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**STUDIES IN RADIATION RISK CRITERIA
FOR SNAP SYSTEMS**

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ABSTRACT

Based on currently available information, a radiation risk criterion of 0.01 fatality, or 750 man-rem, per launch of SNAP systems is suggested as acceptable in light of normally incurred risks.

*NOTE: This paper was presented by M. A. Parsont at the American Industrial Hygiene Association Meeting at St. Louis, Missouri, May 13-17, 1968. This report was distributed in June 1969.

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TABLE OF CONTENTS

	Page
Introduction	5
Discussion	5
Radiation Risk	8
Whole Body Irradiation	8
Internal Organ Irradiation	10
Conclusions	11
REFERENCES	13

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STUDIES IN RADIATION RISK CRITERIA FOR SNAP SYSTEMS

Introduction

The following approach to radiation risk criteria for SNAP systems is an attempt to provide reasonable and workable criteria that will be useful in measuring the safety of any SNAP system early in its design stages. It should be pointed out, however, that the decision to launch a SNAP device is a "risk-benefit" decision made by the AEC and the space council, and use of the criteria presented here does not signify approval or disapproval of any system. These criteria have been useful to us in our studies at Sandia Laboratories, and we hope they will be useful to others who must evaluate the risks of any similar system.

Discussion

Many approaches to radiation criteria are based upon the concept of constant individual risk. The use of this concept is interesting and gives some insight into the range of values that any criteria should meet. However, the concept of constant individual risk is difficult to apply and is not consistent with the risks in our present society. For example, the individual risk to several hazards can be changed appreciably by choice of location.

A person living adjacent to a nuclear power plant has a much larger radiation risk than a person living a thousand miles away. A city dweller has a higher risk from air pollution and vehicular accidents than does a rural dweller. Individual risks can also be changed by choice of occupations or habits. It appears that individual risks are far from constant in the world, and the use of constant risk criteria on SNAP systems would place undue importance and restrictions on launch situations which involve few people.

The criterion that appears to be the most useful and meaningful in a probabilistic safety analysis is the "expected number," $\langle E \rangle$, to receive a fatality or some dose. The term "expected" is used in a mathematical

context which might be misleading to some. It is best described as a probability weighted number, $\langle E \rangle = PN$, where the expected number $\langle E \rangle$ is the product of the probability of the event, (P), and the number of people involved, (N), if the event occurs. In order to choose an expected number for SNAP operations, it is useful to compare expected numbers from comparable ventures. These values are given in Table I.

TABLE I
Expected Numbers

Hazard	Individual risk (per yr)	Population size	Expected number of fatalities (per yr)
Cancer (U. S.) (1)*	1.6×10^{-3}	2×10^8	3.2×10^5
Auto accidents (U. S.) (2)	2.3×10^{-4}	2×10^8	4.6×10^4
Aircraft accidents (U. S.) (2)	5×10^{-6}	3.8×10^7	1.9×10^2
Aircraft bystanders (U. S.) (2)	6×10^{-8}	2×10^8	1.2×10^1
Radiation (somatic) risk from 1 rad (U. S.) (1)	4×10^{-5}	2×10^8	8×10^3
Radiation background (U. S.) (1)	5×10^{-6}	2×10^8	1×10^3
Radiation (somatic) risk from 5 rads (U. S.) (1)	10^{-4}	2×10^8	2×10^4
Radiation (genetic) risk from 1 rad (U. S.) (1)	10^{-4}	2×10^8	2×10^4
Meteorite impact (2)	6.7×10^{-12}	3×10^9	2×10^{-2}
Snake bite (world) (3)	1.3×10^{-5}	3×10^9	4.0×10^4
Lightning (U. S.) (2)	7.5×10^{-7}	2×10^8	1.5×10^2

*Numbers in () refer to references.

Since the risk estimates in Table I are on a per year basis and the SNAP risks are per launch, a reasonable value of the expected number for SNAP ventures might be between 0.01 and 1. Since these risks are third-party risks and several SNAP launches could occur in one year, the value 0.01 was chosen. The criterion, considering all hazard paths, can be stated thus:

$$\langle E \rangle = 0.01 \text{ (the expected number of fatalities per launch)}$$

$$\langle E \rangle = \sum_{i=1}^n P_i N_i P_i^A \text{ for } n \text{ events}$$

or

$$\langle E \rangle = P_1 N_1 P_1^A + P_2 N_2 P_2^A + \text{-----} + P_n N_n P_n^A$$

where

$\langle E \rangle$ = the expected number of fatalities per launch

P_i = the occurrence probability for event i

N_i = the number of people involved in event i

P_i^A = the probability of an individual in N_i actually receiving a lethality from event i , given the event occurs.

Note that there could be several events in each accidental or planned release of fuel. The next step is to relate this expected number in terms of dose.

Radiation Risk

Whole Body Irradiation

The risks from whole body irradiation are both genetic and somatic. Genetic considerations would appear to be the controlling risk since the exposure of a parental generation of one million persons to one rad is estimated to result in 2000 genetic deaths over 10 generations; this is considered to be the possible upper limit of the total genetic injury.⁽¹⁾ The above equation yields a dose response function having a value of:

$$\frac{2 \times 10^3}{1 \times 10^6} = 2 \times 10^{-3} \text{ deaths person-rad}^{-1} .$$

Since these risks occur over a 300-year period, the adjusted value on a yearly basis is: 6.6×10^{-6} deaths person-yr-rad⁻¹ (for simplification of computation, a constant death rate is assumed).

The somatic risk is to whole body radiation and is composed almost entirely of leukemia and other fatal neoplasms. The risk is reported to be 40 cases from the exposure of one million persons to one rad.⁽¹⁾ These risks are experienced over a 10- to 20-year time period, and the dose response function becomes

$$\frac{40}{1 \times 10^6 \times 10} = 4 \times 10^{-6} \text{ deaths person-yr-rad}^{-1} .$$

Therefore, the genetic and somatic risks are approximately equivalent on a yearly basis. The value needed for a valid safety criterion is the total risk from giving so many total man-rads. The genetic risk is most difficult to assess, since it is questionable whether this type of death has the same social and personal importance as, for example, the death of an adult or child from leukemia. The use of the genetic risk value leads to a very conservative allowable dose per launch of 5 man-rem. Therefore, the most reasonable risk value available, which will be used at present, appears to be that of leukemia induction. This value is 4×10^{-5} deaths person-rem⁻¹.*

*"Person" is used in the same sense as "man"; "rem" is used to account for the relative hazards of various types of radioactive emissions.

We have previously stated that the criterion to be used is 0.01 expected fatalities per launch. The units of PND, "expected man-rem," when multiplied by the above dose response function of 4×10^{-5} deaths person-rem⁻¹ yield expected deaths per launch, which can be related to the criteria. Therefore:

$$\sum_{i=1}^n P_i \text{NiDiF} \leq 0.01 \quad \text{for } n \text{ events}$$

where

$$F = 4 \times 10^{-5} \text{ deaths person-rem}^{-1}$$

D = dose (rem) or greater

The total expected man-rem per launch allowed by the criteria becomes 250.

Internal Organ Irradiation

Evaluating risks from internal organ irradiation with respect to establishing a single dose response function is complicated by problems such as dose rate effects, distribution of radionuclides in an organ, general health of the exposed individual, different types of radioactive emissions, varying organ sensitivity, etc. The sources of information upon which one can draw in the attempt to establish such a function are varied, but no individual source, at least at the present time, yields complete or sufficiently accurate data. These sources are as follows.

- 1) Animal exposure data: The difficulties here rest in the validity of extrapolating effects to man and in obtaining information on the effects of low doses.
- 2) Human medical and accidental exposure data*: Other than the radium dial painter incidents, upon which the MPBB of bone-seeking radionuclides is now based, very little information

*There are some data available on the external irradiation of children for enlarged thymus glands, external irradiation for treatment of ankylosing spondylitis, and children irradiated in utero.

is available on the intake by ingestion of large quantities of radioactive material. Medical usage of radionuclides, other than misuse of Ra tonics, etc., in the 1900's, is either in trace amounts from which doses are so low as to lead to undetectable effects or is in amounts so large so as to purposefully destroy infected tissues. Accidental internal exposures to radioactivity have not occurred in the community in sufficient magnitude, with sufficient knowledge of dose or without prompt treatment to reduce the hazard to the individual involved, to evaluate responses.

- 3) Fallout and weapons exposure: In these cases, the dose to humans was either primarily from total body irradiation in which dose estimates were uncertain or, in the case of internal irradiation, the dose was so small as not to produce a statistically detectable increase in any biological end point.
- 4) Uranium-miner mortality data: Dose response functions based on uranium-miner mortality data are not easy to compute because, even in recent times, the doses received by these individuals have not been accurately determined. Certainly estimates of doses received in past incidents of lung mortality in uranium-miners (Schneeberg and Joachimstahl) are more gross. The radioactive materials to which these individuals were exposed are quite well known, but accurate descriptions of their distribution in the body are not available. The presence of α , β , γ radiation complicates the picture.
- 5) Lung tumor induction using data on skin tumors: Dose response functions presently derived from lung tumor induction models were compiled primarily for Aerospace Nuclear Safety purposes to estimate the probability of occurrence of lung cancer from inhaled α particle emitters. One such model, developed by P. Dean at LASL, was based on skin-tumor data of Albert and co-workers at N.Y.U.⁽⁴⁾ In order to obtain the total tumor probability, the model calculates the tumor-formation probability of each individual cell exposed to the radiation and then sums over all exposed cells.

- 6) ICRP commensuration factors between whole body radiation and internal radiation exposure: The use of a commensuration factor between whole body and internal organ exposure is the easiest approach to the problem, but it is probably the poorest. Since the ICRP recommends a whole body limit of 5 rem per year and a lung exposure of 15 rem per year, the implied difference in risk is reduction by a factor of 3. If we decrease the leukemia risk value previously described by this factor, we have 1.3×10^{-5} deaths person-rem⁻¹. Using the previously given equation for expected number and this dose response function, we find that the total expected man-rem per launch allowed by the criterion is 750.

Conclusions

For those who accept the threshold theory of dose-effect response, the previous discussion utilizing a linear relationship between dose and effect may be conservative. However, the linearity of response in the whole-body case, considering genetic effects and leukemia induction, is much better substantiated than is the linearity of response after the exposure of individual organs by alpha emitters. Nevertheless, it seems prudent at present to accept the linear dose-effect response for both cases.

A threshold approach could be employed by selecting a maximum lifetime dose commitment for the general population and apportioning a certain fraction of this total for each using agency. This apportionment has been attempted by the ICRP only in the case of genetic risks. The expected number value chosen is considered to be conservative by a factor of 10 to account for multiple launches per year and third-party risks.

The expected numbers of people to receive doses D or greater are stated matter-of-factly in the text. Actually, the accuracy of these numbers depends upon a thorough safety analysis using knowledge of the probability of events, population distribution functions, radiation density functions, source depletion functions, and the interrelationship of these variables.

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