Nuclear Militarisation

How it threatens humanity

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Medact Nuclear Weapons Group briefing, September 2023

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Dedicated to the memory of Martin Hartog (1931–2023), a physician valued for his kindness and integrity, contributor to Medact's Nuclear Weapons Group, and co-founder of Medact's predecessor body, the Medical Campaign Against Nuclear Weapons (1981–1992).

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Introduction

The discoveries of radioactivity and of atomic structure in the early 20th century led scientists to realise that the sun worked through fusing hydrogen atoms to form helium with the release of vast amounts of energy, and – just before World War II – that vast amounts of energy could also be released by splitting atoms of heavy elements such as uranium. In both cases the energy is released from the mass of the atoms, in accord with Einstein's famous equation $E = mc^2$ (energy is equivalent to mass multiplied by the square of the speed of light). These findings were militarised by the American-led 'Manhattan Project' during and after WW2 and helped to produce the two-headed monster of the nuclear industry.

In 1991 the Strategic Arms Reduction Treaty was signed by the USSR and the USA and was a significant marker of the end of the Cold War. This had a profound effect on the attitude to nuclear war: fear was replaced by relief and the number of nuclear warheads in the world fell. Attention turned elsewhere ('Desert Storm', the Balkans, the 'ozone hole', South Africa, ex-Soviet oligarchs, etc.) and the nuclear risk ignored or even forgotten.

To most people nuclear war came to feel less tangible than climate change, pollution, loss of biodiversity, and food and water safety; but all these issues come from human activity, and are mutually reinforcing and expanding. The worse the global condition, the greater the chances of a nuclear war which, once started, could escalate rapidly and lead to global starvation and even human annihilation. Hence the situation in Ukraine should return us to a sense of urgency – we must remind ourselves about the nature and politics of nuclear warfare and the complications caused by increasingly sophisticated IT and AI.

This briefing, and the webinar planned to accompany it, aim to give a comprehensive, short but reliable account of the nature of the nuclear challenge to global society. Of necessity, some technical knowledge is needed but we will try to be clear and simple and avoid burdensome detail (few references are given but can be supplied). So we hope that folk will be encouraged to work realistically for a peaceful, sustainable and safe world free of nuclear weapons.

I. Principles of nuclear physics, chemistry and atomic theory

All atoms have subatomic particles

Protons and *neutrons* are 'nucleons' bound in atomic nuclei by the 'strong nuclear force'. Each nucleon weighs 1 'Dalton' (D). Each proton has a positive electrostatic charge but neutrons are uncharged. The number of protons in an atom defines its chemistry and gives each element its atomic number (AN; 1 for hydrogen, 2 for helium, 92 for uranium etc.)

Atomic weights depend on the numbers of protons and neutrons: helium atoms have 2 of each so weigh 4 D; most uranium atoms (92 protons and 146 neutrons) weigh 238 D.

Negatively charged *electrons*, each weighing 1/1838th of a Dalton, orbit the atomic nuclei.

Ions contain atoms in which the electron number differs slightly from the AN, so they carry an electric charge and are chemically active.

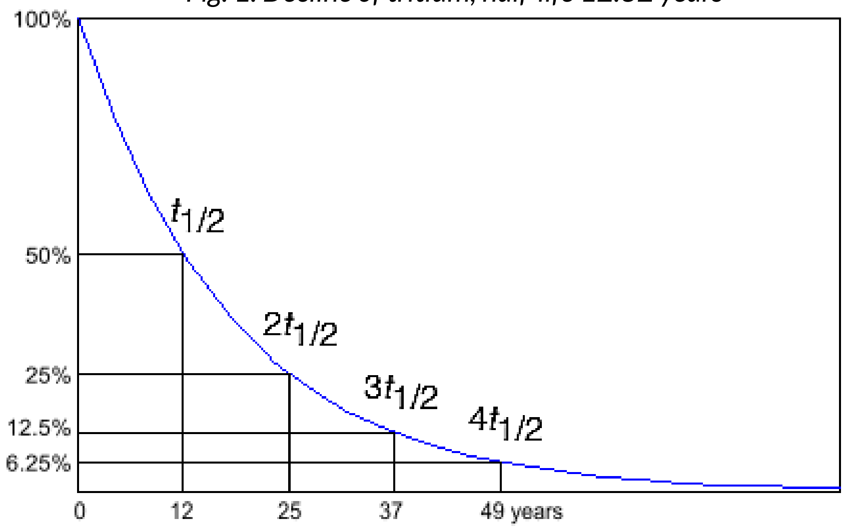
Isotopes (nuclides), radioactivity and half-lives

Every element has more than one 'isotope' (known to physicists as 'nuclides'): these are atoms sharing an element's AN and chemistry but differing in neutron number and hence atomic weight. Isotopes can be stable or unstable. Nuclei of deuterium (^{2}H), a stable isotope of hydrogen, have a neutron and a proton. Tritium (^{3}H, 2 neutrons, 1 proton) is an unstable isotope of hydrogen used in nuclear fusion bombs.

Each unstable isotope has a characteristic pattern of *radioactive decay* by which it *transmutes* to a new isotope, usually of a different chemical element. Subatomic particles are expelled as energetic rays of three main types – 'alpha', 'beta' and 'gamma'. The most unstable isotopes are the most radioactive. Alpha rays consist of helium nuclei which do not travel far even in air, but if an alpha emitter like uranium is swallowed or inhaled, local tissue cells are damaged. Beta rays are electrons and are more penetrative. Gamma rays are like X-rays and are very penetrative.

Traces of 'primordial' radioisotopes remain on Earth from when the solar system formed: they include potassium 40 (^{40}K – half-life 1.25 billion years), thorium 232 (^{232}Th – half-life 14 billion years) and the uranium isotopes 235 and 238 (^{235}U, ^{238}U, half-lives 710 million and 4 billion years respectively). Carbon (AN 6) has two stable isotopes: 98.8% are ^{12}C, 1.2% are ^{13}C, while traces of radioactive ^{14}C (half-life of 5730 years) are derived from 'cosmic rays' and the tests of nuclear weapons in the atmosphere before 1963. ^{14}C contributes to our bodies' radioactivity, with traces of tritium and natural uranium, thorium and ^{40}K from the soil. Tritium (half-life 12.32 years – see Figure 1.) is a vital component of thermonuclear nuclear bombs: it decays to the rare yet stable isotope of helium 3 (^3He, 2 protons, 1 neutron). Fresh tritium is needed to replenish undetonated bombs every 12 years or so.

Fig. 1: Decline of tritium, half-life 12.32 years



II. Uranium and thorium: the role of decay and fission in nuclear industry

Uranium

Chemical symbol 'U', AN 92. Uranium ores (uraninite) are found in many parts of the world but excavation needs care as, after taking the uranium from the ore, the surface tailings retain most of the radioactivity. This is very hazardous and is due to uranium decay products accumulating over the geological aeons.

Although just 0.72% of natural uranium is the naturally *fissile* ^{235}U (see below), this is very significant as the civil and military nuclear industries depend on it as it is the *only naturally occurring spontaneously fissile nuclear material on Earth*. The other 99.28% is ^{238}U, in which fission can only occur in a full-scale nuclear explosion, so ^{235}U is the essential source of the nuclear industries, military and civil.

Thorium

Chemical symbol 'Th', AN 90. Its main isotope, ^{232}Th, is five times more abundant than uranium and interests the nuclear industry as, although not fissile, neutron bombardment transmutes it to ^{233}U (half-life 160,000 years) which *is* fissile and could be militarised. However, managing the unique radiation hazards of the transmutation processes, and other inevitable complexities, is deemed to be too costly.

Nuclear decay 1 – alpha decay

This is the main mode of spontaneous decay for thorium and uranium. At each stage in a series of eight or so steps, an alpha particle is expelled from the original thorium or uranium nucleus until a stable isotope of lead (Pb, AN 82) results. Each loss of alpha particles reduces the atomic weight by 4 D and the AN by 2. Expulsions of beta particles at each stage cause further changes in AN (transmutations) until the final lead isotope is reached.

Many of the isotopes formed at each stage (except the last) are highly radioactive. A notably hazardous product of ^{238}U decay is radon 222 (^{222}Rn, half-life 3.8 days), a chemically inert gas that seeps into dwellings in areas rich in granite. The ^{222}Rn and its decay products get adsorbed by particles of dust that on inhalation can induce lung cancers. Remedies such as sealing the foundations of buildings in prone areas reduces the harm.

Nuclear decay 2 – spontaneous fission

This form of decay applies mostly to nuclides of uranium (^{233}U and ^{235}U) and of plutonium (^{239}Pu – see later). Within uranium-containing rocks, decay slowly releases 'free neutrons' which occasionally collide with neighbouring nuclei of uranium. This causes the parent nucleus to split (fission) into two unequal fragments of between 85 and 150 D (and occasionally a third lower-weight fragment). **The combined weights (in Daltons) of these fragments is fractionally lower than the original non-fissioned nuclide, and at the same time a powerful burst of energy, derived from these losses of mass, is released.** Energy continues to be released as the fragments undergo further radioactive decay.

If the 'mass' of ^{235}U or ^{239}Pu is large enough, the free neutrons can collide with neighbouring nuclei frequently enough to sustain and amplify the release of energy; if unconstrained, this becomes explosive. The 'critical mass' for a sphere of ^{235}U is about 50 kg, while for ^{239}Pu it is about 10 kg. Above these masses there will be a nuclear explosion with the release of vast amounts of radioactivity. Smaller masses will fission if the sphere is wrapped in neutron-reflecting materials such as nickel foil, or if a special device placed inside the sphere (or 'pit') delivers a burst of neutrons.

The 0.72% of ^{235}U in a mass of pure uranium is too low to allow the release of enough neutrons to cause a sustained 'chain reaction', but if the proportion of ^{235}U is increased ('enriched') a chain reaction can be induced. In nuclear power plants (NPPs), enrichment up to 4% ^{235}U suffices. For modern nuclear submarines engines, up to 20% enrichment is required. For nuclear weapons, more than 95% enrichment is needed. Iran's uranium enrichment programme is of concern as it would increase the risk of weapons-proliferation.

Depleted uranium

When uranium is enriched, it leaves 'depleted uranium' (DU) – a residue which contains up to only 0.3% ^{235}U instead of the natural 0.72%. Its density is 19 (by comparison, the density of lead is 12). As its production is very costly, nuclear industrialists do not want to 'waste' it, so one use for it is as armour plating for US tanks even though it is still radioactive (at about 60% of natural uranium), although the exposure to tank crews can be reduced by 'shielding'.

Projectiles containing DU are very penetrating: on impact, DU shells spread inflammable and toxic dust. DU traces were found in Iraq after the 1991 and 2003 wars but reports of significant adverse effects to local populations have been compromised by difficulties in study design and unintended bias. However, effects such as lung cancer through inhaling DU dust seem highly likely, but cancer onset may be delayed so may not yet be seen. The chemical toxicity of DU, especially renal, is undoubtedly significant. DU should be banned.

Production of plutonium (^{239}Pu)

Within a nuclear reactor, ^{238}U nuclei can absorb a free neutron and transmute to ^{239}Pu which is fully fissile and has a critical mass of about 10 kg. It also undergoes alpha decay and fissions with about 10 times more energy than ^{235}U. Its half-life is 25,000 years, so it does not occur in nature and is entirely man-made. ^{239}Pu is now the preferred primary material for nuclear weapons. Its main source is spent nuclear fuel (SNF) in reactors from which it can be chemically removed (reprocessed) giving highly-pure weapons-grade ^{239}Pu. The UK has enough ^{239}Pu to make over 20,000 Nagasaki-type nuclear bombs.

III. Nuclear reactors and power plants (NPP)

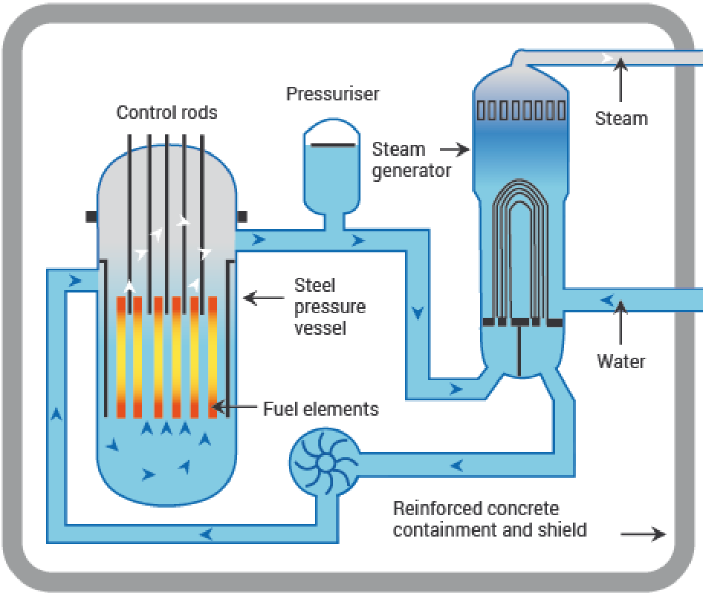
The first civil nuclear reactor was at Calder Hall, Sellafield, Cumbria. It was commissioned in 1956, mainly to produce weapons-grade Pu. After decades of use, Sellafield has become the UK's most radioactive site. In 1957, a fire in its uranium-containing reactor spread to the local environment resulting in an estimated 240 cases of fatal cancer.

Location of Calder Hall, Sellafield, Cumbria, UK (Google Maps)

Aerial view of Sellafield (Photo: Sellafield Ltd)

Sellafield is Europe's largest nuclear site with the most diverse range of nuclear facilities in the world. Covering 650 acres, with over 200 nuclear facilities and 1000 buildings, it stores used fuel from the UK's NPPs and processes spent fuel from several countries as well as over 100 tons of weapons-grade ^{239}Pu. Sellafield is so contaminated that final decommissioning is estimated to take at least 100 years.

Fig. 2: A pressurised water reactor



(Source: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx)

The most common design for Russian and US NPPs now is the pressurised water reactor (PWR) in which water under pressure is superheated while being pumped around rods containing 'fuel elements' (see Figure 2). This is used to boil water in a secondary 'steam generator' from which steam escapes to power the electricity-generating turbines. Heating depends on the number of neutrons causing the fuel elements to fission; this can be moderated by control rods which on insertion between the fuel elements slow down the fission rate and hence the heating. Neutrons in the fuel are also slowed by the water circulating around the reactor rods.

The fuel element for NPPs is uranium oxide enriched to about 4% of ^{235}U and supplied as 1-cm-long cylindrical pellets sintered into hollow reactor rods made of heat-resistant alloys. There are 50,000 or so reactor rods – each being 5 metres long – in each pressure vessel.

Over 18 months or so, the fission products in the pellets become 'too hot to handle' so must be withdrawn and refuelled with fresh rods. The 'spent nuclear fuel' in the old rods must be cooled for decades in ponds of flowing water: this causes a profound problem which has no long-term solution. If the ponds dry out (as at Fukushima) the exposed highly radioactive superhot rods would rupture and endanger the environment very seriously.

Some important features of NPPs

1. Decommissioning. Maintaining NPPs is hard work and not cheap yet essential to contain radioactive leaks. The longest-acting NPPs have to be decommissioned after 50 or so years due to the extraordinary wear and tear, aggravated by constant radiation. Decommissioning is a lengthy and costly process.

2. Water. Enormous supplies of water have to cool the reactors and supply the steam turbines. This comes from local rivers or the sea. Ecological consequences can be quite profound. Rising sea-levels because of climate change threaten NPPs sited on any coast.

3. Even after cooling, the rods and the waste products of decommissioning must be kept safe for yet more decades before 'final disposal' in 'deep geological repositories', but *no UK sites have been identified*. (The UK does not classify SNF as nuclear waste because 'useful materials' such as Pu could be recovered.)

4. Although breaches in the integrity of NPPs are rare, Chornobyl and Fukushima were major disasters. Protection from terrorist attacks requires highly expensive buildings.

5. The six NPPs in Zaporizhzhia, Ukraine, have been targeted, which endangers the reactors. An act of folly, targeting NPPs is now a military option. Zaporizhzhia's newest NPP is 26 years old so 2000 tons of radioactive waste are at risk. Chornobyl's two-year-old NPP, with less waste, released 200 times more radiation than Hiroshima and Nagasaki.

'New nuclear'

The powerful nuclear industry is lobbying the UK to revive fissile NPPs as a low-carbon fuel. Hinkley Point C (now under construction in Somerset) was meant to herald a start for new builds such as **Sizewell C** and the highly promoted 'Small Modular Reactors' (SMRs).

But although some SMRs may be designed to be refuelled less frequently, they:

- are not so small and not so cheap; carbon is generated during building
- still carry risks from the nuclear cycle (mining, waste, decommissioning)
- produce far more waste than 'conventional' NPPs
- are not needed because renewables offer a much quicker and cheaper alternative
- retain military links, for example with Rolls Royce's submarine engine division.

Tackling climate change

More frequent and ever-harsher 'extreme weather' will increase insecurity and militarisation, and hence the chances of nuclear war. **It should be noted that military activities have a very substantial 'carbon bootprint'.** Claims that 'new nuclear' is needed for a zero-carbon future are misleading: NPPs will not help tackle climate change and UK NPPs such as Sizewell are vulnerable to sea-level rises.

Renewables generate electricity more cheaply than steam turbines, including nuclear. The 'base-load' argument (that *'the wind doesn't always blow, and the sun doesn't always shine, but nuclear guarantees continuous generation*') is superficially plausible but actually wrong. More electricity storage and a better grid could cover 'downtimes' better than NPP baseloads, and the UK has recently declared that it doesn't matter where any 'baseload' comes from. However, battery-storage is heavily reliant on lithium which is rare, hazardous to mine and ecologically potentially very harmful – this requires more rigorous assessment and alternatives need to be sought.

IV. Radiation and health

Ionising radiation (IR) strips electrons from the outer shell of atoms, turning the atom into a chemically active oxidising ion. Irradiated water produces hydrogen peroxide and is a significant contributor to DNA damage which can transform genes into oncogenes.

Oncogenes – 'cancer-forming genes' – arise from mutations of normal somatic genes and cause excessive growth of new cells or diminished loss of outworn cells. The DNA of any gene is also prone to damage by the normal energy-generating oxidising metabolic activities by which we live but effective gene-repair mechanisms, whether from damage by irradiation or from metabolic activities, have evolved from the beginning of life on Earth.

The most common sort of damage, whether from metabolic excess or ionising radiation, is the breaking of chemical bonds governing the sequence of nucleotide bases in the double helix of DNA. Gene-repair mechanisms, which re-align the correct nucleotide sequence, can heal the broken bonds and restore normal physiological function; but sometimes the repair processes are misaligned. Often this is of no consequence, but the mis-healed DNA would be passed on to any somatic progeny and the new cell-line may be vulnerable to more mutations and eventually diseases such as cancers. Hence, the altered gene is now an 'oncogene'. The normal gene from which it mutated was a 'proto-oncogene', the function of which would have been involved in cell-growth and division.

There are some important points to consider:

- Living cells are quite robust and have evolved to cope with damage
- Somatic mutations are often neutral
- DNA damage by radiation may be no more difficult to repair than metabolic damage
- But any stress on cell growth patterns by doses of radiation extra to background could increase the risk of cancer and other non-communicable diseases.

IR includes:

- X-rays and gamma rays
- alpha rays
- neutrons
- electrons

And it can come from:

- external sources (including natural rocks and medical devices)
- inhaling or ingesting radioisotopes such as ^{14}C or ^{40}K
- traces of naturally occurring uranium and thorium, and their decay products, including ^{222}Rn – the human body has always been slightly radioactive
- leaks of radioactive materials from weapons testing and nuclear accidents.

NPPs and childhood leukaemia

Concern has been expressed about the valid finding of excessive leukaemia incidence in some children living within 5 km of a NPP. It was surmised that radioactive discharges – perhaps unacknowledged or unauthorised – could be responsible. An alternative explanation is based on epidemiology (peak age three years) and the nature of the associated oncogenes, and involves the highly-complex physiological mutations in the rapidly dividing lymphocytes. These are essential for the neonate to develop the immunity to combat infections and meet the challenges of extrauterine life. Very occasionally the mechanism for these immunogenic mutations spreads to other genes giving rise to oncogenes. Even if radiation from NPPs is not mainly responsible for the excess leukaemias, the case against nuclear power is not affected: low-dose ionising radiation can cause many other cancers.

Measuring radiation, including the amount in the background

The physical unit of the amount of ionising radiation is the '**becquerel**' (Bq) – a measure of the number of atoms disintegrating per second, best detected by 'Geiger counters'.

Radiation 'doses' are better expressed in units of *energy*:

> The radiotherapy dose unit is '**gray**' (Gy)
>
> 1 Gy = 1 joule / kg (**USA 'rads'**; 1 rad equals 0.01 Gy or 10 milligrays – mGy).

Exposure to radiation involves various biological and radiation factors, whether external (from gamma and beta rays) or internal radiation from alpha particles.

Background natural environmental doses

Exposure to external gamma and beta rays is measured in '**sieverts**' (Sv): 1 Sv = 1 Gy. (The USA uses the term '**rem**' – radiation equivalent man – 1 rem equals 10 mSv).

The annual amount of naturally-occuring ionising radiation in the UK is officially about 2.7 mSv, but varies with local geology. The components and their proportions are as follows (UK Health Security Agency, 2022):

- ^{222}Rn gas from the ground – 48%; terrestrial gamma radiation – 13%
- Cosmic radiation – 12%; medical radiation – 16%; intakes of radionuclides – 11%
- *Nuclear fallout legacy; 0.2%; occupational; 0.02%; discharges (NPPs etc); 0.01%.*

As internal exposure of tissues, particularly from alpha-emitting isotopes, are more dangerous, the received dose is calculated in millisieverts (mSv) adjusted for what a milligray would do by applying 'weighting factors'. For alpha-emitters, the factor is **20**; so 1 mGy of alpha radiation internally would give a dose of 20 mSv to the locally irradiated tissue cells.

This complicated system allows for different effects of the varying sources of radiation on different biological tissues, including bone-marrow, skin and solid organs, each of which have adjusting factors of their own. For whole body exposure the factor is 1.0. Different factors are applied for age and gender as women and children are more sensitive to radiation. These factors are not 'exact' but are useful for radiological protection policies.

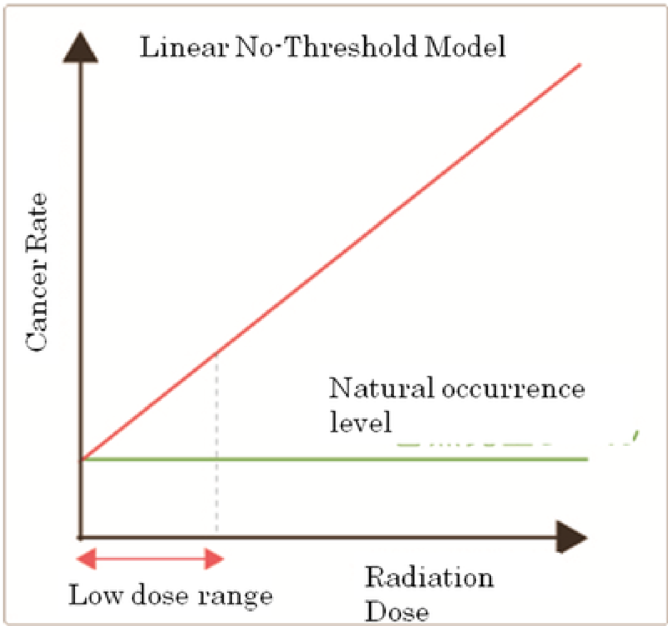
There are no 'conversion formulae' between Bq (which is a count) and Gy or Sv (units of radioactive energy), but a high count does correlate approximately with high radioactivity.

Dose-response relationships models

The responses to higher doses are now understood quite well, but at exposures lower than 100 mSv a year the effects are difficult to ascertain unless very large numbers of people are studied. The effects of more than 100 mSv are more predictable and known as 'deterministic', whereas lower doses are less predictable and more random.

Figure 3 predicts a linear extra risk for cancers rising diagonally from no-dose, on top of the natural occurrence, and is favoured by the International Commission for Radiological Protection (IRCP).

Fig. 3: Model 1 – Linear No Threshold



(Source: https://energyeducation.ca/encyclopedia/Linear_no-threshold_model)

Figures 4 and 5 suggest that lower exposures are less risky, and that below 'thresholds' there is no extra risk. These models are accepted less widely.

Fig. 4: Alternative hypothetical models

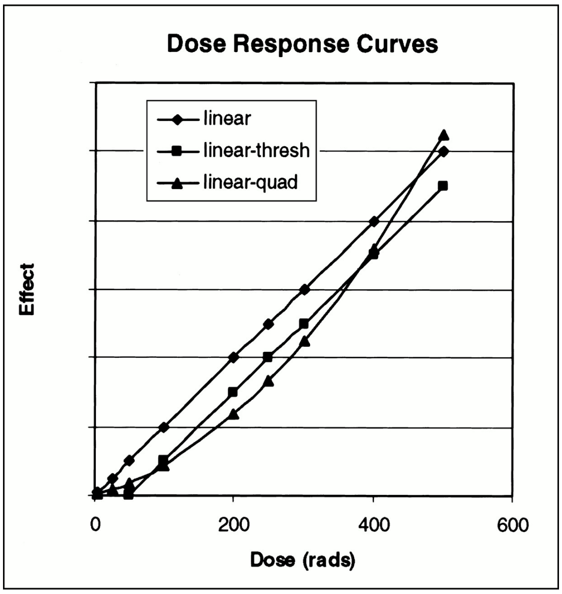
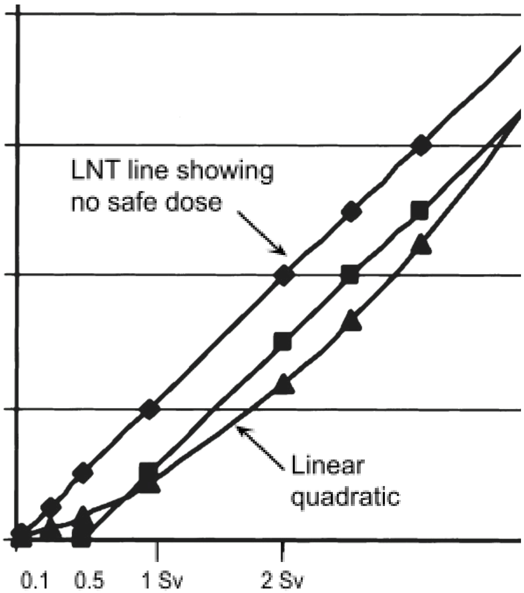


Fig. 5: Enlargement of the lower-left portion of Figure 4 (2 Sv = 200 rads)



(Source for Figures 4 and 5: Bolus, 2017, "Basic Review of Radiation Biology and Terminology", Journal of Nuclear Medicine Technology, 45 (4) 259-264, https://doi.org/10.2967/jnmt.117.195230)

Analyses for very low exposures are less predictive. The 'linear-quadratic line' in Figure 5 hypothesises that above 0.5 Sv there is an above-zero extra risk but not as high as the 'no safe dose', while the unlabelled line (linear with threshold) hypothesises no extra risk until 0.5 Sv, above which risks increase linearly. This remains speculative. Furthermore there is little evidence for 'hormesis' – the idea, analogous to vaccination, that a little low-dose radiation can be protective. This has little biological sense as radiation effects cannot be distinguished from metabolic oxidants.

Effects of time

Acute, chronic and internal exposures to the same total dose

Exposure may be acute or over a few days. Assuming that total dose matters most is an over-simplification: various 'adjustment' factors have been applied by some authors but inconsistently, especially for low doses, so are not considered further here.

The International Commission on Radiological Protection (ICRP) advises that 'normal occupational exposures' be limited as follows:

> Whole body – 20 mSv/year, averaged over 5 years, i.e. a limit of 100 mSv in 5 years with the further provision that in any single year the dose should not exceed 50 mSv: So if in a 5-year period someone gets 50 mSv in one of those years, for the remaining 4 years the total dose must not exceed 50 mSv (https://remm.hhs.gov/ICRP_guidelines.htm)

Other clinical effects of ionising radiation

Exposure to ionising radiation has adverse effects on the cardiovascular system, even at lower doses. Cataracts can form after exposure to higher doses. The acute radiation syndrome following high doses features organ failure and brain oedema.

Summary of radiation-induced health effects

Adapted from ICRP (https://journals.sagepub.com/doi/pdf/10.1177/ANIB_35_1, Page 5)

Dose (mSv)	**Effects on individuals**	**Consequences for an exposed population**
Very low: up to 10	No acute effects; extremely small additional cancer risk	No observable increase in the incidence of cancer, even in a large exposed group
Low: 10 to 100	No acute effects, subsequent extra cancer risk less than 1%	Observable increase in cancer incidence if over 100,000
Moderate: 100 to 1000 mSv (acute whole body dose)	Nausea, vomiting, bone marrow depression (mild); subsequent extra cancer risk approx 10%	Observable increase in cancer incidence if exposed group is over a few hundred
High dose: above 1000 mSv (acute whole body dose)	Severe nausea, bone marrow syndrome; high risk of death from > 4000 mSv without treatment; significant additional cancer risk	Observable increase in cancer incidence

Medical benefits from the nuclear industry

The nuclear industry has undoubtedly benefited humankind, particularly for diagnosis and radiotherapy. Nuclear reactors were important sources of materials, but technological advances such as nuclear accelerators have released us from relying on reactors.

Particle accelerators as sources of medical isotopes:

- are specifically made to produce medical isotopes
- produce negligible amounts of wastes
- have decentralised production and can be conveniently located at hospitals
- have low transport risks
- are not dangerous
- have no risk of weapons-proliferation
- have no terrorism risk.

The few other isotopes can be made by accelerator-driven systems.

Among other factors, nuclear reactors produce radioactive waste that can be a weapons-proliferation risk, have transport problems especially for short-lived isotopes, and their facilities could be targets for terrorism.

V. The science of nuclear weapons

Nuclear bombs (‘warheads’)

There are three main types:

- **Fission** – the basic type as used in Hiroshima and Nagasaki, using either ^{235}U or ^{239}Pu
- **Boosted fission** – incorporates a small amount of *fusion fuel* to increase yields
- **Thermonuclear** – which uses an initial fission to trigger a full-scale *fusion* reaction to produce a high yield.

All fission reactions developed for military purposes use either ^{235}U or ^{239}Pu. Higher yields can be produced in bombs encased with natural uranium or DU which, although not ‘fissile’ are ‘fissionable’ when bombarded by neutrons released by the explosion, which increases the bomb’s yield.

Fusion reactions in a thermonuclear fusion warhead

All fusion reactions require nuclei of tritium and deuterium, whether in boosted fission or in thermonuclear bombs.

Tritium (see section I.) is a radioactive light gas which is difficult to store and transport. Although stocks need constant replacement, it can be produced by neutron bombardment of the stable isotope ^{6}Li (lithium) in the form of lithium deuteride, a much more easily transported and managed source. Deuterium, the other fusion reactant, is supplied from the ‘deuteride’ at the same time. A neutron absorbed by a ^{6}Li nucleus transmutes it into an alpha particle and a tritium nucleus. However ^{6}Li is only 7% of the geological deposits of Li, the remaining 93% being ^{7}Li. Except under only very energetic neutron bombardment, ^{7}Li is not a fertile source of tritium. So the Li in thermonuclear bombs is highly enriched in ^{6}Li.

The ‘Castle Bravo’ test at Bikini Atoll, Marshall Islands, on March 1st 1954 was expected to yield 5 Megatons (Mt, 1 Mt is equal to the force of one million tons of TNT). Although the tritium-generating Li was enriched to 40% ^{6}Li, it still had 60% ^{7}Li which was not expected to produce tritium. But on detonation, ‘energetic’ neutrons caused the ^{7}Li to produce more tritium so the yield was 15 Mt, causing immense damage to local communities and industries, and losing much data from damaged monitoring instruments.

The basic design of a thermonuclear warhead

A thermonuclear warhead has two stages – a 'primary' and a 'secondary'.

The **primary** stage is essentially a 'boosted fission bomb' in which fission of ^{235}U or ^{239}Pu creates the hot pressurised conditions to trigger the second stage. The materials are:

- a hollow sphere ('pit') of ^{235}U or ^{239}Pu, inside which is a…
- *neutron initiator* which, on detonation, releases neutrons to 'kick-start' the fission
- the 'pit' is surrounded by a layer ('tamper') of uranium or DU, which in turn is…
- surrounded by conventional explosives which, on detonation, compress the pit
- the pit becomes supercritical and, with the neutron initiator, boosts the fission reaction of the now supercritical pit
- the 'fissionable' U in the tamper fissions, boosting the yield of this primary stage.

The secondary stage is:

- a closed hollow cylinder of uranium inside which is
- the fusion fuel, a non-radioactive compound of lithium 6 (^{6}Li) and deuterium
- and an inner core ('spark plug') of ^{239}Pu.

The whole complex has a reflective outer casing. Neutrons of the primary stage bombard the ^{6}Li-deuteride fuel which produces tritium and deuterium for the major fusion reaction.

The effects of a nuclear detonation

A nuclear detonation instantly creates a highly radioactive flash and an intensely hot fireball, and a mushroom cloud. Of the bomb's energy:

- about 5% goes into the flash
- about 35% goes into the fireball where anything within range will be vaporised
- about 50% into the hypersonic radiating shock blast (super-gales)
- about 10% goes into the radioactivity and kinetic ejection of the fission products.

Fireballs touching the ground ('ground-burst'; GB) produce 'fall-out' downwind, making large areas of ground fatally radioactive for several hours: carcinogenic levels of radioactivity linger, possibly for years. 'Airbursts' (AB) produce less fallout but the fission products get dispersed globally and the blast is amplified by bouncing off the ground.

Very-high altitude detonations release a powerful pulse of photons (electromagnetic pulse; EMP) damaging electronic devices across borders and severely disrupting communications.

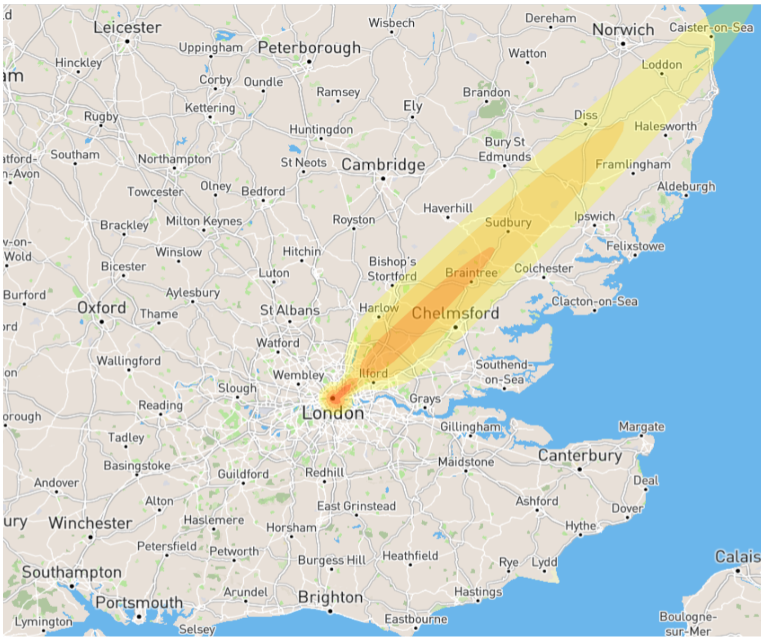
The explosive 'yield' is expressed as equivalents of TNT in tons or kilotons (kt). Nuclear bomb yields vary between <1 kt and 50 Mt (50,000 kt). Most are between 10 kt and 1000 kt, as bigger bombs offer less military advantage.

Effects of a 100 kt bomb on the Houses of Parliament in London

A 100 kt (the yield of a UK nuclear warhead) groundburst on London is expected to kill about 130,000 and injure 355,300 people in the first 24 hours. The radius of heavy blast (20 psi) damage would be 1 km, with 2 km of a 5 psi blast, and 4.5 km of a light blast. People within a radius of 4 km would get severe heat burns.

A light 15 mph south-west breeze would spread a radioactive fallout of 10 mSv per hour beyond Norwich and 1 Sv per hour beyond Braintree although within 24 hours the radioactivity would decline to about 1% of the original.

Fig 6: The effects of a 100 kt bomb on London's Houses of Parliament (Source: https://nuclearsecrecy.com/nukemap/)



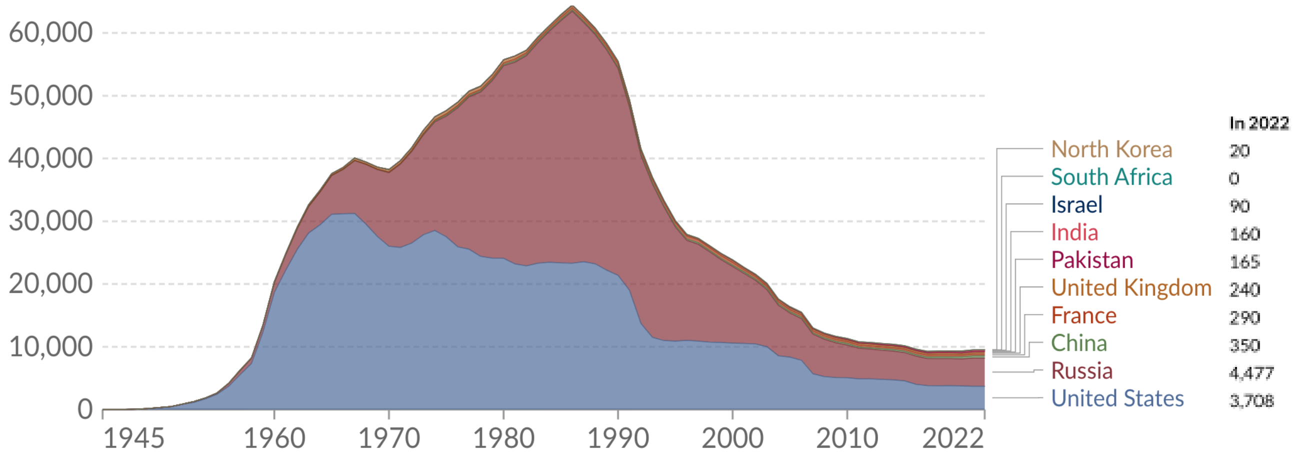
Management of radiological emergencies.

In 2019, Public Health England (now the UK Health and Security Agency) published "Public Health Protection in Radiation Emergencies" – a 61-page booklet outlining the planning principles behind managing a radiation emergency. These explicitly do not consider the detonation of a nuclear weapon but do include emergencies following accidents to NPPs and other nuclear installations overseas which threatened UK mainland areas – learning from Chornobyl and Fukushima. The instructions include the circumstances for staying indoors or the planning of temporary or long-term evacuations, and the need to balance the immediate trauma of whatever mitigation measures were taken with possible long-term traumas, including mental health effects. As such they may be relevant to the potential of missile and rocket attacks on Ukraine's NPPs during the current conflict.

VI. Nuclear warheads and delivery systems

Nuclear warheads by numbers

Fig. 7: The number of nuclear warheads in the world by country since 1945



(Source: Federation of American Scientists 2022)

Delivery systems; Rockets, missiles, vehicles, warheads and 'platforms'

Rockets: Propelled by fuel, aimed at the target but not guided – they explode on impact.

Missiles: Their ranges can be short (within 100 miles), mid (up to several hundred miles), or long (intercontinental – up to 7000 miles) –

- **Ballistic**: Supersonic propulsion in the 1st phase, then guided by gyroscopes and timers as in German WW2 V2 'rockets'; current ballistic missiles are guided by radio signals, lasers etc.
- **Cruise**: Subsonic propulsion during flight; internal pre-programmed guiding controls
- **Vehicles:** carry and guide warheads until their final destination (target)
- **MIRV**: Multiple independently targeted reentry vehicles; an intercontinental missile travelling at supersonic speed, on re-entering the atmosphere the final stage releases many vehicles each with a warhead; each vehicle successively detaches and manoeuvres to release its warhead; targets in a defined area are scattered; *five 20 kt detonations in a defined area do more damage than one of 100 kt.*

‘Platforms’:

- **Land**: Missiles from silos or mobile launchers
- **Sea**: Missiles from submarines – nuclear armed submarines are usually nuclear powered (but not all nuclear powered submarines are nuclear armed). Note: the US Navy’s aircraft carriers are powered by nuclear engines but are not nuclear armed.
- **Aircraft**: direct ‘free-fall’ bombing, as in Hiroshima and Nagasaki. Note: 21st century F15 bombers will use free-fall B61-12 bombs ‘guided’ by gyroscopes and fins – ‘hypersonic glide vehicles’ – to out-manoeuvre air defences.

Current number and delivery of UK nuclear warheads

UK Trident nuclear-armed nuclear-powered submarines

- **4** Vanguard class UK-built submarines
- **8** or more Trident D-5 MIRV ballistic missiles on each sub, leased from USA
- At least **40** UK-built nuclear warheads on each submarine (**160** deployable warheads, plus an extra 80 ready to be deployed, making a total 240 currently in stock)
- Yield of each warhead: **80–100 kt** (the Hiroshima bomb had a yield of **12 kt**)
- Command and control system

Continuous-at-sea-deterrence (CASD)

- One UK submarine is always on active ‘silent’ patrol for up to 4 months; a **1000 metre aerial trails** behind for incoming messages; voyages can be tracked by non-UK forces
- Two submarines are in port at Faslane or on exercises; the 4th is being re-fitted at Devonport
- From 2021, the stockpile cap of the 80–100 kt warheads will be increased to 260, but the actual numbers of warheads retained will be kept secret
- From this it can be seen that in practice, at any one time 40 warheads are actually deployed on one submarine, and an extra 40 or even 80 on one or two of the submarines ashore are ready to be deployed at short notice.

Trident replacement programme

All the UK’s Vanguard Class submarines will be replaced by new ‘Dreadnought’ Class submarines, commissioned for the late 2030s (so far on track in spite of the COVID-19 pandemic). The costs will amount to **£41 billion**, including £10 billion contingency just for the submarines. In 2016, Parliament estimated that **£179 billion** would be spent on replacing Trident over a 40 year lifetime. The UK Defence budget for 2023 is £55.5 billion, of which 6% (£3.3 billion) is for operating Trident. The UK spent £283 billion on healthcare in 2022 – the billions or so spent on the ‘deterrent’ and its replacement programme could therefore make a valuable contribution to the UK’s over-stressed health and welfare systems.

The Royal Navy Trident Submarine HMS Victorious, leaving the naval base at Clyde, June 2013 (Photo: LA(Phot) Will Haigh/MOD)

VII. How nuclear weapons are 'used'

Since 1945, no nuclear weapons have been detonated as an act of war. However, they have been and continue to be used 'politically' for national 'security' and as potential threats based on the doctrine of deterrence, most notably by Russian forces in Ukraine.

The literature on **deterrence theory** is extensive: its ultimate premise is Mutually Assured Destruction (MAD). If a Nuclear Weapons State (NWS) is warned of an impending attack, it may 'strike first' (preemptively). There have been several 'close shaves' since 1945, usually due to defective responses to apparent warnings: the world has escaped episodes of MAD by 'luck' or intuitive disobedience of military commanders correctly believing that the monitoring systems were sending false alarms. The NWSs have various 'Missile Defence Systems' (MDS) designed to destroy incoming missiles, but (as Ukrainian experience has shown) these are not always effective and 'hypersonic missiles' are designed to evade detection. Also, the concept of nuclear deterrence is flawed, not least because of 'non-state' actors which are unaccountable to treaties or law. Preventive and protective measures such as MDS cannot be 100% effective, and bunker-style shelters cannot offer long-term survival.

Can nuclear wars be won?

To 'keep ahead of the game', NWS governments are constantly 'improving' their weapons, delivery, targeting and defence systems. This includes the deployment of nuclear weapons on 'undetectable' ('stealth') submarines. Such developments are ongoing even though many regard them as impractical, and could be countered by more sensitive methods of detection; however, such developments are very expensive – and very rewarding for the arms traders.

Following ridicule of government booklets in the 1980's, the UK has abandoned 'home-guard' systems of improvised domestic shelters and bunkers purpose-built for the elite. Better ways of protecting 'home populations' are very difficult to design, let alone put into practice.

'Strategic' and 'tactical' use of nuclear weapons

The widespread targeting of nuclear weapons on cities and military installations has been labelled as 'strategic', and would clearly cause massive destruction.

An alternative approach, developed in the Cold War, would be to restrict targeting to non-civilian sites such as 'battlefields' to a low number of 'low-yield' (below 1 kt) weapons. However, some of these so-called 'tactical' weapons could exceed 100 kt – the yield of a UK Trident warhead. There is no specific treaty concerning tactical use.

American war-games during the Cold War showed that tactical weapons exercises very often expanded to a full strategic exchange due essentially to escalation of 'tit-for-tat' responses. This sort of threat is a type of bluffing which could well fail.

Nuclear winter (famine)

This is the most important consideration concerning nuclear war. Although by 1993 there had been about 2500 tests of nuclear devices, and people suffered radiation exposures, the tests were, of course, not conducted over major centres of population. This delayed a realistic understanding of the consequences of a large-scale strategic nuclear war. Large amounts of soot particles thrust into the upper atmosphere could obscure sunlight for up to a decade – enough to cause crops to fail and people to starve during a 'nuclear winter'. An example could be a war between India and Pakistan in which both states used most of their warheads (about 160 in each country with yields between 10 and 50 kt, many being carried on missiles). More recent climate models reinforce these conclusions and indicate that the risks are severe. The following table, taken from a study in 2022, shows the possible results of exchanges of only a small proportion of the world's nuclear arsenals.

Number of weapons on urban targets, yields, direct fatalities and resulting number of people in danger of death due to famine

(https://doi.org/10.1038/s43016-022-00573-0, 2022)

Number and yield of weapons	Teragrams* soot generated	Direct fatalities (millions)	People without food after 2 years (millions)
100 x 15 kt	5	27	260
250 x 15 kt	16	52	930
250 x 50 kt	27	97	1400
250 x 100 kt	37	127	2100
500 x 100 kt**	47	164	2500

** A 'teragram' is 10^{12} grams – equivalent to a million tonnes*
*** 5% of the world's arsenal*

The bottom row of this table represents less than 5% of the world's total nuclear firepower. The effects of the reduced crop yields would be aggravated by severe disruptions in trade transport and fuel, and recovery may require many decades. Were just a quarter of the arsenals of the West and of Russia (about 2500 warheads in total) to be detonated over cities and inhabited land, humanity could be totally annihilated.

The general public, distracted by war, disease, political rhetoric, disinformation and economic crises, is largely unaware of these important studies which reveal a massive threat to all humanity. (See https://www.cam.ac.uk/research/news/public-awareness-of-nuclear-winter-too-low-given-current-risks-argues-expert)

VIII. Arms control measures and treaties

Many treaties governing the 'rules of war' have appeared since the late 19th century (the Geneva Conventions). UN-brokered treaties include bans on landmines, chemical, and biological weapons. Bilateral agreements on arms control became prominent after 1989. Treaties between the USA and USSR/Russia included the Intermediate-Range Nuclear Forces (INF) Treaty which required each party to eliminate all their ground-launched ballistic and cruise missiles with ranges of 500 to 5500 kilometres. Other treaties such as the Comprehensive Nuclear-Test-Ban Treaty and bans on fissile materials are not yet in force.

United Nations brokered treaties involving nuclear weapons include:

- Partial Nuclear Test Ban Treaty (1963)
- Nuclear Non-Proliferation Treaty (NPT) (1968)
- Treaty on the Prohibition of Nuclear Weapons (TPNW) (2021)

Other 'bilateral' treaties include those between the USA and USSR:

- Strategic Arms Limitation Treaty (SALT) (1972)
- Strategic Arms Reduction Treaty (START) (1991)
- New START (between USA and Russia) (2010, suspended by Russia in 2023)

There is NO specific treaty against tactical nuclear weapons.

The 'Advisory Opinion' of the UN's International Court of Justice in 1996 was that the threat or use of nuclear weapons would be **unlawful** except '*in an extreme circumstance of self-defence, in which the very survival of a State would be at stake*'.

NPT, IAEA, ICAN and TPNW

The NPT of 1968, in force since 1970, is essentially a bargain between the five accredited Nuclear Weapons States – China, France, Russia, UK, USA (the 'P5' veto-carrying members of the UN Security Council) – and the non-Nuclear Weapons States (non-NWSs) that:

- in time, the NWSs will disarm all nuclear weapons (in 'good faith')
- while non-NWS would be prevented from arming, but
- non-NWSs would be allowed to develop civil nuclear power under international control by the **International Atomic Energy Agency** (IAEA – a United Nations body).

The aim was to stop any more countries developing a nuclear arsenal. Nevertheless four non-signatory states have developed their own arsenal – India, Pakistan, Israel and North Korea. Others, e.g. Iran, may be considering their options. The IAEA has conflicting roles, for while it is supposed to promote and facilitate peaceful uses and maximise safety, it is also supposed to prevent any military uses. These two aspects, which have always been intertwined, are inherently incompatible and have been described as making the IAEA's work seem ‘mission impossible’. It has no role in regulating military nuclear activities among the NPT’s five approved Nuclear Weapons States.

Many non-NWSs became concerned about nuclear war and a consequent ‘humanitarian catastrophe’, but no practical disarmament among the five NWSs seemed forthcoming. So, in 2006, the **International Campaign to Abolish Nuclear Weapons (ICAN)** was founded to promote a more radical treaty: in 2016 ICAN supported the UN General Assembly to draft the **TPNW (Treaty on the Prohibition of Nuclear Weapons)**. This includes comprehensive prohibitions on participating in any nuclear weapon activities such as developing, testing, producing, acquiring, stockpiling, and using or threatening to use nuclear weapons. The TPNW has been in force since 2021, having acquired the requisite number of ratifications by UN Member States. It has a long way to go but many in the international peace movements regard it as a highly promising development providing a rational route toward effective global nuclear disarmament.

IX. Conclusion and how to take action

Nuclear war remains a distinct possibility, aggravated by deteriorating global security in the face of environmental degradation, the climate crisis and the unjust exploitation of the world's resources by the few.

Once started, even by a tactical use of nuclear weapons, it would be difficult to limit a nuclear exchange before a major crisis develops: indeed the prospect of human annihilation cannot be discounted.

The nuclear and climate crises augment each other, but while the climate crisis is becoming more apparent, the nuclear crisis remains below the headlines for most people – even the Ukraine crisis seems not to raise such concerns. While many citizens – especially of the P5 nations and their allies (see for example this YouGov study in the UK: https://yougov.co.uk/topics/politics/articles-reports/2022/09/21/part-three-nuclear-weapons-and-war) – consider that nuclear deterrence is keeping them safe, we feel by contrast that global security would be better served by comprehensive and co-ordinated international welfare systems. These would be for a world society free of nuclear weapons in which armed enforcement is confined and compatible with a peace for a diverse, ecologically balanced and mobile world community.

Specific actions

- **Take part in the ICAN Cities Appeal** campaign – an international campaign led by the International Campaign to Abolish Nuclear Weapons, which aims to build local civil and political support for the Treaty on the Prohibition of Nuclear Weapons (TPNW) to ultimately influence national governments. You can make use of ICAN campaign resources and lobby your city councillors to sign on. https://www.medact.org/2021/headlines/ican-cities-appeal/

- **Campaign for ethical divestment from nuclear weapons manufacturers – 'Don't Bank on the Bomb'** (https://www.dontbankonthebomb.com/) is a regular report on the private companies involved in the production of nuclear weapons and their financiers. Campaign groups such as '**Don't Bank on The Bomb Scotland'** (https://nukedivestmentscotland.org/), use published information to campaign for ethical divestment of private companies from nuclear weapons manufacturers. Have a look at their work and take action where you are!

- **Familiarise yourself with the issues** – especially the health effects, nuclear winter, and the aggravating effects of fossil-fuelled climate change and loss of biodiversity on economic injustice and the threat of conflict: greed, fear and corruption – promoting conditions for a fairer and more healthy society would help address the fundamental causes of insecurity.

- **Take action in your community** – contact your local MP and local councillors to make your views known, speak to colleagues, friends and neighbours about the importance of campaigning for nuclear abolition, and keep up-to-date with the wider nuclear disarmament movement by following:

- Campaign for Nuclear Disarmament (CND) – cnduk.org
- International Physicians for the Prohibition of Nuclear Weapons – ippnw.org
- International Campaign Against Nuclear Weapons – icanw.org
- Peace News – peacenews.info

You can also come along to a Medact Nuclear Weapons Group meeting!

Medact's Nuclear Weapons Group holds regular meetings online where we share news about the latest developments and public demonstrations, and focus on the health and humanitarian effects of nuclear weapons. Newcomers are very welcome to join by signing up online to the email list: https://www.medact.org/membership/groups/nwg/