No. S-28-94
Tel. 301-415-8200

Remarks by Dr. E. Gail de Planque
Commissioner, U.S. Nuclear Regulatory Commission
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In Search of . . . Background

It is a pleasure to be here this morning at the NRC Workshop on Site Characterization for Decommissioning. I'm so pleased to see so many in attendance because I think that the issue of decommissioning is one of the most significant issues on the Commission's plate, one that will have long lasting and far reaching impacts.

Introduction

As you know, the NRC is undergoing a lengthy process aimed at formulating radiological criteria for the decommissioning of NRC-licensed facilities. During that process, extensive discussions have focused on four possible approaches to this task: (1) establishing an annual risk or dose limit for an individual; (2) establishing an annual risk or dose goal; (3) requiring use of the best available technology; or (4) requiring return of the site to background radioactivity. While many commenters preferred a risk-based or dose-based standard, many others favored the "return-to-background" approach.

The proposed rule attempts to accommodate both groups by establishing a dose limit for release of the site of 15 millirem per year Total Effective Dose Equivalent (TEDE) for residual radioactivity distinguishable from background with further reductions As Low As Reasonably Achievable, or ALARA.

First, an aside. To make life easier, I will usually use the quantity total effective dose equivalent expressed in units of mrem. But for brevity's sake, I will use the term "dose" when speaking of total effective dose equivalent.

The objective expressed in the proposed rule is to cleanup up to dose levels that are indistinguishable from background. Return to background!

Sounds good, doesn't it? On the surface, this seems like a relatively easy, common-sense approach: for example, survey a nearby spot unaffected by a nuclear facility, use that radiation level as a baseline, clean up the contaminated site to that level, and . . . voila! The site is decommissioned, the method indisputable, the job completed.

But, as we all know, the devil is in the details. And in this case, the devil could produce a series of torments for those involved in returning a site to background.

I'd like to discuss some of the details with you this morning, particularly the details that are relevant to determining what background is and how it is measured. But I'd also like to place this discussion of the details within the broader context of a regulatory decision-making process.

Risk-Based Decision-Making

The decision-making process I'm referring to is "risk-based" decision-making, a process gaining popularity both in the Clinton Administration and in Congress, and widely advocated by the most recent Supreme Court member, Justice Stephen Breyer. Let me say at the outset that as far as I know this particular mode of making decisions was not followed in any rigorous way in formulating the proposed rule. Nevertheless, for reasons which I hope will be clear later in this talk, it may offer a useful framework for working out the details of a decommissioning program.

Risk-based decision-making allows for the assumption that the resources available for limiting risks are not inexhaustible and seeks to ensure that the resources which are available to society as a whole will be put to the best overall use considering risk, cost and benefit. It can be divided into three basic components as illustrated by the following Sydney Harris cartoons: (1) risk assessment, (2) selection of an acceptable level of risk, and (3) risk management. In the context of decommissioning, risk assessment is an evaluation of the hazard associated with residual radioactivity remaining at a site released for unrestricted or restricted use. Selection of an acceptable risk level involves weighing the benefits of lowering risk to a certain level against the costs and may involve comparing the risk at issue with other similar risks confronting society. Risk management consists of a regulatory process designed to keep the risk below the level found to be acceptable.

Risk Assessment

As the NRC begins to formulate a regulatory program to manage the risk associated with sites cleaned up to levels of radiation contamination that are indistinguishable from background, it might be useful to revisit Step 1 of the risk-based decision-making process: risk assessment. Perhaps this can most easily be done by reviewing the levels of radiation to which humans are typically exposed and the health consequences of those levels.

Broadly speaking, the average American's annual radiation dose is attributable to two sources: naturally occurring radiation which, in the U.S., produces about 82% of the dose, and anthropogenic radiation which produces the remaining 18%. Humans are bathed in a sea of naturally-occurring radiation which has been present since the formation of the earth. About 56% of the average annual dose is from radon and its decay products. Another 11% is from other internal sources, mainly from inhalation and ingestion of food and water which contain naturally occurring radioactive elements. The remainder is from external sources, about 7.5% from cosmic rays and about 7.5% from terrestrial gamma ray sources such as uranium, potassium, and thorium, that are present naturally in soil and rocks.

Just to complete the picture, let's look at the anthropogenic sources. About 11% of the average annual dose comes from medical x-rays, about 4% from nuclear medicine, and about 3% from consumer products such as smoke detectors. The small remainder is from fallout from weapons testing, and occupational exposures at various nuclear facilities.

The proposed rule defines "background radiation" as:

> radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); and global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents like Chernobyl which contribute to background radiation and are not under the control of the licensee.

Although naturally-occurring radiation and fallout from atmospheric weapons testing and the Chernobyl accident are present everywhere, each of these components of what I'll refer to as background, and the corresponding dose delivered, is by no means constant. Background levels fluctuate significantly due to various physical phenomena that differ from place to place and change with time at any given place. For example, over the long-term, cosmic radiation varies by about 10% over the 11 year solar cycle. Seasonal cycles produce changes in soil moisture, rainfall, snow cover, and evapotranspiration that cause variations in the dose from terrestrial gamma radiation, fallout and radon. Many sporadic geophysical phenomena, volcanic eruptions or earthquakes for example, can also introduce radioactivity into the environment.

Temporal variations can also occur over the short term. Rain, for example, will wash out radon and other radionuclides from the air causing an immediate rapid increase in dose that typically decreases exponentially after the rain stops. Doses from radon typically exhibit a diurnal cycle due to local climate conditions.

Radiation varies spatially. The dose from cosmic radiation is a function of both latitude and altitude. The population of the city of Denver, at an altitude of a mile receives an annual cosmic ray dose that is a factor of 2 higher than the U.S. average. Terrestrial gamma radiation, including fallout, varies from place to place because of differing amounts of uranium, potassium and thorium in the earth's surface material and can easily differ by a factor of 10 across the country. Granite, for example, contains higher than average uranium concentrations and monazite sands can have particularly high concentrations of thorium. Furthermore, humans sometimes alter soil content with fertilizer which contains varying amounts of potassium-40. Spatial variations occur locally as well; the well-known Reading Prong in New Jersey provides an interesting regional example. The average annual dose from gamma radiation is approximately 50 mrem but if one resides closer to the rock formations along the prong, the annual dose can be much greater. About sixty miles away at the New Jersey shore, the gamma radiation dose levels fall to less than 10% of the average measured over the Prong.

Even in the immediate environment of a typical facility site (this happens to be Shoreham, Long Island), significant fluctuations occur (Figure 1). For this site with an annual average terrestrial gamma dose of about 35 mrem, when measured simultaneously, levels varied by more than 50% over a distance of only a mile within the site boundary, and the areas within a 4- or 5-mile radius of the site exhibited variations with even greater extremes.

This site in rural New Jersey, used as a background monitoring station, is only 50' by 200' (Figure 2). And even within such a small area, simultaneously measured terrestrial gamma radiation dose levels, which average about 125 mrem per year, differ by as much as 30% from spot to spot. That translates into differences of close to 40 mrem per year.

Other local variations occur due to the types of houses and buildings in which people live and work. Persons living in a wood frame house usually receive lower doses than persons living in an all brick house because, even though brick is a better shield of outdoor radiation, it has higher concentrations of naturally occurring radioactivity than wood. Persons working in granite and marble buildings may receive higher doses due to the radioactivity in the stone. Even moving from a rural to an urban setting may increase an individual's annual dose, due to the level of radioactivity present in concrete. The dose from cosmic rays can be measurably higher on the top floor of a high rise than on the ground floor. Measurements in a 12 story building in Manhattan indicated a cosmic ray dose on the ground floor one third that on the 12th floor, due principally to the shielding effect provided by many stories of concrete from the building in question as well as adjacent structures. In addition, a person's annual dose from radon can vary dramatically, by a factor of 10 or more, depending upon where they are and the adequacy of ventilation.

To further complicate matters, these temporal and spatial variations can be interdependent. For example, determining the average annual dose received from terrestrial gamma radiation cannot be done simply by measuring differences in soil concentration, since it is also affected by weather conditions. Moreover, usage must be considered and can result in what is often referred to as technologically enhanced natural background radiation. Finally, the actual dose to particular humans is heavily dependent upon the specific external and internal pathways of exposure.

Obviously then, there is no single number that represents the annual dose to U.S. citizens from background. But for perspective, it is useful to know that the average annual background dose for the U.S. population is about 300 mrem with about 200 mrem from radon, about 40 mrem from other internal sources, about 25 mrem from cosmic rays and about 25 mrem from terrestrial gamma rays. The average annual dose from fallout is less than 1 mrem.

However, because of the many factors that cause both spatial and temporal variations, the annual U.S. dose from background can easily range from 100 mrem for people who live in well-ventilated wooden houses on sandy soil at sea level to about 1000 mrem for people living in the Denver area, a factor of 10 (Figure 3). At the Shoreham site, annual doses from terrestrial gamma radiation differed with location alone by as much as 25 mrem per year. At the small New Jersey site, the equivalent spot to spot difference was as high as 40 mrem per year. It is in the context of these variations that the selection of 15 mrem over background as the acceptable annual dose for residual radiation from a decommissioned site must be viewed. For additional perspective, consider that we rarely choose our residences or domestic habits based on exposure to background radiation, yet the choice to live in a brick rather than a wood-frame house can increase one's annual dose by 45 or 50 mrem. A gas stove can deliver about 15 mrem per year to the lungs due to naturally occurring radioactive elements in the gas and a single flight across the U.S. yields about 4 mrem. A Denver resident can receive double the cosmic ray dose, triple the terrestrial dose, quadruple the radon dose, and a higher intake of radionuclides in drinking water compared to persons living in a coastal region--and if the house is not well ventilated the total dose could be still higher!

Selection of an Acceptable Level of Risk

To place the risk from exposure to background radiation in context, let's look at some general risks to the population. About 33% of the general population in the United States die of heart disease and about 23% die of cancer. Non-cancerous lung disease (7.7%), strokes (6.7%) and accidents (4.3%) also figure strongly as major causes of death (Figure 4). Comparing these causes of death, all of which carry a risk of greater than 1%, with the elective or accidental risks faced by selected groups or by the general population illustrates the complexity of adding societal choice to risk-based decision-making in terms of selection of an acceptable level of risk (Figure 5). Smoking one pack of cigarettes daily will result in death from a related cause for about 28% of smokers and a motorcyclist has about an 11% lifetime chance of dying in a motorcycle accident. By comparison, the average American's risk of dying in an air accident is several orders of magnitude lower, about 0.02%.

As I said earlier, the annual dose from natural background in the U.S. ranges from 100 to 1,000 mrem with an average of about 300 mrem. When relating these annual doses to risk, the risk assessment models developed by the International Commission of Radiological Protection (or ICRP) are usually applied. The ICRP performs risk assessments for both deterministic and stochastic effects of exposure to radiation based on research reports of radiation effects on tissues and animals, as well as on human epidemiology studies and modeling. For the purposes of radiation protection, the ICRP *assumes* a linear non-threshold dose-effect model and basically extrapolates to estimate the probability of harm resulting from low doses and dose rates where there is little, if any, human health effects data.

Using ICRP's method of risk assessment, the average annual 300 mrem dose from background produces a lifetime risk of fatal cancer of slightly less than 1 in 100, or approximately 0.82%. The corresponding lifetime fatal cancer risk for 100 and 1000 mrem are approximately 0.27% and 2.7%, respectively (Figure 6).

So how would an additional increment of 15 mrem change the public's risk from natural background? Looked at in isolation, 15 mrem per year over a 70-year lifetime would result in a risk of about 0.04% yet another decade lower on this log scale. When added to the risks associated with low, average, and high annual doses from background it is barely distinguishable (Figure 7). Indeed 15 mrem represents 5% of the average annual dose and is lost within the range of background which spans a factor of 10.

It is perhaps useful to note that for members of the public, the NCRP recommends an annual limit of 100 mrem for continuous exposure and an annual limit of 500 mrem for infrequent exposures due to all anthropogenic sources and recommends that ALARA be practiced below that. They further recommend that where there are multiple sources, no single source or set of sources under one control should result in an individual being exposed to more than 25 mrem annually.

What does one conclude from all of this? The limit of 15 mrem, including 4 mrem from drinking water which in itself is material for a lengthy lecture which I won't attempt to address here, carries a risk that is a small increment over the risk from background itself. Given that the risk is small and masked by the variation in the risk over the range of background doses, one must ask what all this should imply for the third or final component of risk-based decision-making, risk management.

Risk Management

The major questions for risk management are: (1) What is it that will be measured or used to represent "background" at a particular decommissioning site? (2) What will be measured to determine compliance with the 15 mrem limit? and (3) What margins of error or what uncertainties will be considered acceptable in determining compliance?

The difficulties involved in answering these questions become apparent when a site's decommissioning efforts are broken down into a series of steps and the complications that can exist with each step are examined. The overall process consists of, first, an analysis of the activities that have been performed at the site to be decommissioned; second, an assessment or survey to establish what represents background and a survey of the site to determine the degree of cleanup required; third, cleanup; fourth, a resurvey of the site; and, finally, release of the decontaminated site.

Each of these activities can be further broken down into sub-steps. For example, the person performing an analysis of the activity at the site must ask a series of questions: (1) Did the licensed activities involve single or multiple radionuclides? (2) With respect to each radionuclide, does it also exist in background or is it only produced as a result of licensed activities at the site? (3) For each radionuclide, are there single or multiple pathways that may result in exposure to humans?

Surveying also has multiple sub-steps. Survey methods and the required number of surveys of each type must be determined to establish the background level or levels. The corresponding number of site surveys that will be necessary to establish the level of residual radioactivity on site with reasonable confidence must be determined and the background surveys and initial site surveys must then be performed.

The site is now ready for cleanup. Based on the analysis and survey results, the appropriate methods must be chosen and cleanup performed with periodic re-surveying to determine the level of progress until the release criteria are met and the site is ready for release.

Let's consider a few examples of how this process actually works. First, consider a simple example in which the residual radioactivity involves a single, non-naturally occurring nuclide. For simplicity's sake, postulate that the radionuclide has only one pathway of exposure. This will result in a single set of surveys, presumably a single method of decontamination, and a straightforward path toward releasing the site.

For a second example, let's consider a slightly more complicated scenario, involving multiple naturally occurring nuclides, at least one of which is known to result in human exposure via several pathways. This analysis is still relatively simple, but the surveys will be somewhat more complex. In this situation background will have to be established in a manner that accounts for variability, and that will differentiate quantitatively between background radiation and that produced by site activities. The clean-up may also be somewhat more complex due to the multiple nuclides and pathways of exposure.

The third scenario, unfortunately, may be the most realistic picture for most licensees, including reactor facilities. In this case, the analysis may involve a whole spectrum of radionuclides, some, but not all, of which occur in background. It may also involve a variety of interrelated pathways of human exposure. As a result, establishing background becomes much more complicated, even for a site with a detailed pre-operational survey. Multiple elements of spatial and temporal variation will complicate this scenario further, requiring a higher number of surveys and sometimes multiple methods to achieve the necessary degree of confidence. The decontamination of such a site, of course, will be correspondingly more difficult, involving multiple clean-up methods and, quite possibly, repeated attempts, with re-surveys performed as necessary until the criterion of 15 mrem above background has been met and the site is ready for unrestricted release.

How does this affect cost, certainly an element in risk-based decision-making? Survey costs alone, not even considering cleanup costs, will vary based on the complexity of the situation considering the number of surveys taken and the quality of those surveys in terms of the degree of confidence required, or level of uncertainty considered acceptable.

Consider the cost per sample of various radiation measurements likely to be used in any major decommissioning effort (Figure 8).[1] Assessing the potential radiation dose to humans for a multi-nuclide site could require a complete pathway analysis, including measurements of external gamma dose; air, soil and vegetation samples; and samples of surface water, drinking water, and precipitation. Obviously, to attempt to sample and measure every cubic meter of the relevant

[1]NUREG-1496, Vol 2, "Generic Environmental Impact Statement in Support of Rulemaking on radiological Arteria for Decommissioning of NRC-Licensed Nuclear Facilities," Appendices, p. A-44, August, 1994.

environment would be both impractical and prohibitively expensive. Instead, a sampling strategy must be developed combining radiation survey readings over large areas with selective sampling and analysis at representative locations, using the results of past measurement programs as appropriate.

Even with an efficient sampling strategy, however, the cost of performing surveys just to establish background can escalate sharply depending on the degree of uncertainty that is acceptable, which will directly influence both the survey methods employed and the number of surveys taken. In general, measuring smaller doses means increasing costs as more sophisticated techniques are employed.

Similarly the costs of site surveys and decontamination increase based on the background criteria employed and the level of sensitivity and confidence desired. For some radionuclides, the detection limits of standard laboratory instruments can be reached, causing the survey costs to rise dramatically as sophisticated research techniques become necessary. For naturally occurring radionuclides or those present in residual levels from weapons fallout, it may be virtually impossible to distinguish the contribution of site activities given the spatial and temporal variations in background discussed earlier.

Just as an example, consider the cost of measuring cesium-137 in soil (Figure 9).[2] At dose increments of about 30 mrem per year or higher, the cost is about $50 per sample. The cost roughly quadruples when trying to measure at levels of 10 mrem per year or less--based on the need for more sensitive laboratory methods--and increases dramatically again, to about $500 per sample, when measuring at a level of 0.3 mrem per year, which requires sophisticated research techniques. Because cesium-137 is present in residual radioactivity from weapons fallout, the typical levels and degree of variability make the cost of measuring this radionuclide at dose increments of 0.1 mrem per year more or less indeterminate.

What all this reveals is that every assessment of dose due to either natural or anthropogenic radiation will entail some degree of uncertainty. Whether that uncertainty stems from spatial or temporal variations, the limitations of the measurement technique, or the ability of the analyst to interpret data, it is still uncertainty, and it can never be entirely eliminated. Now let's review how the compliance process might work. First, background (χ_o) must be determined. But, unless it is zero, this is clearly not well-defined and carries an uncertainty (σ_o). To determine if cleanup is sufficient, the site must be surveyed to determine what remains (χ_1) which may or may not include natural background as discussed earlier. This, too, of course, carries an uncertainty (σ_1). Compliance requires that what remains after cleanup not contribute more than 15 mrem above background.

In addition, the proposed rule requires that further reductions be made As Low As Reasonably Achievable. Defining ALARA, in this framework, might be much more problematic than when working with higher, more readily measurable doses. Can ALARA be assigned a cost-

[2]NUREG-1496, Vol 2, "Generic Environmental Impact Statement in Support of Rulemaking on radiological Arteria for Decommissioning of NRC-Licensed Nuclear Facilities," Appendices, p. A-53, August, 1994.

per-dose-increment value, as is done for occupational exposures? Is it simply a matter of vague principle? And how will it take into consideration other risks, such as those associated with the decommissioning activities themselves? These are the questions of the risk management phase of risk-based decision-making.

Now let us return to the framework of risk-based decision-making which is premised on balancing risk, cost, and benefit. To implement the 15 mrem criterion, as well as ALARA, in this context, one needs to ask at least two fundamental questions:

1) How should both background and residual radioactivity be defined or measured in practical terms, and what degree of uncertainty will be considered acceptable? Recall from the examples of our earlier discussion that if one takes into account spatial or temporal variations of background, not to mention measurement uncertainties, the sigma may easily be of the same order as, or even multiples of, the 15 mrem criterion.

2) The second question follows naturally from the first: given that the risk associated with a 15 mrem residual dose adds very little to the risk of exposure to background and indeed is buried in the noise of the natural variations of that background, then how much money and effort should be spent not only to clean up to this level, but to assure compliance?

Conclusion

These are among the questions that we, as regulators, licensees, and members of the public must consider as we proceed toward final decommissioning rulemaking. And remember, I've only touched the surface. For example, we haven't even discussed the proposed 4 mrem criterion for the water pathway and the associated risk management scheme necessary to assure compliance. These are challenges of risk-based decision-making as we all go in search of background.

In this endeavor, I would urge that we be ever mindful of our goal as captured in the NRC's mission, that is, "to help assure that the use of nuclear materials is carried out in such a way that public health and safety, the common defense and security and environment are protected," and that we be mindful of the principles of good regulation, namely, independence, openness, efficiency, clarity, and reliability. This is our challenge as we strive to protect the citizens of our nation and fulfill our responsibilities as stewards of our planet. I, for one, welcome the challenge, daunting as it may seem, and I look forward to the contributions and participation of all parties as we proceed toward what I hope will be rational and responsible final rulemaking.

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