sufficient to cause major damage to the power station or its fuel tanks, the combined effect of two explosions could increase the fire risk. Fires would more extensive if the first blast wave reached the site before thermal radiation from the second explosion.

*Power station 8*

This 605 Megawatt power station would be 4 kilometres from explosion 3.2. Thermal radiation would be 6 cal/cm$^2$ and blast overpressure 1.6 psi. This would cause some damage to the power station and some fires.

*Power station 9*

This 250 Megawatt power station is 4 kilometres from explosion 3.2. The effects would be similar to those at power station 9.

*Power station 23*

This large power station would be only lightly damaged by blast. However the absorbed radiation dose from fallout would soon reach lethal levels. This would result in the power station being closed down.

## 5. Variable factors

*Civil Defence*

Russia retains a network of civil defence bunkers to protect some of the population in the event of nuclear attack. Moscow City regulations state:

“Civil defence facilities are provided in the basement of residential buildings, public facilities, shopping, sporting, cultural, community and transport facilities, underground car-parks and surface car-parks in accordance with the duly approved planning documentation”[65]

65 Resolution of the Government of Moscow from January 19, 2010 № 25-PP "On approval of the placement of civil defense structures in Moscow" http://www.garant.ru/products/ipo/prime/doc/293892/

The government allocates resources to maintain key military and government command bunkers, but the status of bunkers for residents is not clear There are examples on the Emergency Ministry website of recently renovated civil bunkers.[66] There are documented procedures for activating bunkers within 12 hours.[67] However, it is likely that many bunkers for residents are in a poor state of repair. Moscow has one of the largest subway networks in the world, with 186 stations. The regulations for civil defence in Moscow refer to potential use of the Metro.[68]

A large number of people could shelter in Metro stations and civil defence bunkers. These would have a considerable effect in reducing exposure to fallout, although only those bunkers which are properly maintained would be able to provide thorough protection. If residents were able to shelter in the Metro and bunkers this would reduce the number of fatalities. But if there was a firestorm, many residents in basic shelters would be asphyxiated by carbon monoxide poisoning.

In 1978 the British government were concerned that the Soviet Union was planning to build shelters for up to 30% of their population. But the MOD concluded this problem could be countered so long as the option of ground-burst explosions, resulting in extensive radioactive contamination, was not ruled out - "The civil defence programme would not provide adequate protection against the risk arising if warheads were to be ground rather than air-burst."[69] The current nuclear attack plan probably involved ground-burst detonations.

*Response of residents*

The way residents responded to an imminent attack would have a significant effect on casualties. If there was advanced notice, it is likely that the government would advise people to take shelter, rather than to evacuate. However, a study in the US found that 65% would evacuate if there was no advice and 40% of people would evacuate even if they were told not to.[70]

Many residents would try to find their relatives. They would travel to their children's school or to their home. Family consolidation and unplanned evacuation would result in traffic congestion.[71] Across Russia there is an average of one car for every five people.[72] If an attack took place while a large proportion of the population were travelling then casualties would be higher, because vehicles provide very little protection from radiation or the other effects of a nuclear explosion. In practice many residents, if given notice, might move from the city to the suburbs, including to summer cottages. Many of these suburban areas would be subject to significant amounts of nuclear fallout.

66 http://www.63.mchs.gov.ru/upload/go/3/3.24.php
67 Plan to bring readiness maintenance of Civil Defence protective structures; Рекомендации по содержанию (структуре) Плана приведения в готовность группы (звена) по обслуживанию защитного сооружения ГО
68 Resolution of the Government of Moscow from January 19, 2010 № 25-PP
69 This was based on an MOD assessment of a ground-burst attack on Leningrad: "in near-still-air conditions ground-bursts would subject 55-60% of the city to a radiation dose sufficient to cause rapid debilitation followed by death for most people in the area, and to contaminate food, water, air and both damaged and undamaged buildings. Residual radiation would remain a hazard for many years to come. If there was a wind, the fall-out would be carried beyond the city limits to extend the hazard to people locally dispersed". Factors Relating to Further Consideration of the Future of the United Kingdom Nuclear Deterrent, Part II, Annex A Unacceptable Damage, TNA DEFE 25-335
70 Spontaneous evacuation following a dirty bomb or pandemic influenze: highlights from a national survey of urban residents' intended behaviour. 2007. http://www.norc.org/PDFs/Walsh%20Center/Links%20Out/SpontaneousEvacuationFollowingaDirtyBomborPandemicInfluenza.pdf
71 Analyzing evacuation versus shelter in place strategies after a terrorist nuclear detonation, LM Wein, Y Choi and S Denuit. 2010.
http://iis-db.stanford.edu/pubs/23053/Wein_-_Evacuation_vs_Shelter_in_Place_after_Terrorist_Nuclear_Attack.pdf
72 http://themoscownews.com/business/20120117/189374885.html. One report says there are 6 million cars used by the 16 million people in the Moscow commuting area. http://rt.com/business/news/moscow-road-pricing-scheme/

*Emergency response*

Medical assistance would be very limited, because most hospitals would be destroyed or badly damaged. Fire stations would also be put out of action. There would be some parts of the South and North of the city which were not badly affected. In these places there might be some effective emergency response measures. However, these areas would soon be swamped by thousands of injured residents escaping from the heavily damage areas, where organised assistance would be almost non-existent.

After the first day there would be around one million survivors who had received an absorbed dose which was likely to prove fatal within two months. In this timescale, some casualties could be evacuated to other parts of Russia or treated at emergency facilities established after the attack. However, effective treatment would only be available to a small proportion of those at risk.

The civil defence command centre at Nesterovo, 70 kilometres East of Moscow, would survive the attack. Officers in the centre might be able to estimate which areas were damaged and which were likely to be affected by fallout. However the resources which they could deploy would be very limited. One example of an army unit which might be available is the 2nd Guards Tamar Motor Rifle Division, near Alabino, 30 kilometres West of Moscow. Troops from here could be deployed to the capital, but they would be exposed to fallout as they moved towards the city. In some weather conditions, their base would receive lethal levels of fallout.

*Weather*

The weather would have a significant effect on fires and fallout. Fires are more likely to spread between buildings when the wind is stronger. If the wind changes direction after fires have started, the total area consumed by fire will be greater. A firestorm is more likely to develop when the wind is light.

The scenario described above is based on average wind conditions and not on the worst possible wind direction or speed. If it was calm, nuclear fallout would be concentrated close to each explosion and the number of casualties would be higher. There would be more casualties if the wind was from the North or South, as this would blow fallout from the city centre across a larger part of the city. A wind shift of only 22$^{o}$, from South-West to South-South-West, would have a significant effect on radiation levels in Moscow, because fallout from twelve explosions at bunkers near Chekhov would be blown across the city.

*Warhead numbers and ABM*

When Britain deployed Polaris there was always a second submarine at 24 hours notice to fire missiles from its berth and at 47 hours notice to sail, in addition to the one on patrol. Today there will be a target plan for an attack on Russia with 80 warheads from two submarines. Most warheads would be targeted on the Moscow area and in some cases two warheads would be targeted at the same aimpoints, to increase the probability of destroying command bunkers. In addition the 80-warhead plan may include launching single missiles, with 5 warheads each, at the General Staff Alternate Command Centre at Kuznetsk-8 and the Strategic Rocket Forces secure command centre at Kitlim. An 80-warhead attack could result in 7-8 million fatalities.

Some warheads might be intercepted by Anti-Ballistic Missiles deployed around Moscow. If half the warheads from one submarine were intercepted, the number of fatalities might be reduced to 3 million. In an 80-warhead attack with one third to one half of the warheads intercepted, the number of fatalities would be similar to the basic 40-warhead scenario.

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