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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

NATIONAL RESEARCH ON SPACE DEBRIS

SAFETY OF NUCLEAR-POWERED SATELLITES

PROBLEMS OF COLLISIONS OF NUCLEAR-POWER SOURCES WITH SPACE DEBRIS

Note by the Secretariat

Addendum

1. The Secretary-General addressed a note verbale, dated 13 July 1994, to all Member States inviting them to communicate information on national research on space debris, safety of nuclear-powered satellites and problems of collisions of nuclear-power sources with space debris.

2. The present document contains information provided in replies received from Member States between 3 and 7 February 1995.

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* This document has not been formally edited.

REPLIES RECEIVED FROM MEMBER STATES

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

[Original: English]

A. United Kingdom measures to minimise space debris

The United Kingdom recognises the unique nature of the geosynchronous altitude and the need to preserve this global resource for future development and exploitation.

Consequently, the Skynet family of geosynchronous communications satellites controlled by the United Kingdom have the following operational requirements:

- For all satellites which are currently in orbit, a fuel budget is allocated which is capable of performing a tri-impulse manoeuvre to a circular orbit with a minimum altitude of 150 km above the geostationary ring at the end of operational life; and

- Design requirements for future series of satellites specify a capability to achieve a minimum altitude of 500 km above the geostationary ring using a similar tri-impulse manoeuvre at the end of the operational life.

For all cases, in order to eliminate the potential for explosion, appropriate operational procedures shall be established to passivate all energetic subsystems when the satellite has been placed in a graveyard orbit.

B. The justification for the risks from space nuclear power systems

It is considered inevitable that the revision of the safety principles for nuclear power sources (NPS) in space will encompass the principle of justification, a fundamental requirement to satisfy the recommendations of ICRP and an underlying assumption of the IAEA nuclear safety principles. Following a discussion of the problems involved, it is concluded that, subject to confirmation that the space liability convention applies to all countries suffering damage, a plausible qualitative case can be made to satisfy the justification principle for missions otherwise generally regarded as acceptable. It is suggested that the quantitative justification for all future space missions involving NPS be presented to the Committee pending the establishment of a consensus space nuclear safety culture at international level.

1. <u>Introduction</u>

The adoption by the General Assembly of Safety Principles for Nuclear Power Sources (NPS) in Space in December 1992[1] represented the culmination of a debate that had continued for over a decade. The many countries involved in that debate presented a diversity of view which made a consensus difficult to achieve. The serious compromises that were necessary to reach a consensus led to the simultaneous decision by the General Assembly to begin a process of revision.

The problem of devising NPS safety principles for space is rather different to the terrestrial problem. Space NPS are a potential hazard to all countries beneath the orbit involved whereas for terrestrial NPS the hazard is largely confined to the country of origin - exceptions have been dealt with by a variety of Conventions[2,3,4,5,6] and bilateral agreements. The Convention on Nuclear Safety[6] promulgated in 1994 under the aegis of IAEA has gained widespread support, but is specifically limited to land-based civil nuclear power plant.

Among the areas of difficulty identified[7] in the existing Safety Principles for space NPS are the exclusion of important areas such as nuclear propulsion; their formulation in technology dependent terms which are becoming outdated as new developments occur; and some lack of consistency with the better-developed safety principles for terrestrial NPS. Although there is as yet no consensus on the framework for a revised set of Principles it seems inevitable that any revision must include the principle of *justification*, the requirement to demonstrate a net positive benefit from the use of NPS in space. This requirement for justification of risks is fundamental to the radiological protection principles promulgated by ICRP[8] and is assumed in the IAEA considerations of nuclear safety[9].

The discussion of the extent to which the requirement for justification can be met is presented here in qualitative terms. That will be shown to be adequate to demonstrate that for a wide variety of space missions the risk from the use of NPS is likely to be justified by the benefits. It does not obviate the need for a quantitative evaluation of risks and benefits for each space mission or class of mission within an acceptable safety culture[7] to demonstrate a positive net balance.

2. The concept of justification

Pioneers of new technologies invariably accept substantial risks. The early days of steam engines, railways, electricity supply, radiography, air transport, etc. were characterised by injuries and deaths among the enthusiasts and even among the public. As these technologies matured and found wider application, public concern for safety required substantial curtailment of the risks. From this process has developed general safety principles which all technologies are expected to follow.

Space exploration is following a similar pattern but with the earlier curtailment of risks because of the existing safety culture developed from established technologies. Extra precautions have been introduced following fatalities during spacecraft launches in response to public concern about the level of occupational hazard and the risk to the general population.

The regular re-entry of orbiting objects is not generally perceived as an unacceptable risk: many of these items burn up in the atmosphere and the larger objects capable of impacting the earth's surface constitute such a low flux that no significant problem is perceived. Even the arrival in Australia of some 50 tonnes of Skylab in 1979 did not give rise to a general public outcry despite some media hype prior to re-entry.

In contrast, the risk from the use of nuclear power sources (NPS) in space is perceived as a matter of international concern, triggered by the arrival of COSMOS 954 on Canadian soil in 1978. This concern was undoubtedly exacerbated by the perceived hazard from terrestrial nuclear systems, despite the excellent safety record of space nuclear systems.

Radiological protection[8] and the safety of nuclear power[9] are well developed international disciplines in terrestrial applications. The implication of these existing safety regimes for space NPS has been discussed previously[7], identifying an approach which both generalised the existing Safety Principles and improved consistency with the established terrestrial safety framework. However, whatever approach is used to revise the space NPS Safety Principles, a fundamental requirement arising from the work of ICRP[8] and IAEA[9] is the principle of justification, demonstrating that the risks are fully offset by the benefits. The parallel principles requiring risks to be within acceptable limits and to be as low as reasonably practicable are not discussed here.

It was not until the publication of ICRP-26 in 1977[10] that a formal principle requiring justification was recommended alongside the other major principles of limitation and optimisation - no practice shall be adopted unless its introduction produces a positive net benefit. Prior to this the lack of quantitative data on radiation risks had limited ICRP to defining an acceptable dose, but the logic of justifying risks by the benefits obtained was implicit in some of the earlier deliberations of ICRP.

In the 1990 recommendations promulgated in ICRP-60[8], more extended wording was used - no practice involving exposure to radiation should be accepted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. Similarly, in the evolution of international standards on the safety of nuclear installations, cumulating in the 1993 consensus Safety Fundamentals report from IAEA[9], the trade-off between risks incurred and benefits yielded was recognised. The General Nuclear Safety Objective is to "protection individuals, society and the environment.......against radiological hazards", for which purpose national protection systems are required to be implemented: these are commonly based on ICRP or equivalent recommendations.

The detailed interpretation of the justification principle requires consideration of situations where some or all of those suffering the risk are sharing little or none of the benefits, a situation which can, at least in principle, arise in the case of NPS in space. Some guidance on balancing risks and benefits is provided by ICRP - this broad process of balancing would, however, be legitimate only if the detriment to each individual does not exceed an acceptable level[10] - and by IAEA where it is recognised that present international practice implies risks from nuclear installations should contribute only a small increase to the risks from other comparable industrial activities. In addition, considerations of national sovereignty suggest that the justification principle should be satisfied within each country. In general it does not seem to be acceptable for risks to be imposed on a country without commensurate benefit arising.

Thus to satisfy the justification principle for NPS in space it seems necessary not only that there is a global net positive benefit but also that within each country at risk the benefits are sufficient to justify that risk. It also seems necessary to ensure that even within one country any individual not sharing in the benefits is only subject to a negligible level of risk: in practice the low overall level of risk from NPS in space should not make this requirement onerous.

3. Global risk justification

For the purposes of this discussion the risks involved in satellite launches will be excluded. Those risks are mainly incurred by the launching organisation and are mission specific. In practice the global launch risk can be made very small by selection of the launch trajectory and it has not in general been a significant cause for international concern. Its consideration should be included in the mission safety case. Here the attention will be restricted to objects in orbit.

Currently there are over 7000 trackable objects (>10 cm) in orbit round the earth, the vast majority debris from past missions. All of them are destined to re-enter the atmosphere at some future time and a minor proportion will survive re-entry heating to reach the earth's surface. All locations with a latitude less or equal to the orbital inclination are at risk of impact from a re-entering object. Since most of the catalogued objects have orbital inclinations in the range 60-110 degrees (Fig. 1), most countries are at risk of re-entry impact.

The sub-population of known NPS in orbit comprises 45 objects arising from the COSMOS series of satellites. All have orbit inclinations close to 65° (64.4°-65.8°) and hence can potentially impact most countries. The probability of these NPS re-entering at a particular latitude has a distribution (Fig. 2) which is strongly peaked at the orbit inclination around 65°. The orbits are near circular, maximum eccentricity 0.0086, with apogee altitudes ranging from 635-937 km corresponding to orbital lifetimes of about 60-600 years barring debris collisions or other external interference. The effect on these orbit lifetimes of collisions with debris could be of major importance to the re-entry risk: it remains to be evaluated in quantitative terms, a task which is beyond the scope of this discussion.

Some indication of the risks involved is provided by the experience of the Cosmos 954 re-entry[11] which spread radioactive particles and larger objects over some 100,000 km^2. The problem of clean-up for other re-entries could be quite different to that for Cosmos 954: the debris could be deposited in a much less remote location, but the population density could be much higher, perhaps leading to fatalities. It seems reasonable to assume an average cost of the order of $10M per re-entry on land. Bearing in mind the fraction of re-entries over the deep ocean, the cost for all 45 NPS currently in orbit could be of the order of $100M, spread over several centuries.

There can be no serious doubt that the overall benefits of the space programme greatly exceed risks of this order to the world's population. The annual budgets of organisations such as ESA (3000 Mecu) and NASA ($14,000M) provide some measure of the value placed on space activities. For research and exploration missions, the effect of accidents and routine operational risks has not stopped the vigorous pursuit of these programmes despite some delays to remedy specific hazards experienced during the course of these missions. The world-wide advantages that have accrued from the subsequent application of the knowledge gained from this class of mission have been considered to amply justify the risks involved. More generally, the risks of investment in research and exploration are widely accepted as justified by the long term benefits from new knowledge.

However, for the future the majority of the investment in space systems and hence most of the risk will arise from applied missions exploiting the research knowledge for practical purposes. Within a modern safety culture each such mission or class of mission should demonstrate a global benefit which exceeds the risks involved. That should not be difficult in the majority of cases.

For example, there have been enormous benefits from the advent of communication satellites, including direct broadcasting from satellites; there have been widespread benefits from improved weather forecasting; and earth monitoring satellites have fully justified the risks involved to the global population. The principal exceptions to this global justification argument have been proposals which would interfere with other activities through polluting the space environment.

NPS have been used in only a small minority of space missions, and hence nuclear risks would not have been an issue in the justification of the majority of missions. Because of the cost and complexity of NPS they have only been used in situations where the alternative was technically unsatisfactory - primarily in extraterrestrial exploration and in defence-related missions. Whilst with hindsight the collective risks associated with these missions - essentially the cost of the Cosmos 954 clean-up plus the future costs from the re-entry of the Cosmos NPS still in orbit - may not be universally accepted as outweighing the benefits arising, there seems no reason in principle why future NPS missions should not show a net positive benefit.

Such a result could be achieved, for example, either by intact re-entry or by escape from earth orbit, so that a terrestrial radioactive release only occurred in the case of an improbable accident. The intact re-entry approach has been used in the case of RTG's: only in unlikely circumstances is any release expected and that may be confined to a relatively small area conducive to simple decontamination. Intact re-entry has been considered for a reactor NPS but significant problems remain unresolved: interplanetary propulsion would seem to give rise to less difficult justification problems for a reactor NPS application.

4. National justification

As noted earlier, to satisfy the justification principle, it also seems necessary to show that within each country the benefits are sufficient to justify the risks. For this purpose it is then necessary to examine each class of mission in more detail.

Perhaps the most widespread application of space technology is in the field of tele-communications. The International Telecommunications Union (ITU) with an annual budget of about SFr150M has some 170 member countries (Table 1). The benefits of their use of this technology is very substantial measured by the investment it has justified, although the benefits are not uniformly distributed. For example, some countries can make effective use of opportunities such as direct broadcasting by satellite whereas others lack the infrastructure and investment resources to engage in the more demanding aspects of telecommunications technology. At present none of the satellites involved make use of NPS. However, if this proved a desirable development - perhaps to give stronger signals, more channels, longer lifetime - a net positive benefit from such use could probably be demonstrated for each of the ITU member countries, even if eventual (long-delayed) re-entry to the atmosphere was involved.

Meteorology is another area of widespread application of satellite technology. Major advances have consequently become possible in the availability and detail of atmospheric data and in the reliability of weather forecasting. The World Meteorological Organisation (WMO) with an annual budget of SFr60M has some 170 member countries (Table 1) equipped with around 700 ground stations for receiving satellite data. Again, NPS are not in general use to support meteorological space applications nor are the benefits from these applications uniformly distributed but it seems likely from the substantial scale of investments that each of the WMO member countries would perceive a net positive benefit if the use of NPS proved desirable in the future on technical grounds.

A more difficult future situation could arise if the potential for catastrophe monitoring were exploited using NPS. The GEOWARN[12] study highlighted natural disasters as a cause of annual costs to the world economy in the region of $100B. Preventative and relief measures in respect of floods, hurricanes, draughts, earthquakes, volcanic eruptions and crop devastation by disease or infestation were estimated to have the potential to yield benefits which would easily offset the global risk from the use of NPS in satellites to provide the necessary data. However, the benefits would largely accrue to some 30 countries identified in the study as most likely to be subject to such disasters (column 6 of Table 1) , whilst the risks would be spread among many other countries for whom straightforward justification arguments would be difficult to identify.

A class of mission which has made extensive use of NPS is the exploration of the solar system. These missions have added dramatically to our knowledge, particularly for the outer planets, and would not have been possible without the extensive use of RTG's. If these are to be followed by manned missions to even the nearer planets it seems likely that the higher energy output available from nuclear reactors will be necessary. The global justification for the risks involved by the long term benefits expected from research and exploration should in principle apply at the national level provided the results are published.

An alternative approach to the justification of risk by individual countries, assuming there is adequate global justification, is to invoke the *de minimis* argument. In a previous presentation[7] it has been suggested that annual risks to an individual of less than 10^{-7} or to a coherent group of N people of less than $10^{-7}/\sqrt{N}$ are of little concern and can be ignored. Radiological risks at this level from the use of NPS would not be detectable in any country and might therefore be regarded as acceptable. (In contrast, the physical risks from large items of re-entering debris, nuclear or not, could cause attributable deaths).

For the case of the 45 COSMOS NPS still in orbit, the final column of Table 1 shows the approximate number of re-entries within the territory of each country based on the latitude re-entry probabilities given in Fig. 2. (No allowance has been included for the area of re-entry footprint. This should be substantially less than for COSMOS 954 due to the long period for radioactive decay but could exceed the area of the smaller countries and hence increase their probability of a re-entry impact). The largest number of re-entries are estimated for Russia (about 5) and Canada (around 2 or 3) due to their extensive land area spanning the most probable re-entry latitude. Countries with more than a ~40% chance of a re-entry impact are the USA, China, Brazil and Australia and a further ten countries have more than a ~10% chance of re-entry impact. There is then a very gradual decline in probability among the remaining countries. Assuming each re-entry is detectable and a recovery operation is carried out as effectively as for COSMOS 954, the risk to individual members of the general public seems likely to be below a reasonable *de minimis* level. However, exceptions could arise in remote rural communities if large highly-active components were recovered by unskilled hands.

For the Cassini mission to Saturn planned for launch in October 1997, the draft Environmental Impact Statement[13] indicates that a *de minimis* risk justification case could be sustained. For the preferred Venus-Venus-Earth-Jupiter Gravity Assist (VVEJGA) trajectory, using a Titan IV with a solid rocket motor upgrade and a Centaur upper stage, the post-launch risk arises from an inadvertent re-entry during the earth swing-by with an estimated probability of $7.6x10^{-7}$. If such an event occurred, the number of additional cancer fatalities resulting from the release of plutonium-238 from the three RTG's on board is expected to be 2300 spread over several decades among a population of 5 billion. In statistical terms the pre-launch probability of a single death is the product of these two factors, $1.7x10^{-3}$. The average individual risk is $3.4x10^{-13}$, obtained by dividing by the number of exposed individuals. The highest individual risk is estimated to be $8x10^{-9}$ and all the risks are reduced by some two orders of magnitude if individual doses below 10^{-5} Sv are ignored. Clearly the overall risk to an individual would be below *de minimis* levels.

In summary, a plausible case can be made to justify the risk from the use of NPS in many important classes of mission for most countries. For a minority of countries the risk may not be justified for some classes of mission because they gain little or no benefit, although this problem could be eliminated in most cases if the *de minimis* argument is acceptable. However; some classes of mission could be difficult to justify.

Before concluding this discussion there remains one further consideration arising from the international civil liability provisions which is helpful in meeting the justification principle.

5. Civil liability

Satisfying the justification principle involves weighing improbable consequences against benefits extending into the distant future. A quite different situation arises when space NPS actually impacts the surface of the earth. There may be actual consequences for people and the environment in the vicinity, with consequential costs for clean-up and restoration for which recompense may be sought.

The first international agreement covering liability for nuclear damage in other countries was the 1960 Paris Convention[2], extended by the 1963 Brussels Convention[3], developed under the aegis of the OECD Nuclear Energy Agency to facilitate nuclear international trade. Similar cover was provided under the 1963 Vienna Convention on Civil Liability for Nuclear Damage developed by IAEA[4]. Some rationalisation of the position was introduced by the 1988 Joint Protocol[5] which linked the Paris and Vienna conventions, effectively combining the two sets of provisions. However, there is continuing international debate as to whether these Conventions are adequate in respect of terrestrial NPS[14] and it is doubtful whether any of them apply to space nuclear activities -certainly nuclear propulsion is excluded by provisions concerned with nuclear ships. Moreover, among the countries not party to these Conventions are China, France, India, Russia, Ukraine, the United States and the United Kingdom. Those seeking recompense for damage from a space NPS re-entry must therefore look to the 1972 Convention on International Liability for Damage Caused by Space Objects[15].

This Liability Convention was adopted by the UN General Assembly on 29 November 1971 and entered into force on 1 September 1972. Some 70 countries have acceded to the Convention (at March 1994) by depositing instruments of ratification or accession with the Depository Governments (Russia, UK, USA) and nearly 30 further countries have signed but not yet ratified the Convention. The States party to the

Convention have agreed that a launching State shall be absolutely liable to pay compensation for damage caused by its space object both on the surface of the earth and to aircraft in flight. Provisions are included to deal with joint launches, damage to another space object and failure to agree on the extent of the liability. Exceptions are provided to cover gross negligence or act of omission by the claimant and damage to nationals of the launching State or to foreign nationals participating in the launch.

On a global scale the provisions of the Liability Convention do not help in satisfying the principle of justification. The settlement of a claim under the Convention merely transfers cost from one party to another without increasing the integrated global benefit. But in respect of national justification the provision of compensation for damage, if it occurs, could make a dominant contribution to the balance of risks and benefits seen by an individual country. Effectively, it removes the downside cost from the national equation so that any benefit, however small, makes a net positive national contribution.

Two aspects then remain to be dealt with concerning national justification. Firstly, it still seems necessary to limit the level of risk to third parties even if full compensation is guaranteed. The occurrence of death or injury to persons and/or damage to property from a re-entry may be a traumatic experience for those concerned and it would be unacceptable for that to be a frequent occurrence. Limiting the risk to a *de minimis* level would be an appropriate degree of protection, reflecting the guidance provided by ICRP quoted previously. Secondly, it is not entirely clear that the Liability Convention would apply to claimants not party to the Convention or who ratified the Convention only after damage was caused by a re-entry. Neither possibility seems to be excluded by the text of the Convention but it would seem prudent to invite the Legal Sub-committee to clarify the position.

6. Conclusions

It is considered inevitable that any revision of the safety principles for NPS in space must incorporate the principle of justification, a requirement to demonstrate sufficient benefit to individuals and society to offset the inherent risks. On a global scale it is qualitatively plausible that the collective benefit to the world population from a range of missions - telecommunication, meteorology, earth monitoring, research and exploration - is sufficient to justify the integrated risk even if the satellites involved were to use NPS, which is by no means universally the case at present. Exceptionally there are missions which fail this global net positive benefit test: for the examples identified, this failure is consistent with the accepted view.

In addition to global justification, it is considered that it is necessary to demonstrate national justification for each country at risk. It seems unlikely for most classes of mission that this criterion could be satisfied for all countries - there are inevitably some countries subject to too high a proportion of the risk for too little of the benefit - unless the provisions of the Liability Convention are available to effectively offset the risks and unless the level of risk is acceptably small. This latter condition seems unlikely to be a problem and is in any case desirable to remove any difficulty noted earlier over the variation of benefits within a country. However, it is suggested that the validity of the Liability Convention should be referred to the Legal Subcommittee for the cases of countries not party to the Convention or ratifying the Convention after damage in their territory has occurred from an NPS in space.

The question of international endorsement of the justification for future missions involving space NPS remains to be addressed. Until the safety culture for space NPS is extended to the international level[7] it is suggested that justification for future nuclear space missions, demonstrating quantitatively a net positive benefit, should be presented to the S&T Subcommittee prior to launch.

Fig. 1 - Distribution of orbital inclinations within the catalogued population

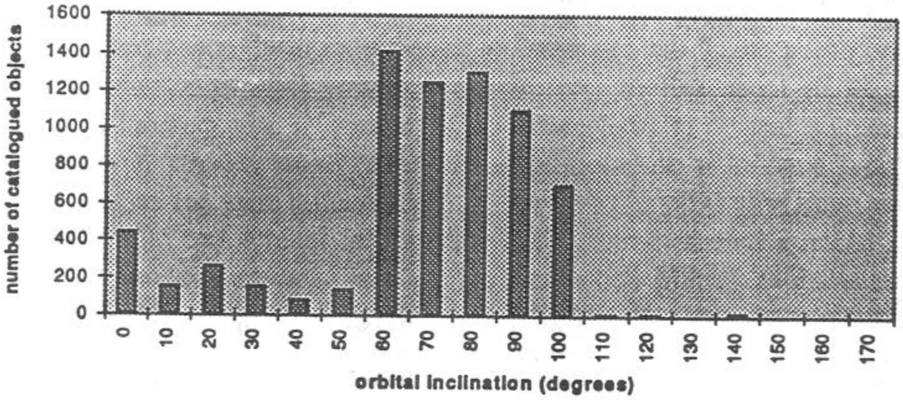

Fig. 2 - Re-entry latitude probability distribution for existing NPS satellites

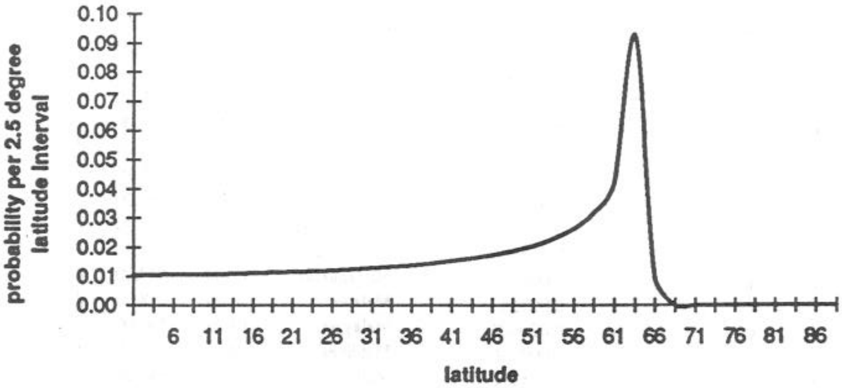

Table 1
Member countries of international organisations involved in space and nuclear activities
and their approximate risk of space NPS impact

Country	Population millions [1]	Area $10^3 km^2$	ITU [2]	WMO [3]	GEO WARN [4]	IAEA [5]	COSMOS NPS re-entries [6]
Afganistan	16.40	652.00	√	√		√	0.041728
Albania	3.30	29.00	√	√		√	0.002378
Algeria	25.00	2382.00	√	√	√	√	0.135774
Angola	10.00	1247.00	√	√	√		0.054868
Antigua-Barb.	0.08	0.40	√	√			0.000019
Argentine	32.60	2767.00	√	√	√		0.190923
Armenia	3.30	30.00	√	√		√	0.002340
Australia	17.10	7687.00	√	√		√	0.407411
Austria	7.80	84.00	√	√		√	0.008820
Azerbaijan	7.00	87.00	√				0.006786
Bahamas	0.25	11.00	√	√			0.000484
Bahrain	0.50	0.60	√	√			0.000032
Bangladesh	109.30	144.00	√	√	√	√	0.007344
Barbados	0.26	0.40	√	√			0.000018
Belarus	10.20	208.00	√	√		√	0.035360
Belgium	9.80	31.00	√	√		√	0.003875
Belize	0.19	23.00	√	√			0.001058
Benin	4.70	113.00	√	√	√		0.004859
Bhutan	1.50	47.00	√				0.002632
Bolivia	7.40	1099.00	√	√			0.051653
Botswana	1.30	582.00	√	√			0.029100
Brazil	153.30	8512.00	√	√			0.425600
Brunei	0.27	6.00	√	√			0.000252
Bulgaria	9.00	111.00	√	√		√	0.009435
Burkina Fasu	9.00	274.00	√	√			0.012056
Burundi	5.50	28.00	√	√			0.001176
Cambodia	8.70	181.00	√	√		√	0.007964
Cameroon	11.80	475.00	√	√		√	0.020425
Canada	26.80	9976.00	√	√			2.663592
Cape Verde	0.37	4.00	√	√			0.000184
Cent.Afr.Rep.	3.00	623.00	√	√			0.026789
Chad	5.70	1284.00	√	√	√		0.059064
Chile	13.40	757.00	√	√	√		0.062831
China	#####	9561.00	√	√		√	0.640587
Colombia	33.00	1139.00	√	√	√		0.048977
Comoros	0.55	2.00	√	√	√		0.000088
Congo	2.30	342.00	√	√			0.014364
Costa Rica	3.00	51.00	√	√		√	0.002244
Cote d'Ivoire	12.00	322.00	√	√		√	0.013846
Croatia	4.70	56.00	√	√		√	0.005320
Cuba	10.60	113.00	√	√	√	√	0.005537
Cyprus	0.71	9.00	√	√		√	0.000603
Czech Rep.	10.40	78.00	√			√	0.009360
Denmark	5.10	43.00	√	√		√	0.008170
Djibouti	0.41	23.00	√	√			0.001012
Dominica	0.08	0.70		√			0.000032
Dom. Rep.	7.20	49.00	√	√		√	0.002352
Egypt	57.00	1001.00	√	√		√	0.055055
El Salvador	5.30	21.00	√	√		√	0.000945
Ecuador	10.80	284.00	√	√	√	√	0.011928
Eq. Guinea	0.35	2.00	√				0.000086
Estonia	1.60	45.00	√	√		√	0.009900
Ethiopia	50.80	1222.00	√	√	√	√	0.053768
Fiji	0.77	18.00	√	√	√		0.000828
Finland	5.00	338.00	√	√		√	0.084500
France	56.60	552.00	√	√		√	0.056304
Gabon	1.20	268.00	√	√		√	0.011256
Gambia	0.86	10.00	√	√			0.000450
Georgia	5.40	70.00					0.005950
Germany	78.50	357.00	√	√		√	0.046410
Ghana	15.00	239.00	√	√	√	√	0.010277

Country	Population millions [1]	Area $10^3 km^2$	ITU [2]	WMO [3]	GEO WARN [4]	IAEA [5]	COSMOS NPS re-entries [6]
Greece	10.30	132.00	√	√		√	0.009900
Greenland	0.06	2175.00					0.304500
Grenada	0.11	0.30	√				0.000013
Guatemala	9.20	109.00	√	√	√	√	0.005014
Guinea	5.80	246.00	√	√			0.010578
Guinea-Bis.	0.96	34.00	√	√			0.001496
Guyana	0.99	212.00	√	√			0.009116
Haiti	6.50	28.00	√	√		√	0.001344
Holy See	0.00	0.00	√			√	0.000000
Honduras	5.10	112.00	√	√			0.005040
Hungary	10.30	93.00	√	√		√	0.009765
Iceland	0.26	101.00	√	√		√	0.045450
India	843.90	3288.00	√	√		√	0.164400
Indonesia	179.30	1905.00	√	√		√	0.081915
Iran	58.00	1648.00	√	√		√	0.088992
Iraq	18.90	438.00	√	√		√	0.028032
Ireland	3.50	70.00	√	√		√	0.010850
Israel	4.80	21.00	√	√		√	0.001281
Italy	57.70	301.00	√	√		√	0.027090
Jamaica	2.40	11.00	√	√	√	√	0.000517
Japan	123.60	378.00	√	√		√	0.028350
Jordan	3.20	89.00	√	√		√	0.005340
Kazakhstan	16.70	2717.00				√	0.326040
Kenya	24.00	580.00	√	√		√	0.024360
Kiribati	0.06	0.70	√				0.000029
Korea DPR	21.80	120.00	√	√			0.009240
Korea Rep.	43.30	99.00	√	√		√	0.006831
Kuwait	2.60	18.00	√	√		√	0.001026
Kyrghyzstan	4.40	199.00					0.016716
Lao	4.10	237.00	√	√			0.011139
Latvia	2.70	65.00	√	√		√	0.013650
Lebanon	3.20	10.00	√	√		√	0.000640
Lesotho	1.80	30.00	√	√			0.001740
Liberia	2.60	111.00	√	√		√	0.004773
Libya	4.50	1760.00	√	√		√	0.095040
Liechtenstein	0.03	0.16	√			√	0.000017
Lithuania	3.70	65.00	√	√		√	0.011700
Luxembourg	0.38	2.00	√	√		√	0.000240
Macedonia	2.20	25.00	√			√	0.002075
Madagascar	11.20	587.00	√	√		√	0.028176
Malawi	8.60	118.00	√	√			0.005310
Malaysia	17.90	330.00	√	√		√	0.013860
Maldives	0.21	0.30	√	√			0.000013
Mali	8.10	1240.00	√	√	√	√	0.058280
Malta	0.36	0.30	√	√			0.000021
Marshall Is.	0.04	0.20				√	0.000009
Mauritania	2.00	1026.00	√	√	√		0.050274
Mauritus	1.10	2.00	√	√		√	0.000096
Mexico	81.10	1958.00	√	√	√	√	0.097900
Moldova	4.40	34.00					0.003570
Monaco	0.03	0.00	√			√	0.000000
Mongolia	2.10	1565.00	√	√		√	0.162760
Morocco	25.10	447.00	√	√		√	0.027267
Mozambique	15.70	802.00	√	√	√		0.037694
Myanmar	39.30	677.00	√	√		√	0.032496
Namibia	1.80	824.00	√	√		√	0.042024
Nauru	0.01	0.02	√				0.000001
Nepal	18.90	141.00	√	√	√		0.007896
Netherlands	15.00	37.00	√	√		√	0.005180
New Zealand	3.40	269.00	√	√		√	0.020982
Nicaragua	3.90	130.00	√	√		√	0.005720

Table 1 (cont'd)

Country	Population millions (1)	Area $10^3 km^2$	ITU (2)	WMO (3)	GEO WARN (4)	IAEA (5)	COSMOS NPS re-entries (6)
Niger	7.70	1267.00	√	√	√	√	0.059549
Nigeria	108.50	924.00	√	√		√	0.040656
Norway	4.20	324.00	√	√		√	0.097200
Oman	2.00	212.00	√	√			0.010176
Pakistan	112.00	796.00	√	√		√	0.046168
Panama	2.50	77.00	√	√		√	0.003311
Pap.Nw.Guin.	3.70	463.00	√	√			0.020835
Paraguay	4.30	407.00	√	√		√	0.020757
Peru	22.30	1285.00	√	√		√	0.055255
Phillipines	62.90	300.00	√	√	√	√	0.013200
Poland	38.20	313.00	√	√		√	0.043820
Portugal	10.50	92.00	√	√		√	0.007084
Puerto Rico	3.60	9.00					0.000423
Qatar	0.37	22.00	√	√		√	0.001144
Romania	23.20	238.00	√	√		√	0.023800
Russia	148.10	17075.00	√	√		√	4.951750
Rwanda	7.20	26.00	√	√			0.001092
Samoa	0.17	0.20	√				0.000009
San Marino	0.02	0.06	√				0.000005
Sao Tome-Pr.	0.12	1.00	√	√			0.000042
Saudi Arabia	10.50	2150.00	√	√		√	0.109650
Senegal	7.30	197.00	√	√		√	0.009062
Seychelles	0.07	0.40		√			0.000017
Sierra Leone	4.20	72.00	√	√		√	0.003096
Singapore	3.00	1.00	√	√		√	0.000042
Slovakia	5.30	49.00	√			√	0.005880
Slovenia	1.90	20.00	√	√		√	0.002000
Solomon Is.	0.32	30.00	√	√			0.001290
Somalia	7.50	638.00	√	√	√		0.027434
South Africa	35.30	1221.00	√	s		√	0.068376
Spain	39.00	505.00	√	√		√	0.042925
Sri Lanka	17.00	66.00	√	√		√	0.002838
St.Lucia	0.15	0.60		√			0.000027
St Vincent	0.11	0.40	√				0.000018
Sudan	25.20	2506.00	√	√	√	√	0.112770
Surinam	0.42	141.00	√	√			0.005922
Swaziland	0.77	17.00	√	√			0.000918
Sweden	8.60	450.00	√	√		√	0.193500
Switzerland	6.70	41.00	√	√		√	0.004223
Syria	12.10	185.00	√	√		√	0.012210
Taiwan	19.70	36.00				√	0.001836
Tajikistan	5.20	143.00					0.011154
Tanzania	25.60	945.00	√	√		√	0.040635
Thailand	54.50	513.00	√	√		√	0.023598
Togo	3.50	57.00	√	√	√		0.002451
Tonga	0.09	0.10	√				0.000005
Trinidad-Tob.	1.20	5.00	√	√			0.000220
Tunisia	8.20	164.00	√	√		√	0.010496
Turkey	58.70	779.00	√	√		√	0.056088
Turkmenistan	3.60	488.00					0.035624
Uganda	16.60	236.00	√	√		√	0.009912
UK	55.50	245.00	√	√		√	0.051450
Ukraine	51.80	604.00	√	√		√	0.069460
U.A.E.	1.60	84.00	√	√		√	0.004284
Uruguay	3.10	177.00	√	√		√	0.010974
USA	248.70	9373.00	√	√		√	0.712348
Uzbekistan	20.30	447.00	√	√			0.036207
Vanuatu	0.15	15.00	√	√	√		0.000690
Venezuela	19.70	912.00	√	√		√	0.039216
Vietnam	66.20	330.00	√	√	√	√	0.014850
Yemen	12.00	528.00	√	√			0.024288
Yugoslavia	12.50	127.00	√	√		√	0.011430
Zaire	35.60	2345.00	√	√		√	0.100835
Zambia	7.80	753.00	√	√		√	0.033885
Zimbabwe	9.40	391.00	√	√		√	0.018377
							14.659533

Footnotes

1) Variously 1989-1991 population data
2) International Telecommunication Union member governments at 31 August 1992
3) World Meteorological Organisation member governments at 14 January 1993: s - membership suspended
4) Potential major users identified in the GEOWARN study
5) Member States at September 1994
6) Approximate number of the 45 NPS currently in orbit which will re-enter within the latitude and area of each country (see text)

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