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# Nuclear terrorism

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**Summary**

Neutron weapons are designed for the destruction of living organisms; they are not designed for the destruction of building and technical facilities. The miniature nuclear fission weapons (about 1 kt) have similar characteristics and they are most suitable for terrorist attacks. Irradiation of mammals by fission neutrons results in a more severe deterministic (acute) as well as stochastic (late) radiation damage in comparison with gamma rays. Traditional physical shielding materials (steel, lead) cannot provide protection, and biological protection mechanisms (tissue hypoxia, radioprotective chemical drugs) are also not effecive. Water and plastic materials (polyethylene) *are* suitable for shielding.

*Keywords:* nuclear terrorism – weapons – neutron – biological effects – radioprotection

## INTRODUCTION

Nuclear weapons (NW) are characterised by a nuclear charge in which nuclear energy is suddenly released in the course of the explosion. The nuclear charge is situated in different types of munitions (rocket, warhead, air bomb, artillery shell, mine, etc.), which are brought to the target with the help of particular weapon systems (Forrow and Sidel 2000, Kuna, et al 1991, Neruda 2001). The choice of a suitable NW carrier particularly depends on the power of the NW. It is necessary to realize that when providing a terrorist attack with a nuclear weapon, the attacker must solve, in addition to acquiring the NW, an enormously complicated problem: how to transport the NW to the site in the presence of existing protection and defence systems (Flemming 2001, Helfand et al. 2001, Hogan And Kellison 2002, Moulder 2002, Simon 1999).

In the NW, the energy is released in the course of the explosion either from nuclear fission of heavy atomic nuclei (uranium or plutonium) or from the synthesis of nuclei of light elements (deuterium, tritium, lithium).

Fission charges are those in which the energy is released due to the fission of heavy nuclei during the explosion, particularly of $^{239}$Pu etc. The following steps are necessary for starting the fission chain reaction:

a) The absorption of neutrons by nuclei of the specified elements. The source of primary neutrons triggering the fission chain reaction may be e.g. a mixture of radium and beryllium.
b) The acquisition of a minimum amount of the nuclear fuel necessary for starting the fission reaction. In fission NW, the fuel (0.5 to 50 kg) is divided into two or three parts of the nuclear explosive, which are combined at the moment of the explosion, thus forming a supercritical amount of the fuel which makes possible the occurrence of the chain reaction.
c) For the restriction of neutron losses, it is necessary to provide a spherical shape for the nuclear charge. Further escape of neutrons is prevented by the so called reflector, which is a layer, e.g. of graphite, situated on the charge surface, which returns a proportion of the neutrons back into the nuclear charge, where they can be used for further events of fuel nuclei.

The chain reaction is accomplished in an extremely short time interval, of the order of magnitude of millionths of a second, releasing enormous amounts of energy in the form of immediate ionizing radiation (neutrons, gamma radiation), pressure waves, light and thermal radiation and the so called residual (induced) radioactivity including ionizing radiation (gamma, alpha and beta particles) emitted in the course of further disintegrations of fission products in what is called a radioactive track. In the course of the fission reaction only about 5% of energy is released in the form of ionizing radiation for up to 1 min.

A thermonuclear charge uses energy which is released during the fusion (synthesis) of light element nuclei. For nuclear fusion, high temperatures ($10^6$ to $10^7$ °C) are necessary. A small nuclear fission charge serves as a source of these high temperatures, thus playing the role of initiator of the thermonuclear reaction, in the course of which temperatures of several tens of millions °C are achieved and many neutrons are emitted. However, no fission products are obtained. The thermonuclear bomb has no critical amount and its destructive action increases with the amount of the charge, which is theoretically unlimited.

The amount of energy released during the explosion is expressed in trinitrotoluene, also named tritol (TNT) equivalents. One metric ton (t) of TNT serves as a unit. NW of tritol equivalents from 0.1 t to several tens of Mt (1 Mt = $10^6$ t) are currently available.

Depending on the tritol equivalent mass, the NW may be divided into the following groups:

- very small calibre (power) up to 1 kt ($10^3$ t);
- small calibre: 1 to 10 kt;
- intermediate calibre: 10 kt to 100 kt;
- large calibre: 100 kt to 1 Mt;
- very large calibre: over 1 Mt.

There is a considerable difference between fission and thermonuclear weapons in different energy distributions; in the course of the thermonuclear reaction, no radioactive fission products are obtained, and thus there is no source of radioactive contamination of the field as in fission weapons. Hence the name “clean NW”. The distributions of the energy released from both types of weapons are summarized in Table 1.

Table 1. **Types of weapons**

| Destructive factor | Portion of energy released in fission weapon in % | Portion of energy released in thermonuclear weapon in % |
|---|---|---|
| Pressure wave | 35 | 8 |
| Light and thermal radiation | 35 | 8 |
| Immediate ionizing irradiation | 5 | 70 |
| Radioactive contamination | 6 | 0 |
| Cloud energy | 19 | 14 |

Neutron weapons are miniature thermonuclear weapons with a calibre of about 1 kt (at most up to 15 kt), where a fissioning initiator triggers the thermonuclear synthesis of tritium and deuterium. In the course of this synthesis, as much as 80% of energy is released in the form of immediate penetrating neutron radiation with high energy. Thus, the neutron weapon is referred to as a weapon with amplified radiation. The effective range of the immediate radiation is about 1.5 km, the range of severe effects of the thermal and pressure wave is only 0.3 to 0.5 km. Thus, the area where unsheltered people are killed by a high ionizing radiation dose is several times larger than that where people are killed by pressure wavs or light and thermal radiation.

When the altitude of the neutron bomb explosion is 300 to 500 m above the terrain (explosion in air) an area larger than 10 km$^2$ will be irradiated by a lethal ionizing radiation dose (5 Gy and above), the irradiation time being shorter than 1 ms. The radiation results from the emission of neutrons, $1.5\times10^{24}$ neutrons per each kt of the charge, and gamma radiation, which is emitted in the course of interaction of neutrons with nuclei of atoms of the surrounding environment along the whole length of their flight path. Thus, the neutron weapon is a point source of high-energy neutrons from the charge at the moment of the explosion and a source of gamma rays in an area limited by the range of neutrons in the given environment. The portions of neutrons and gamma rays contributing to the radiation dose vary with the distance from the explosion centre in favour of gamma rays. However, in a rough approximation, they may be considered as equivalent.

In the case of a neutron weapon explosion, there are only small amounts of fission materials produced in the fissioning initiator, and there is only a small zone of radioactive contamination – only several km long, depending on local conditions.

Induced radioactivity is produced by the interaction of neutrons with atomic nuclei in the environment,. It may be found in the terrain over an area of about 0.8 to 1 km in diameter from the epicentre. One hour after an explosion of the intensity of about 1 kt at an elevation of about 200 m above the terrain, and at a distance of 200 m from the epicentre, the dose rate will be about 1.5 Gy (150 rad) per hour; in the epicentre itself it will be higher by a factor of about 10. A decreasing elevation of the explosion above the ground produces a dose rate increased by as much as several orders of magnitude. Significant contamination of the soil from the induced radioactivity persists only for hours.

In the soil, particularly $^{24}Na$, $^{31}Si$, $^{56}Mn$ and further radionuclides are produced, which are beta and gamma emitters and their half-lives are short, from 30 min to 15 hours. Radioactivity can also be induced in military and other equipment, where radionuclides of manganese, tungsten, copper, iron, cobalt, etc., frequently with long half-lives, can be found. Because of this, even mechanically intact technical devices may not function for a period.

The radiation dose resulting from neutron flux and gamma radiation achieves considerable values close to the epicentre. At distances up to several hundred metres from the epicentre, where mechanical damage to technical devices, building structures and shelters is not necessarily incurred, an ionizing radiation dose of more than 5 kGy, may be present, resulting in damage not only to living organisms but also to inanimate objects.

Materials exert individually different sensitivities to radiation depending on their physical and chemical arrangement. The ionizing radiation effects are sometimes manifested only in the course of irradiation where electric parts and equipment are in operation, in some other cases they occur only after a certain time – in plastic materials, etc. Microelectronic elements and equipment (semiconductors) are among the most sensitive materials. Appliances may be particularly easily destroyed if they are in operation at the time of irradiation.

Based on our knowledge of the interactions between neutrons and a range of materials it is possible to consider that shielding with the help of materials with a large specific mass and high atomic numbers (iron, lead) will be inefficient and that it is necessary to use stratified materials providing combined shielding with a number of different materials. Good protection against neutrons is provided by water, thick walls and ceilings of deep shelters with moist earth. In contrast to this, it is reported that persons hidden behind a hindrance (e.g. terrain wave, trench, etc.) will receive about 20% of the ionizing radiation dose corresponding to the given site, whereas in the case of classical NW they would receive only 5% of the dose in comparison with unshielded space. The higher proportion of irradiation results from neutron scattering in the air.

It must be remembered that even fission weapons of very small (< 1 kt) and small (1 to 10 kt) calibres have a longer effective range of immediate radiation than heat, light and pressure waves. With increasing calibres of nuclear weapons, the effective range of the heat light and pressure waves increases more rapidly than the effective range of the immediate ionizing radiation from the site of the explosion. Thus, in nuclear weapons of the largest calibres (strategic NW) the area of lethal doses of ionizing radiation is smaller than that of the destructive effects of thermal light and pressure waves.

Thus, we can use the experience from the nuclear explosions in Japan in 1945 to consider differences between the effects of fission and neutron NWs on the human population.

To compare the biological effects of different types of ionizing radiation, the value of relative biological efficiency (RBE) is employed. The difference in biological effects is accounted for:

a) by the nature of the linear energy transfer of the ionizing radiation type considered;
b) by the ionization density resulting from this, and
c) by the penetrability of radiation through absorber layers (tissue cultures, tissues of the human organism or of other mammals studied, etc.).

The relative biological efficiency of the radiation considered is a number, which is obtained as a ratio of the dose of the standard ionizing radiation of gamma rays from a radiocobalt source ($^{60}Co$) or X-rays 220 kV to the dose of the radiation considered (e.g. neutrons) resulting in the same chosen biological effect. Since it is possible to select a number of biological effects for the comparison, we also obtain different values of the RBE for each radiation type considered.

In Hiroshima, the fission bomb used had a calibre of 12.5 kt (*Little Boy*). The total radiation dose was divided between gamma radiation (75 to 80%) and damage by neutrons (20 to 25%). The nuclear weapon used in Nagasaki, of a calibre of 22 kt (*Fatman*) resulted in radiation damage almost exclusively by gamma rays (98–99%). Neutrons contributed only 1 to 2% to the total dose.

A comparison of the radiation damage to persons in both cities involved made it possible to estimate the RBE values for fission neutrons depending on acute and late effects.

## ACUTE (DETERMINISTIC) RADIATION EFFECTS

When evaluating the epilation (losses of scalp hair and body hairs) the RBE is of about 4.0, based on acute skin changes it is of 2.5, based on the severity of hemorrhagy (hemorrhagic syndrome) it is of about 5.0, and based on the cataract abundance during 3 to 5 years after irradiation the RBE is of 5.9 to 10.0.

The extent and severity of the radiation damage to humans is decisively affected by the dose macrodistribution and magnitude inducing different degrees of the acute postirradiation syndrome (APS). The half life of repairing the radiation damage in persons exposed to whole body gamma radiation is of about 30 days, in the case of neutrons, it is longer by a factor of 2 to 3.

## LATE (STOCHASTIC) EFFECTS

These effects were larger after the explosion of the nuclear weapon in Hiroshima than those in Nagasaki where a stronger NW was used which, however, exerted a prevalent radiation effect from gamma rays. Based on the abundance of leukemias, it is possible to consider the RBE of 3.0 for fission neutrons. A relatively higher abundance of this disease was encountered in irradiated persons younger than 10 years of age and older than 50 years of age. In women younger than 30 years of age, there was a higher abundance of the mammary carcinoma, in persons older than 50 years of age at the time of radiation, lung carcinoma occurred more frequently.

A comparison with the non-irradiated population indicates that the risk of occurrence of tumor diseases after a neutron dose exceeding 1 Gy (100 rad) is greater, always with factors higher than 1, for acute leukemia 10, for mammary carcinoma 3.3, for thyroid cancer 2.5, for lung cancer 18. The latency period of the acute leukemia occurrence in children is of about 5 to 10 years, in persons older than 40 to 60 years it is of about 10 to 20 years after the exposure. For carcinomas of the mammary gland, thyroid gland and lungs, the latency period ranges between 10 and 20 years.

As far as further stochastic effects are concerned, after exposure to neutrons, no more rapid manifestation of ageing were recorded in comparison with changes after gamma irradiation. An independent problem is the consideration of the RBE of neutrons when evaluating genetic changes in subsequent generations, which have been up to now studied only experimentally (Klener 2000, Kuna et al. 1991, Neruda 2001, Skorga et al. 2003).

Based on analyses of the biological effects of neutrons on the level of cells:

a) The damage by neutrons is more difficult to repair.
b) Changes in the dose time distribution have, in the case of exposure to neutrons, low effects on the final exposure result (missing repair).
c) At the level of cells, the RBE of neutrons most typically achieves values of 2 to 5, in the choice of different types of radiation damage, the RBE is always larger than 1.
d) Biological effects of neutrons are less affected by the partial pressure of oxygen in tissues and by the presence of radioprotective chemical substances administered prior to the exposure.

## CONCLUSIONS

- Neutron weapons are designed for the destruction of living organisms, they are not intended for the destruction of buildings and technical devices. The miniature fission NWs have similar characteristics and they are most likely to be used for terrorist attacks.
- Irradiation of persons (and, generally, of mammals) by neutrons results in more severe deterministic (acute) radiation damage in comparison with gamma rays.
- Severe stochastic (late) effects – tumor diseases and genetic changes – will occur earlier and more frequently in persons exposed to neutrons.
- Protection is provided efficiently neither by traditional physical shielding materials (steel, lead etc), nor by biological protecting mechanisms (hypoxy, radioprotectants). Water and plastic materials are suitable for shielding.

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