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Use of nuclear power sources in outer space

Review of international documents on radiation protection of particular relevance to nuclear power sources in space

Working paper submitted by the United Kingdom of Great Britain and Northern Ireland

I. Introduction

1. In its report to the Scientific and Technical Subcommittee at its thirty-seventh session (A/AC.105/736, annex III), the Working Group on the Use of Nuclear Power Sources in Outer Space identified four series of international documents that might be relevant to the safety of space nuclear power sources. The report of the International Atomic Energy Agency (IAEA) to the Subcommittee at its thirty-seventh session (A/AC.105/754) deals with two of these, namely:

(a) The provisions of the Convention on Nuclear Safety,[1] the Convention on Early Notification of a Nuclear Accident[2] and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency;[3]

(b) The relevant Safety Series publications of IAEA.

2. The IAEA report noted that, during the process of preparation of the above Safety Series documents, account was taken of the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation and the recommendations of the International Commission on Radiological Protection (ICRP). However, the report did not specifically review the documents of either body from the point of view of safety of nuclear power sources in space. It also recognized that new

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documents had been recently published or were being prepared that might also be relevant. The purpose of the present paper is to consider the relevance of specific ICRP and Scientific Committee documents, including the most recent ones, which have been developed since the adoption by the General Assembly of its resolution 47/68 of 14 December 1992, entitled "Principles relevant to the use of nuclear power sources in outer space". It also provides some comments on possible future developments in the control of radiation risks that may have a bearing on safety of nuclear power sources in space.

3. The present paper should be regarded as complementary to the IAEA report and the working paper submitted by the United States of America to the Scientific and Technical Subcommittee at its thirty-eighth session (A/AC.105/C.1/L.244), which provides a comprehensive database of international documents of potential relevance to space nuclear power sources.

II. Relevant reports of the United Nations Scientific Committee on the Effects of Atomic Radiation

4. The estimation of cancer risks following exposure to ionizing radiation has been the subject of numerous reports over many decades. The United Nations Scientific Committee on the Effects of Atomic Radiation submitted major reports to the General Assembly in 1977,[4] 1988,[5] 1994,[6] and 2000,[7] giving estimates based largely on data from survivors of the atomic bombs at Hiroshima and Nagasaki, supplemented, as appropriate, by information from studies of medically exposed groups. The most relevant information is contained in the most recent report, so the present working paper concentrates on that report, as well as summarizing the uncertainties in the risk estimates contained in it.

5. The first general conclusion is that, overall, the estimates of total cancer risk following radiation exposure at high doses and high dose rates derived in the 2000 report are consistent with those in the corresponding 1994 report. Applying an age-at-exposure model to a Japanese population of all ages, the lifetime risk of exposure-induced death from all solid cancers combined following an acute dose of 1 sievert (Sv) is estimated, in the 2000 report, to be about 11 per cent averaged over genders. That value compares with 10.9 per cent in the 1994 report. However, that excellent level of agreement has to be viewed in the context of the uncertainties in such estimates, perhaps of the order of a factor of 2 higher or lower.

6. Although there are substantial problems in translating risks from the Japanese Life Span Study to other populations, and these become even greater when specific cancer sites are considered, nevertheless the site-specific values in the 2000 report are generally consistent with the earlier estimates of 1994 and in ICRP-60.[8] Further, for all solid cancers combined, the Life Span Study data are consistent with a linear dose-response relationship. It is suggested in the 2000 report that, as a first approximation, linear extrapolation of the solid cancer estimates at 1 Sv acute dose could be used to estimate risks at lower doses. The Scientific Committee estimates that cancer risks are 4-6 per cent per Sv at low to moderate doses, which are similar to its previous estimates. For leukaemia the lifetime risk of exposure-induced mortality is estimated in the 2000 report as 1 per cent following an acute dose of 1 Sv, which compares with 1.1 per cent in the 1994 report.

7. So, overall, it is clear that there is an encouraging level of consistency between the latest estimates of radiation-induced cancer mortality and those used previously, in particular in ICRP-60. It is also interesting to note that the Scientific Committee intends, as part of its future work programme, to evaluate the health effects of radiation exposure to heavy particles present in cosmic radiation at high altitudes and in outer space. This reflects the Committee's view that, in years to come, the potential radiation hazard to space travellers is likely to become a matter of considerable importance.

III. Relevant reports of the International Commission on Radiological Protection

A. ICRP Publication 60

8. As noted in a previous working paper of the United Kingdom of Great Britain and Northern Ireland (A/AC.105/C.1/L.203), in the 1980s the only existing international consensus on radiation risks relevant to the problem of developing safety principles for nuclear power sources in outer space was the 1977 ICRP recommendations that had just been published as ICRP-26.[9] In the event, the public dose limit in ICRP-26 was used in a way not intended by ICRP as the technical basis for General Assembly resolution 47/68.

9. However, even before resolution 47/68 had been adopted, ICRP had issued new recommendations, ICRP-60,[8] which included some principles for protection of the public in emergencies, where dose limits do not apply. They had also shifted away from the concept of a "system of dose limitation", as in ICRP-26, to a "system of radiological protection", which is based on the following general principles:

(a) No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes ("justification");

(b) In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures where the latter are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints) or on the risks to individuals in the case of potential exposures (risk constraints) so as to limit the inequity likely to result from the inherent economic and social judgements ("optimization");

(c) The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from those practices in any normal circumstances ("limitation").

When these principles are implemented for practices, it is necessary to consider not only normal operation but also the potential for exposure from accidents. Once any practice has been justified, the doses and risks have to be optimized within the dose or risk limits specified for individuals.

10. In its 1990 Recommendations, for the first time, ICRP made it clear that, when it specified a dose limit, it was making a judgement about the acceptability (or rather the unacceptability) of individual risk. This was an extremely important clarification of the two quite distinct roles that ICRP fulfils when it makes recommendations: on the one hand it assesses the latest scientific information, including studies such as those carried out by the United Nations Scientific Committee on the Effects of Atomic Radiation, and provides health effects estimators for workers and members of the general public, while on the other, it makes judgements about the levels of risk that might be considered "unacceptable", "tolerable" and "acceptable" for both workers and members of the public.

11. On the basis of its judgement that a risk of death of 1 in 1,000 per year is about the most that is ordinarily accepted under modern conditions for workers, ICRP recommended, in ICRP-60, an average dose limit of 20 man-sieverts (mSv) per year, with the possibility of going up to 50 mSv in any particular year.

12. It is, of course, much more difficult to decide about the level of unacceptable risk for members of the public. ICRP took note of a number of suggestions for the upper limits to acceptable levels of imposed risk, as well as the variation in natural background radiation, when recommending a public dose limit of 1 mSv per year.

13. Dose limits apply to the total exposure of individuals from all sources under control and are particularly difficult to apply to members of the public, so the Commission introduced the concept of a "constraint", which is a restriction of individual dose from a single source. A constraint is not a subsidiary dose limit, but is seen as a prospective upper bound to optimization that ensures that the risk from that source is acceptable and the total risk does not approach the unacceptable. The Commission now recommends a maximum constraint of 0.3 mSv per year for members of the public.

B. ICRP Publications 63, 64, 76 and 82

14. Publication 63[10] presents principles for intervention for protection of the public in a radiological emergency. It recommends that simple countermeasures that involve little risk, such as sheltering, should be implemented to avert doses of a few mSv. More disruptive countermeasures such as evacuation should not be contemplated unless doses of a few tens of mSv are to be averted. The general international guidance on long-term relocation defines a criterion of an averted dose over a lifetime of 1 Sv and the optimum figure for dose-rate at 10 mSv per month.

15. Publications 64[11] and 76[12] deal with protection from potential exposures. ICRP-64 ("Protection from Potential Exposure: A Conceptual Framework") supplements ICRP-60 by addressing the probabilistic aspects of unplanned events and accidents. It looks at potential exposure situations in terms of probability of exposure, dose received given the exposure and approaches to establishing acceptable envelopes of probability of exposure versus dose received as part of design objectives. ICRP-76 ("Protection from Potential Exposures: Application to Selected Radiation Sources") expands on ICRP-64 by addressing potential exposure primarily affecting individuals who are also subject to exposures in normal practices (either occupationally, as members of the public or as patients).

16. Publication 82[13] deals with the protection of the public in situations of prolonged radiation exposure. In it the Commission makes recommendations for dealing with long-lived radioactive residues already in the environment arising, for example, from past practices that were not regulated. It is recommended that an existing annual dose of around 10 mSv may be used as a generic reference level below which intervention is not always likely to be justifiable.

IV. Possible future developments in the thinking of the International Commission on Radiological Protection

17. In ICRP-26 the Commission dealt with stochastic risks where the probability of harm was proportional to dose. This raised questions about the acceptability of risk, since there was no threshold below which there was zero risk. “Acceptability” was determined by the “as low as reasonably achievable” (ALARA) requirement, using cost-benefit analysis and collective dose. The Commission was essentially saying that if society was adequately protected then the individual was also adequately protected.

18. During the last 10 years, however, ICRP recommendations have been more in terms of controlling the maximum stochastic risk to the individual, with a corresponding reduction in the emphasis on collective dose and cost-benefit analysis. In doing this, ICRP has been reflecting the changing values of society that appear to show an ever-increasing concern about the welfare of the individual.

19. ICRP has recently started a fundamental discussion about a revised, simpler approach to radiation protection, based on an individual-based philosophy using the concept of controllability of sources.[14] The argument starts from the premise that all individuals have unconditional rights to certain levels of protection. The guiding principle being proposed is that if the risk of harm to the health of the most exposed individual is acceptable, then the total risk is acceptable, irrespective of how many people are exposed.

20. ICRP has begun to discuss the possibility of a single scale of individual dose such as that shown in the table. Under most circumstances, the maximum value would be around a few tens of mSv in a year, which is the level at which the present system of protection recommends taking action, whether it is occupational exposure in a practice or public exposure in an intervention. Doses significantly above that level occur only in uncontrolled accident situations or in life-saving medical procedures and would be classed as “serious”.

21. Within the proposed scheme, exposures of a fraction of a mSv would be the most that would ever be allowed to a member of the public from a single source, irrespective of the number of sources. The term “constraint” could still be retained and the principle of optimization applied for each source. At the lowest level, doses of a few tens of microsieverts would be considered to be so low as to be exempted from regulatory action and so there would be no need to involve any control system below those levels. If agreed, this would have important implications for low-level waste disposal, the clean-up of contaminated land and the clearance of contaminated materials from reactor decommissioning and so on.

Table
Individual dose scale

Importance	*Dose (in man-sieverts)*
Serious	30-300
High	3-30
Moderate	0.3-3
Low	0.03-0.3
Trivial	<0.03

22. Other consequences of the proposals would include a reconsideration of the Commission's principles of justification and optimization. It is argued that, since radiological protection plays such a minor part in political decisions about the justification of a given use of radiation, consideration should be given to elevating the principle to the responsibility of Governments and their regulatory agencies. This would remove justification from the radiological protection recommendations, which would then start with consideration of an already justified practice.

23. The principle of optimization would need to be rewritten with the replacement of "as low as reasonably achievable", which has been too closely associated with cost-benefit analysis and the use of collective dose, by another descriptor when individual dose is the determining criterion. The principles of protection might then become:

(a) Control the dose to the representative member of the most highly exposed group;

(b) Ensure that the resulting dose is "as low as reasonably practicable".

There would be considerable scope for a simplification of the system of protection and the removal of confusion by not distinguishing between "practices" and "interventions". Additionally, there may no longer be a need to differentiate between "occupational", "public" and "medical" exposures. Importantly, there would be no need for the existing 1 mSv dose limit for the public.

V. Conclusions

24. The reports of the United Nations Scientific Committee on the Effects of Atomic Radiation, in particular the 2000 report to the General Assembly,[7] are of fundamental importance as the scientific basis for evaluating radiation risk, establishing radiation protection and safety standards and regulating radiation sources. It is reassuring that the most recent estimates of radiation-induced cancer risks are quite similar to the estimates in the 1994 report,[6] though additional study is still needed to reduce the uncertainties.

25. ICRP has published a number of documents in the past decade that are of importance to safety aspects of the launch and peaceful use of nuclear power sources in outer space. The most notable is ICRP-60,[8] which gave the 1990 Recommendations and which introduced the concept of "constraint" and differentiated between "practices" and "interventions". The Commission has also

published recent documents on potential exposures in accidents and the protection of the public in situations of prolonged radiation exposure that are relevant to nuclear power sources in space.

26. Finally, it appears likely that ICRP will develop a new set of recommendations during the term of the new Commission (2001-2005), based on an individual-based philosophy using the concept of "controllability of sources". The hope is that this will produce a simpler single scale of protection levels and make it easier to communicate with the public about radiation risks. The implications of the new approach for nuclear power sources in space will need to be kept under review as it develops. In particular, the Scientific and Technical Subcommittee will need to take a position about the balance to be struck between the desirability of updating the space nuclear power sources principles to properly reflect the recommendations in ICRP-60 and subsequent documents and the likelihood that ICRP may make significant changes to its protection philosophy over the next few years. The factors that are likely to influence that balance and the timing considerations associated with any possible updating of space nuclear power source principles will be discussed in the report that the Working Group is due to present to the Scientific and Technical Subcommittee at the end of the present work programme, in 2002-2003.

Notes

[1] International Atomic Energy Agency, "Convention on Nuclear Safety" (INFCIRC/449).

[2] United Nations, *Treaty Series*, vol. 1439, No. 24404.

[3] Ibid., vol. 1457, No. 24643.

[4] *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation; 1977 Report to the General Assembly, with Annexes* (United Nations publication, Sales No. E.77.IX.1).

[5] *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation; 1988 Report to the General Assembly, with Annexes* (United Nations publication, Sales No. E.88.IX.7).

[6] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation; 1994 Report to the General Assembly, with Annexes* (United Nations publication, Sales No. E.94.IX.2).

[7] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation; 2000 Report to the General Assembly, with Annexes* (United Nations publication, Sales No. E.01.IX.3).

[8] "1990 Recommendations of the International Commission on Radiological Protection", ICRP Publication 60, *Annals of the IRCP*, vol. 21, Nos. 1-3 (1991).

[9] "Recommendations of the International Commission on Radiological Protection", ICRP Publication 26, *Annals of the ICRP*, vol. 1, No. 3 (1977).

[10] "Principles for Intervention for Protection of the Public in a Radiological Emergency", ICRP Publication 63, *Annals of the ICRP*, vol. 22, No. 4 (1992).

[11] "Protection from Potential Exposure: a Conceptual Framework", ICRP Publication 64, *Annals of the ICRP*, vol. 23, No. 1 (1993).

[12] "Protection from Potential Exposures: Application to Selected Radiation Sources", ICRP Publication 76, *Annals of the ICRP*, vol. 27, No. 2 (1997).

[13] "Protection of the Public in Situations of Prolonged Radiation Exposure", ICRP Publication 82, *Annals of the ICRP*, vol. 29, Nos. 1-3 (2000).

[14] R. H. Clarke, "Control of low-level radiation exposure: time for a change?", *Journal of Radiological Protection*, vol. 19, No. 2 (1999), pp. 107-115.

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