RADIATION PROTECTION GUIDELINES FOR RADIATION EMERGENCIES

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I will discuss the system of dose limitation and present guidance for emergency workers and for intervention on behalf of the public.

DOSE LIMITATION

There are three elements for the system of dose limitation: justification, optimization, and dose limits. The first element, justification, is basically a political process in this country. Justification is based on a risk-benefit analysis, and justification for the use of radioactive materials or radiation is generally not within the authority of radiation protection managers. Radiation protection managers typically assess detriments or harm caused by radiation exposure and have very little expertise in assessing the benefits of a particular practice involving nuclear material. However, there are a few practices that are easy to rule out, such as not permitting the use of a radioactive toy or radioactive jewelry. But outside of obvious practices that give little or no benefit, society generally performs the justification procedure through the political system.

The second element in the system of dose limitation is optimization. The optimization procedure follows the recommendation of the International Commission on Radiological Protection (ICRP) that all doses be kept as low as reasonably achievable, often termed "ALARA," which is synonymous with optimization. ALARA is simply weighing the cost of radiation detriment against the cost of a protective measure. There are many indirect costs aside from those of health costs, including those related to insurance, public relations, hiring and training personnel, and protective equipment. In the United States, we are willing to pay $100 to $10,000 to reduce one man-rem of detriment. This value judgment translates to between $600,000 and $60,000,000 per statistical life. Making such calculations might seem a bit cynical or inhuman, but remember that this cost-detriment analysis is not used in the justification process but in the optimization process. Society has justified the use, and radiation protection managers must ensure that the use leads to doses that are ALARA.

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The third part of the system of dose limitation is dose limits. The system should be implemented in the priority given here. In general, one needs dose limits because the risk and benefits are distributed between two different groups of people. If the people who were receiving the benefit were the same people taking the risk, the justification and optimization procedures would be adequate for radiation protection. Since these groups are different, with the exception of medical applications of radiation, we need dose limits.

Dose limits are upper bounds to the justification process. They are not used as a primary basis for planning or design; rather, ALARA is used. Certainly you have heard this during previous sessions and I will just state it briefly: Dose limits are designed to prevent early or nonstochastic health effects and to limit the probability of stochastic effects to levels that are acceptable. Early or nonstochastic effects of radiation include bonemarrow cell depletion, impairment of lung function, skin damage, and cataracts. These are effects that vary with the dose and for which a threshold may occur. Dose limits are set below the relevant threshold. The long-term or stochastic effects include the increased incidence of cancer, which may be spread over several decades following exposure, and inherited and demonstrated genetic effects that occur in the offspring of the exposed person. The dose equivalent of rems to the whole body is generally the most suitable radiation protection unit used to limit the stochastic effect.

In the ICRP system, the risk of fatal cancer and severe genetic effects in two generations of offspring should be no greater than the risk of fatal injury in safe industries. The truncation of risk after two generations is related to the impact of genetic effects on the exposed worker, that is, he or she is generally still alive to see these effects in his or her offspring. The ICRP recommends a limit of 5 rem per year for workers and this limit is associated with stochastic risk. ICRP indicates the risk factor is 0.0002 (2×10^{-4}) mortalities and genetic effects per rem. Others have indicated that numerical values for this risk factor are slightly different. There is a factor of two for associated uncertainty.

For safe industries, the risk of death is presently 0.0001 per year. The dose limit incurs or results in an average risk of about 1×10^{-4} mortalities each year. The U.S. Environmental Protection Agency determined that the average dose for all monitored radiation workers in the United States is 0.3 rem. The implied risk at the 5 rem per year annual limit is very high compared to the safe worker risk; however, because of the ALARA principle, a dose near the limit is fairly rare. Limits really indicate a region of undisputed unacceptability rather than a guide for the dose that might be acceptable.

The annual limit for prevention of nonstochastic effects is 50 rem for any organ or tissue except the lens of the eye. This is based on a lifetime threshold of 2,000 rem. Actually, the threshold is 2,000 rad; however, ICRP prefers to use 2,000 rem as the basis for the nonstochastic limit. (In our discussion, the rem and the rad are used interchangeably.)

In addition to doses that might be received in the course of normal work operations, there may be some operations in a nuclear facility where a higher dose is necessary. Thus, flexibility is needed in a 5 rem per year system. Doses greater than 5 rem per year, which is called the planned special exposure, are to be used only in exceptional situations when alternatives that might avoid the higher dose are unavailable or impractical.

In 1977 the ICRP recommended a limit for the lifetime accumulation of planned special exposure of 25 rem. The single event limit is 10 rem, which is independent of the 5 rem per year annual dose system. In the United States, the draft Code of Federal Regulations 10 CFR part 20 also specifies a dose limit of 10 rem per planned special exposure, but the annual limit must be included in this system. Thus, the dose received from routine operations plus the dose from planned special exposure must not exceed 10 rem. The draft planned special exposure lifetime limit is 25 rem. In order to have a planned special exposure accepted by the Nuclear Regulatory Commission (NRC), the Code of Federal Regulations specifies that the dose must be as low as reasonably achievable. This same recommendation is made by the ICRP and the National Council on Radiation Protection and Measurements (NCRP).

ICRP Publication 40 provides guidance for an emergency. I list guides in the order of priority. One should try to stay within the occupational limit. If one cannot, planned special exposures should be tried, and, finally, if one cannot meet that particular limit, volunteers with knowledge of the risk should be used. The aim, however, is to keep exposures to the whole body below 50 rem. At the 50 rem level, one would not expect the nonstochastic effect of vomiting.

Radiation damage to bone marrow may be the most important lethal effect following unintended releases from nuclear power plants, given the composition of radioactive materials that are likely to be released from these plants. The threshold for nonstochastic radiation damage to the bone marrow is 100 rad. That is, a small fraction of the population may be very radiosensitive, and death may occur from as little as 100 rad to the bone marrow. Threshold doses are the basis for intervention. There is one other threshold dose that you should be aware of and it is for radiation in utero. The median lethal dose for radiation in utero is between 100 and 300 rad. Additionally, serious mental retardation has been noted for radiation in utero between the ages of eight and fifteen weeks. The risk factor for mental retardation is 4×10^{-3} per rem, and it may occur without threshold. In addition, the fatal cancer risk, a stochastic effect associated with radiation in utero, is between 2×10^{-4} and 3×10^{-4} per rem, which is slightly higher than that for adult workers.

The ICRP has issued guidance for risk factors for fatal cancers and hereditary effects. They list risk factors for irradiation of specific tissues. These risk factors are used for the purpose of associating health effects with the dose limits for radiation protection. Low-dose risk factors have been adjusted downward to reflect the fact that low doses and dose rates produce lower frequencies of effects. That is, this frequency is lower than the frequency observed for the high doses and dose rates for which health effects were originally quantified. In principle, risk factors should be adjusted upward for emergencies involving high doses over a short period of time. However, uncertainty in the dose resulting from an emergency is likely to be much greater than uncertainty in the risk factor, and adjustment is not warranted.

For many emergency situations, certain organs may be irradiated preferentially, for instance the thyroid. The incidence of nonfatal thyroid cancers and thyroid adenomas should be considered, because these effects have both physical and psychological impacts. Follow-up and treatment will have additional health impacts, for instance, thyroid surgery.

The NCRP will issue guidance on emergency dose limits in 1987. They will recommend that for non-lifesaving activities, 10 rem is permissible or acceptable; for example, if you are a firefighter and are fighting fires in order to reduce property losses, it is acceptable to receive up to 10 rem. Receiving a dose above 10 rem is acceptable only if lifesaving is involved. The NCRP will indicate that volunteers are very desirable for the prevention of fatalities and will indicate that these volunteers need information on the nonstochastic effects associated with dosage greater than 100 rem and on the fatal cancer risk, which is between 1 and 2 chances out of 100 for doses of approximately 100 rem.

It is essential that these persons be given this information beforehand. For example, a fire-rescue person generally has no expertise to judge whether saving a life will be worth the risk if he received this information at the time of the emergency. Additionally, the life-saving attempt may not be successful and this factor must be weighed against the potential risk from radiation exposure. The NCRP will also suggest that older workers with a low lifetime-accumulated dose be used in high dose situations. I am told that older workers can act faster anyway because of their greater experience.

Severe nuclear-energy emergencies involve exposure of populations. However, routine operations also expose populations to low levels of radiation. For controllable situations, the recommended limits cited by the NCRP for the public are: 0.1 rem per year for continuous exposure and 0.5 rem per year for occasional periods of time. These occasional periods may be a few years; however, the average should be 0.1 rem per year over a lifetime. This is based on an accepted fatality risk of between 1×10^{-4} and 1×10^{-5} per year, which is the same level of risk that the public is normally exposed to when driving a car.

INTERVENTION

For severe radiation emergencies, intervention is going to be needed. This intervention is not related to the dose limits that limit stochastic effects but to avoidance of serious nonstochastic effects. Since all intervention techniques are countermeasures that interfere with normal living conditions, countermeasures must achieve a positive net benefit when they are instituted. For example, there is a mortality risk associated with evacuation, and this must be less than the mortality risk associated with the whole-body dose that is averted by evacuation. The risk associated with taking a blocking agent like stable iodine must be less than the risk associated with the intake of radioactive iodine. These first two considerations relate to the individual and should be considered prior to making a decision about a countermeasure.

There are several basic principles for decision making. An upper dose level is the point at which a countermeasure must be introduced, that is, the level at which serious nonstochastic effects are predicted to occur from the dosage. There is a lower level at which the introduction of a countermeasure will produce more detriment than the dose that is averted. Below that level you would not introduce the countermeasure. Between the lower dose level and the upper dose level is where the optimization process generally can be applied. Because of the time scale involved in severe nuclear-energy emergencies, optimization will probably not be used. Instead, a countermeasure likely will be introduced based on the potential for a high dose. Use of a countermeasure would depend on the unstable situation or condition at the nuclear plant, and the perception of rapidly deteriorating conditions may precipitate the early introduction of a countermeasure.

The ICRP provides numerical guidance for dose equivalent levels for countermeasures. Countermeasures such as sheltering and stable iodine administration are accepted by many national authorities and constitute a small risk to the individual, that is, if sheltering occurs for a few hours or less. Once you shelter for longer periods, you begin to incur greater detriment than you avert.

The dose limit for the general public, 0.5 rem per year, constitutes the lower level for introduction of countermeasures such as sheltering and stable iodine administration. For doses projected to be below 0.5 rem per year, countermeasures are not necessary. For the radiation worker, the lower level for introduction of a countermeasure is 5 rem. For sheltering and stable iodine administration, ICRP felt that ten times these lower dose levels would constitute justifiable upper dose levels and, therefore, 5 rem and 50 rem were chosen for the upper dose levels for the general public and the worker, respectively.

Evacuation is a very disruptive countermeasure. It has detriment associated with it, and the lower level of dose justifying its introduction is fairly uncertain. However, the upper dose level is fairly certain since it is at the level that avoids nonstochastic effects. The ICRP lists the level as 500 rem to any organ. There is an exception to this of which you should be aware. In many situations a rad is equal to a rem, but among the exceptions is the dose to the lung from alpha radiation. In order to meet the ICRP criteria for alpha irradiation of the lung for acute exposure, one would take the rad dose and multiply it by 10. Thus, for alpha radiation, 50 rad to the lung is the numerical equivalent of 500 rem to the lung. Thus, 50 rad to the lung from alpha radiation would be the upper level for evacuation as a countermeasure. (These dose levels for the evacuation, shelter, and use of stable iodine as countermeasures are from ICRP Publication 40.)

For the intermediate phase after an emergency, there are other countermeasures that can be taken to avert the dose that might be received in the first year. For control of foodstuffs, the lower level is the dose limit to the general public, and the upper level is ten times this, which again is thought to be justifiable. For relocation pending decontamination, the lower level is the annual dose limit for radiation workers. Relocation pending decontamination considerations depends a great deal on the type and number of people involved. The upper limit is simply that which avoids serious nonstochastic effects. There may be a reason to stay in a seriously contaminated area; for instance, there may be some activity or occupation required in the national interest, and one may want to exceed the lower level for workers. However, no situation should require one to exceed the upper level. For organ doses following inhalation or ingestion, there is no guidance given for the intermediate phase because internal exposures of organs can be averted by using respiratory protection or by avoiding contaminated foods.

In addition to ICRP guidance, there are protective action guides for the public that are given by the Environmental Protection Agency (EPA) for whole-body exposure to airborne radioactive material. The protective actions are unspecified. If the whole-body gamma dose for the general public is projected to be between 1 and 5 rem, some protective action <u>must</u> take place. This range does not imply an optimization procedure. If the dosage is projected to be 1 rem and there are no serious constraints, one <u>must</u> institute the protective action.

For emergency workers, the EPA indicates an upper level of 25 rem for special planned exposures and of 75 rem for life-saving activities. For the general public, the EPA suggests protective actions for doses between 5 and 25 rem for inhalation of radioactive iodine. Local constraints may make the lower values fairly impractical to use. In no case, however, should the higher values be exceeded in determining the need for a particular protective action. There is no upper level of thyroid dose given for the life-saving activities because it is felt that loss of the thyroid in order to save a life is acceptable. I wish to point out that ICRP and EPA have fairly similar philosophies.

In addition to EPA, NCRP, and ICRP guidance, there are other interested groups that may regulate food and drugs or may regulate transportation of radioactive materials. For example, the Food and Drug Administration has established response levels for I-131 in milk (Response levels for I-131 in milk. Fed Reg 1982;47:47073-47083).

In summary, serious nonstochastic effects should be avoided by the introduction of countermeasures. The level of stochastic effects should be limited by the introduction of countermeasures having a net benefit and should be further limited by as low as reasonably achievable considerations, even if upper-level doses for countermeasures such as shelter, evacuation, and stable iodine administration are not reached.