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ISSUES RELATED TO ENVIRONMENTAL REMEDIATION OF THE HARM ARISING FROM NUCLEAR WEAPONS TESTING AND USE IN THE CONTEXT OF THE TREATY ON THE PROHIBITION OF NUCLEAR WEAPONS[1]

Background paper for the 4th Session (18 May 2021) of the informal consultations of the 1MSP consultation cycle

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Nuclear weapons treaties prior to the Treaty on the Prohibition of Nuclear Weapons have often made passing mention of the devastating consequences of nuclear war and, in the case of the 1963 Partial Test Ban Treaty, a mention of the desire "to put an end to the contamination of man's environment by radioactive substances…" But they are essentially technical documents, dealing with the balance of nuclear terror, seeking to put a little more "safety" into the grim reality that, in the nuclear weapons age, in Winston Churchill's words to the British Parliament in 1955, "safety will be the sturdy child of terror, and survival the twin brother of annihilation".

The TPNW is the first nuclear treaty to be *founded* on the grim reality of the calamitous destruction that nuclear weapons can visit upon humanity, including to future generations, and to the environment. It is the first treaty to link the severe humanitarian impacts that nuclear weapons testing and use have already had to the far more destructive impacts that a nuclear war at a level beyond the use of the weapons on Japan in 1945 would have. It is the first to acknowledge that safety should not be the child of terror, nor survival a twin of annihilation. Indeed, it is implicit in approach of the treaty that the "child of terror" cannot be sturdy.

The TPNW is the also first treaty to have provisions for assistance on health and for environmental remediation both in and of themselves and as part of the overall purpose of the TPNW. This has an important history for the present paper, which deals with environmental impact and remediation. The very first nuclear weapons treaty, the 1963 Partial Test Ban Treaty, was at least as much an environmental and health treaty as it was a nuclear security treaty. The impetus for it came both from the horror of the thermonuclear bomb tests of the 1950s and the realization that fallout was contaminating the environment and transporting strontium-90 into the milk teeth of babies.

This paper focuses on issues relating to the contamination and remediation aspects of Article 6 of the TPNW. These can be considered in the following categories:

1. Charting environmental contamination and fallout from testing and use[3];

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[1] The author takes full responsibility for the contents of the paper but notes that helpful comments on a draft of were provided by Dimity Hawkins, Chuck Johnson, Elizabeth Minor, Kathleen Sullivan, and Tilman Ruff.

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[3] The term "use" of nuclear weapons in this paper is interpreted in a narrow context of actual nuclear explosions since this is of direct relevance to Article 6. This excludes the important category of "threat of use" in the sense of

2. Estimating the impact of contamination;
3. Evaluating remediation;
4. Setting standards for remediation, environmental protection, and health protection by considering:
    a. Present assessments of the risk of radiation ;
    b. Gaps in radiation protection and emerging understanding of radiation risk.

1. A contextual note

Many of the dangers of the residual risks from nuclear weapons testing and use differ from the discrete dangers from residual munitions like landmines and cluster munitions, which can be physically removed from the environment and disposed of in ways that essentially eliminate the risk, though the process of remediation itself carries some risk. In contrast, much of the radioactive contamination from atmospheric, underwater, and space nuclear tests, as well as from the use of the atomic bombs on Japan in 1945, is dispersed across the world's lands and oceans. Such highly dispersed contamination is, in general, not amenable to remediation, making environmental monitoring and health vigilance essential, especially for long-lived radionuclides – such as cesium-137, carbon-14, technetium-99, and iodine-129 – that persist and that bioconcentrate in seafloor sediments and in the food chain.[4]

Some of the radioactivity is concentrated in hot spots created by fallout, some is in the vicinity of test locations on land, some in atoll lagoons, and some on continental shelves just offshore. In the case of underground tests, most contamination is deep underground at test locations. In such areas varying amounts of remediation may be possible. And research may lead to new more effective and ecologically sound approaches to remediation.

Some of the damage is physical rather than radioactive; the approaches to remediation for such damage will, in general, be different than for radioactive contamination.

2. Charting environmental contamination and fallout

Nuclear weapons testing and other nuclear explosives testing have produced global contamination that is widespread and non-uniform. The most extensive fallout has been from atmospheric testing. The last such test was in 1980. Essentially complete lists of those tests are available. Official bodies, both national and international, have inventoried the radioactivity in global fallout from atmospheric testing. There have also been releases even from underground nuclear tests. These are of various kinds and include accidental releases (which can be, and sometimes have been, substantial); seeps of radioactive gases after the tests, and deliberate releases for operational reasons, such as sampling the radioactivity resulting from a test. There is as yet no global inventory of such releases.

An evaluation of the overall amount and impact of global releases from atmospheric testing was done in 1991 by a Commission of the International Physicians for the Prevention of Nuclear War and the

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nuclear weapons being put on alert or nuclear threats being made in a time of crisis, both of which are relevant for understanding potential obstacles and paths to nuclear weapons elimination.

[4] See the figure on p. 622 in Ken O. Buesseler, "Opening the floodgates at Fukushima: Tritium is not the only radioisotope of concern for stored contaminated water", *Science,* Vol. 369, No. 6504, 7 August 2020. On the Web at https://science.sciencemag.org/content/sci/369/6504/621.full.pdf

Institute for Energy and Environmental Research.[5] This book provides global estimates of health harm from dispersed radioactivity, and to some extent, also of environmental damage. It discusses the complexities of such estimation and the scattered nature of the available data. Such estimates provide only a starting point, because they are necessarily rough approximations that ignore the patterns of fallout and, therefore, the intensity with which they impact different places and countries. They are also limited by the fact that the deepening understanding of radiation risks since that time points to higher rates of harm for children, especially female children (see Section 5 below).

Fallout does not respect national boundaries. Therefore, a critical preliminary task in the implementation of Article 6 would be to assess the extent and nature of the fallout beyond the states where the testing was done, in addition considering the fallout and other contamination in the countries where testing was done, including notably two TPNW states parties – Kazakhstan and Kiribati – and one signatory, Algeria.

Some of the contamination becomes relatively uniformly global; radioactive carbon-14, created during nuclear explosions has become part of the atmosphere as radioactive carbon dioxide. Carbon-14 has a half-life of 5,730 years. But for several critical radionuclides like cesium-137, strontium-90, and plutonium-239, the assessment of contamination at local levels is complex. Despite that, such assessments can be and have been done by governmental bodies as well as non-government institutions, in some cases decades after the test explosions themselves.

A part of the complexity arises from the fact that fallout does not deposit uniformly. It is affected by many factors. For instance, the height of the nuclear explosion above the ground determines the amount of dust that is stirred up; this affects the number and size of the dust particles carrying radioactivity that then, literally, *fall out* of the cloud of radioactive particles, carried where they may be by prevailing weather patterns. Thus, explosions close to the ground result in different patterns of radiation deposition than explosions at higher altitudes (like the atomic bombs used on Hiroshima and Nagasaki). As another example, rainfall causes "hotspots" of radioactivity, where radioactive particles are then taken up by plants and animals, or migrate deeper into the soil and groundwater, or are further dispersed by winds, rain, and fires. Such hotspots have occurred thousands of kilometers from the test locations. The intensity of radioactivity in these hotspots can be a hundred or more times greater than average fallout in the general vicinity of the hotspots.

Fallout patterns far from the test locations are also determined by weather patterns over days or even weeks. Various parts of the fallout cloud break up at different altitudes and can travel in very different directions depending on the wind at those altitudes. This was recognized by official measurements after the very first nuclear test ever conducted, on 16 July 1945, and confirmed by other events in subsequent decades.

Nuclear testing has also polluted ocean waters, sea floors, and benthic and other marine organisms.

3. Estimating environmental damage

Mapping the fallout patterns as quantitatively and accurately as possible is the first step in assessing damage. This can be done with available data on tests, research on weather patterns, and available atmospheric modelling techniques, should states parties want such analyses.

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[5] IPPNW and IEER. *Radioactive Heaven and Earth: The Health and Environmental Effects of Nuclear Weapons Testing in, on, and above the Earth*. Apex Press New York and Zed Press London, 1991. Available for free download on the Web at https://ieer.org/wp/wp-content/uploads/1991/06/RadioactiveHeavenEarth1991.pdf

The impact of the contamination is also determined by the terrain on which the fallout is deposited. This also affects the potential for remediation and the possible methods that can be used. A great deal of fallout has occurred over the seas and lagoons. These present different challenges than fallout over agricultural areas devoted to crops or pasture, where certain radionuclides are concentrated up the food chain, while others are not. Similarly, fallout in forested areas not only affects the vegetation, but can be re-dispersed by forest fires.

Long-lived radionuclides are evidently important from the remediation point of view at the present time, since the short-lived ones, like iodine-131 (half-life about 8 days) have decayed into non-radioactive elements by now. However, these short-lived elements, such as iodine-131, are very important for retrospective health assessments of impacts; understanding of the long-term ecological impacts of genetic harms is still evolving (see section 5 below).

Atmospheric and underwater tests have also caused intensive physical and biological damage to marine ecosystems, including coral reefs. The long-term ecological harm can extend for scores or hundreds of kilometers beyond test locations. In such cases, some or even most, of the harm may arise from the physical destruction or disturbance of natural systems rather than from the radiological aspects.

Other aspects of environmental damage include nuclear waste sites that have been constructed to hold wastes either resulting from tests or wastes that arise from test preparations. Test-related activities such as construction in ecologically sensitive areas can cause significant damage. The test locations themselves have suffered considerable damage and contamination. Both radioactive and non-radioactive damage need to be evaluated.

The damage to the environment from underground testing, especially the potential long-term damage to water resources, largely remains to be assessed. So does the cross border contamination from accidental and non-accidental atmospheric releases from underground testing. It should be noted that, in general, these releases are likely to have much lower cross-border impact than atmospheric test explosions.

Health harms and environmental impacts have many overlaps because food webs and ecosystems are bound up with each other. For instance, damage to ecosystems and to human health should take into account bioconcentration of certain radionuclides, especially the long-lived ones like cesium-137, technetium-99, and iodine-129. The movement and cycling of long-lived radionuclides through ecosystems also supports the notion that monitoring and vigilance are needed to protect human food supply and health.

Much has been learned from direct evaluations of harm from nuclear weapons testing and use. But it should also be noted that there is a great deal to be learned from the literature relating to other nuclear events that have spread radioactivity, like the Chernobyl and Fukushima accidents, and risk assessments relating to other nuclear activities. Examples include evaluations of waste management (positive and negative). Studies of long-term fissile materials management may also be important for states parties, especially in light of the fact that plutonium-239 has a half-life of over 24,000 years.

4. Evaluating remediation

Remediation approaches depend on the intensity and scale of the damage. Remediation in identifiable hot spots, including at the test site locations in the two states parties and one signatory state, would be different and more feasible than the more dispersed contamination where there are low concentrations of radionuclides. Remediation of non-radioactive physical and biological damage would generally require different approaches than remediating radionuclide contamination, when that is possible.

One conventional approach to remediation of radioactive contamination in hotspots involves scraping up soil and disposing of it as radioactive waste. This approach gathers up dispersed radioactivity and thereby spares larger areas from continued pollution. At the same time, the long half-lives of several radionuclides also pose challenges. Leaks of radioactivity over the hundreds and even thousands of years are to be expected. Setting radiation protection standards and putting in place methods for monitoring and compliance assessment are difficult and demanding tasks. Scraping the soil can also involve its own harm, for instance to topsoil, already becoming a scarce resource in its own right. The impact of climate change may also affect the long-term prospects of such approaches.

Bio-remediation is an approach that has been emerging as a less problematic approach to remediation. In effect, this approach uses natural biological processes by which plants and fungi draw radionuclides out of contaminated soils and concentrate them. The secure storage of such bio-wastes would remain as an issue, but potentially a less complex one than large volumes of radioactive dirt. It could be an approach in some situations that states parties may want to explore.

There are many examples of remediation projects that states parties can consider and evaluate. It is safe to say that experience indicates that when projects are designed and implemented with care, risks can be mitigated, though never completely, given the long-half-lives of several important radionuclides. Cesium-137 and strontium-90 impacts must be considered for hundreds of years; for radionuclides like carbon-14, plutonium-239, neptunium-237, technetium-99, and iodine-129 the time frames are vastly longer.

Monitoring of contaminated areas will remain important, even in remediated areas, and more so in areas that are impossible to remediate. Moreover, conditions can change; radionuclides can be dispersed by fires or by underwater landslides. The need for ecosystem monitoring and care will endure intergenerationally due to the long half-lives of radionuclides, especially ones that bioconcentrate and are analogs of non-radioactive elements like calcium and potassium that people and other living beings need. Also important is the fact that testing-related contamination affects a wide variety of ecosystems, making any “one-size-fits-all” approach inappropriate and inadvisable. Therefore, the involvement of affected communities, who have the best knowledge of local ecosystems, as principal parties is critical for remediation, monitoring, standard-setting, and health protection (see Section 5).

States parties may also want to consider protective measures in the short-term, pending remediation, in case they have not yet been taken. They could include publishing and disseminating information about contaminated areas and explanations of radiation hazards as well as installation of markings and, if appropriate, fencing, to reduce the risk of inadvertent exposure.

The above challenges are principally testing-related; another type of problem situation should also be noted. Accidental, non-explosive losses of nuclear weapons and dispersal of nuclear materials have occurred outside of nuclear weapon states; they may occur again. Clean-up has been difficult, posing risks to personnel. Residual radioactivity is an issue for the communities where the loss occurs. Plutonium is generally the main radiotoxic material to be recovered. Known accidents have occurred in remote or rural areas; some evaluations are available in the public domain.

The problem of accidental dispersal of plutonium would be much more complex in case of an accident in an urban area. The relevant literature to evaluate the risks relates largely to the assessment of the impacts of radioactivity dispersal devices, which has been abundant since the events of 11 September 2001 in the United States. However, literature that predates 2001 is also available, since consideration of deliberate dispersal of radioactive materials goes all the way back to World War II. This literature indicates that the economic costs and dislocation could be immense, in addition to the radiological impacts on health. Thus, prevention of accidental dispersal of radiotoxic materials related to nuclear weapons and their deployment is another area in which states parties could promote nuclear safety in their discussions internally and with nuclear-armed states and their allies.

Of course, by far the worst impacts would be the cases of accidental or deliberate nuclear explosions, especially near-surface explosions or ones that are underwater near human habitation. The devastating consequences – physical, biological, ecological, and psychological -- from even a single explosion could be beyond the devastating consequences experienced by the people of Hiroshima and Nagasaki. An official military evaluation of a nuclear test of a size comparable to the Nagasaki bomb noted the following impacts beyond the underwater explosions themselves:

> We can form no adequate mental picture of the multiple disaster which would befall a modern city, blasted by one or more bombs and enveloped by radioactive mists. Of the survivors in the contaminated areas, some would be doomed by radiation sickness in hours, some in days, some in years. But, these areas, irregular in size and shape, as wind and topography might form them, would have no visible boundaries. No survivor could be certain he was not among the doomed, and so added to every terror of the moment, thousands would be stricken with a fear of death and the uncertainty of the time of its arrival.[6]

This stark assessment is a reminder of the foundational merit of the TPNW being based on health, environmental, and humanitarian concerns. There is a considerable literature on similar test evaluations that could be useful to states parties, both for their Article 6 aims and the broader aim of mobilizing the world's publics and governments to make definitive progress on the elimination of nuclear weapons – the ultimate preventive health measure for humanity and the Earth.

5. Standards for remediation, environmental protection, and health protection

Remediation design necessarily involves setting standards by which the effectiveness of different proposals might be judged and compared. There are, in general, two types of standards so far as radionuclides are concerned:

- Limits on radionuclide concentrations;
- Limits on radiation exposure estimated to occur from residual radioactive contamination and waste disposal, or in the aftermath of accidents or deliberate use.

These two kinds of standards are evidently related. A typical approach is to start with radiation dose limit and work backwards to maximum allowable contaminant levels for air, water, and soil (since the radiation dose implications for intake depend on the pathway of exposure). The dose limits, in turn, have typically been set by considering cancer risk.

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[6] U.S. Joint Chiefs of Staff 1947, as quoted in *Plutonium*, Apex Press and Zed Press, 1992, p. 143. On the Web for free download at https://ieer.org/wp/wp-content/uploads/1992/06/PlutoniumDeadlyGold.pdf

There are both strengths and weaknesses in setting standards according to cancer risk. Cancer is a central risk of radiation exposure. The risks of most other diseases are generally lower than cancer per unit of exposure. The usual approach is to estimate a hypothetical individual who might have the largest exposure in the future from residual radioactivity or waste disposal. In some cases, children may be considered, in others a family, and in yet others, an adult male. A critical issue in such approaches is that children and women – as recognized in the preamble of the TPNW – are at significantly greater cancer risk from the same level of exposure than males. The most at risk are female children. Therefore, the exposure limit for protecting an infant female would usually be much lower for a given level of cancer risk, even when lower intake of food and water by children is taken into account.

Older assessments, done prior to the mid-1990s, did not factor in the age and gender differences into account (including the 1991 study cited above) because the understanding that risks to females were much higher than males became much clearer in the late 1990s. The 1990 estimate of the U.S. National Academies for cancer risk to females was just a few percent greater than for males as compared to more than 50% higher in 2006. The TPNW preamble referring to the higher risk faced by women and children is based on the best and most recent research available in this regard; this can provide an important guide to states parties when setting standards for their remediation efforts.

States parties may also want to consider three improvements to existing approaches to radiation standards:

1) Little attention has been paid in setting standards to protect pregnant women and the children they are carrying except for women who work in radiation environments who declare their pregnancies. In such cases, the limit for exposure of the developing fetus is generally set at the same level as an adult member of the public.[7] This needs some tightening in light of the precautionary principle. For example, some radionuclides, like tritium (in the form of radioactive water) and strontium-90 (a calcium analogue) cross the placenta, creating a variety of non-cancer risks in the early stages of pregnancy.[8] These risks are related to the fact that fetal cells divide rapidly without much chance of repair of radiation damage, while at the same time fetal organs are developing. Putting the developing fetus in the same radiation protection status as a fully grown member of the general public does not take these realities into account.

2) Most scientific attention on health risks has focused on radiation damage, including genetic mutations, to the nuclear DNA of humans. But humans, like all animals and plants, also have DNA in organelles called mitochondria whose circular DNA is more susceptible to mutations than nuclear DNA. Health risks from mitochondrial DNA damage may be more varied than cancer, since mitochondria are the core of our energy system. Mitochondrial DNA also interacts with nuclear DNA in the normal functioning of life's processes.

3) In the first few decades of the nuclear age, it was usually assumed that protecting human health – and within that, limiting cancer risk – would generally result in protection of ecosystems as a collateral benefit. However, the evidence of genetic damage in plants and animals as a result of environmental contamination has built up over the last three to four decades. This indicates a

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[7] Radiation workplaces allow maximum doses to workers considerably in excess of members of the general public, with a typical ratio being 20.

[8] Age and gender differential risks as well as the risks associated with selected radionuclides are assessed in a 2006 report, Science for the Vulnerable prepared and published by the Institute for Energy and Environmental Research. On the Web at https://ieer.org/wp/wp-content/uploads/2006/10/Science-for-the-Vulnerable.pdf

need for specific attention to be paid to protecting ecosystems in their own right when considering remediation design.

The most important thing in relation to standards is the involvement of the affected communities, who should be fully informed of the risks and be the principal decision makers in what risks are and are not acceptable.

6. Conclusions

The TPNW provides states parties with the opportunity to improve the lives of their people by pursing the aims of Articles 6 and 7 and, by the same process, to advance the global public's understanding of the dangers of nuclear weapons and the need to eliminate them. The broad charter of Article 7 allows the continuation of the historical collaboration of between the states parties and other institutions in this great purpose. There are significant resources in the global community – in international bodies, governments, non-governmental organizations, and especially in affected communities – that have the depth of experience and understanding that can be of service to the states parties.