



ALL CURIES ARE NOT EQUAL

Carl J. Paperiello
Deputy Executive Director for Materials,
Research and State Programs

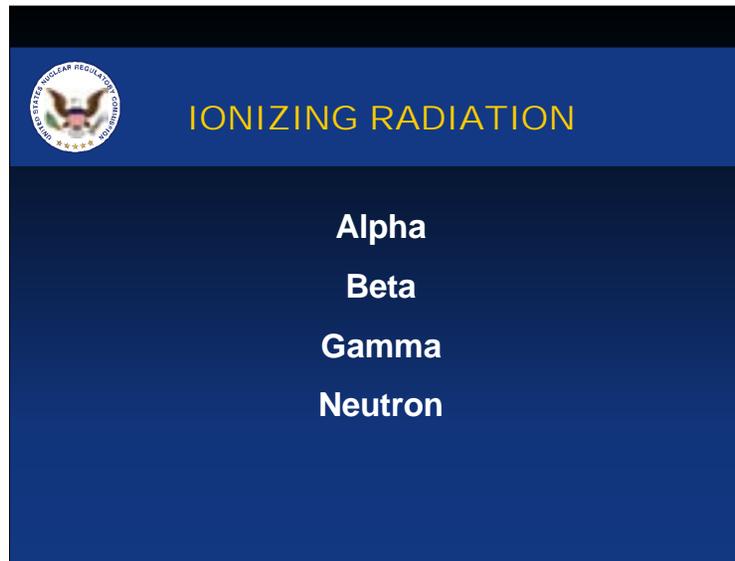
American Nuclear Society Winter Meeting
November 18, 2002

Good Afternoon,

I welcome the opportunity to start this series of presentations designed to help us understand how radioactive material could be used for malicious or terrorist purposes, steps that could be taken to prevent such an occurrence while permitting the beneficial uses of such material, and what steps should be taken if such material were used. I have been asked to present to you today some basic health physics reasons why not all radioisotopes represent the same threat. All curies are not created equal. An essential consequence of my message is that there are a limited number of radioisotopes used commercially that can be used to make credible radiological dispersal devices (RDD's).

Radioactive isotopes with very short half-lives like those used in diagnostic nuclear medicine and those used only in small quantities and with relatively low energy radiation like those used as tracers in biomedical research are not credible sources for RDD's.

For the maximum protection of the common defense and security, the focus of efforts should be on those sources and radioisotopes that due to radiation characteristics, half-life, quantity and physical and chemical form pose the greatest risk.



To set the stage for the series of presentations that we will hear I am going to review some basic health physics to get everyone on a common basis for these discussions. The ionizing radiation that we will be talking about consists of particles both charged and uncharged and electromagnetic radiation characterized by wave length well above the visible or ultraviolet range. It is the ionization effects of the radiation that damage human cells resulting in injury.

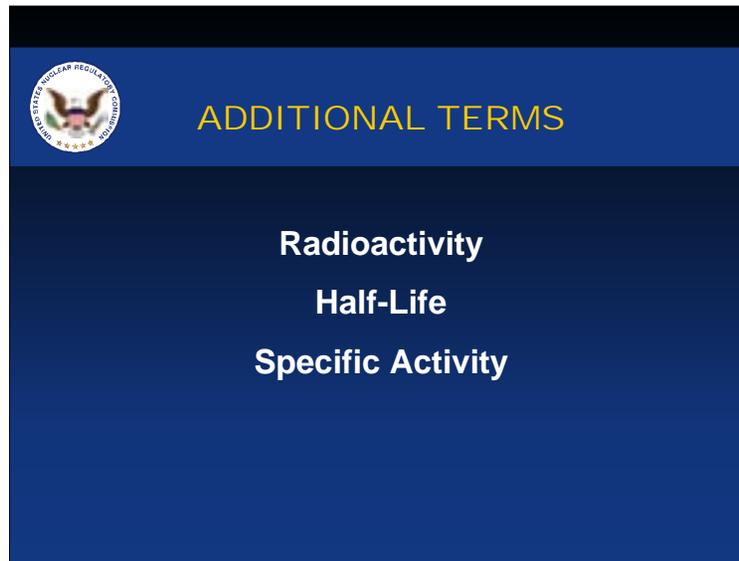
Alpha - Alpha radiation is a heavy charge particle emitted from the nucleus of some radioactive elements, usually very heavy elements such as radium, uranium and plutonium. Alpha particles are the same as helium nuclei. Because they are so massive they ionize heavily and do not penetrate the skin. For the same physical reason they represent a significant internal hazard when an alpha emitting isotope is in the body.

Beta - Beta radiation is a light charged particle emitted from the nucleus of some radioactive atoms. If it is negatively charged it is identical to an electron. If positively charged it is called a positron. Beta radiation is lightly penetrating and can be stopped by a thin sheet of metal. Beta radiation in sufficient quantity can cause severe skin burns and, if ingested in the body, can represent an internal hazard.

Gamma - Gamma radiation is high energy electromagnetic radiation. It is very penetrating and represents a serious external hazard. Radioactive material emitting gamma radiation is usually used and stored in very heavy shielding. Typically lead, uranium, concrete or deep earth barriers are used to shield against gamma radiation.

Neutron - Neutrons are uncharged particles found in the atomic nucleus. Neutron radioactivity is rare but does occur in very heavy radio nuclei. More commonly Neutron sources are made by a mixture of alpha emitters and beryllium. Neutrons are produced in large quantities by fission in reactors and nuclear weapons. Neutrons are penetrating and shielding is required. Neutron shields frequently incorporate hydrogenous material.

As will be discussed in detail later, one major reason that all radioactive materials are not equal is they emit different radiations, with different penetrating powers and different ways of delivering ionizing energy to the body.



We need to understand three other terms which are radioactivity, half-life and specific activity. Radioactivity is the spontaneous transformation of a nucleus. In this transformation the atomic nucleus goes from a state of higher energy to one of lower energy. When this happens energy is released usually by the emission of one or more forms of ionizing radiation. Radioactivity is conventionally measured in curies which is the number of transformations per unit time. One curie is 3.7×10^{10} transformations/sec. Another unit is the Becquerel. It is one transformation per second. So one curie is 3.7×10^{10} Becquerels. As material transforms it no longer exists in the original form. The time it takes for half the material to change is called half-life.

Specific activity is the transformation rate per unit mass. If the specific activity is low the material has a long half life. Uranium has a low specific activity. One curie of uranium has a mass in the order of several metric tons, its half-life is in the order of 4 billion years. If the specific activity is high, the material has a short half-life. One curie of technetium-99m, the most commonly used diagnostic medical isotope, has a mass in the order of 5 micrograms. It has a half-life of about 6 hours. This is another important factor in determining what radioactive material could be used for a RDD. For very short half-lives the material decays before it can be used. For very long half lives a significant quantity of radioactive material is so massive that it is very difficult to disperse and even handle.



DETERMINISTIC HEALTH EFFECT - THRESHOLD

Prodromal symptoms	50 - 100 Rads
Blood syndrome	200 Rads
Gastro-intestinal syndrome	500 Rads
Lung fibrosis	1000 Rads

The reason why we are concerned with ionizing radiation exposure is that it can have deleterious effects on human health. We usually split these health effects into two categories, acute, short term, deterministic effects and long term, stochastic effects. Acute effects are characterized by a threshold. Below the threshold the effect does not occur. Sunburn is an example of an acute effect of ultraviolet sunlight. Below a certain level a burn does not occur. With ionizing radiation we have the same principal. Actually for the same reason, ultraviolet light is on the threshold of ionizing electromagnetic radiation. This slide shows the thresholds at various exposure levels. These values are valid for short term exposures at high dose rates over the whole body. If the dose is protracted enough, no acute effect will occur. If dose is localized, the effects are localized. In humans in normal health, a whole body dose in the order of 400-500 rads, is likely to result in the death of half an exposed population. Lung fibrosis is a special case. A number of inhaled alpha emitting radioisotopes are not very soluble in body fluid. If they are inhaled, they remain in the lung and almost all their radiation is delivered to the lung. Fatality from lung dose is in the order of thousands of rad.



LONG TERM HEALTH EFFECTS

Linear No Threshold Model(LNT)	
Cancer	5%/ 100 REM
Genetic	1%/ 100 REM

The long term effects of radiation exposure are twofold but with a common origin. Ionizing radiation is one of a number of substances that can alter DNA in cells. Some alterations result in the death of the cell. At high doses and dose rates so many cells die that the effects are acute. Many alterations are repaired by special mechanisms in the cell. Actually DNA damage in the cell is relatively common and repair mechanisms have evolved. Some DNA damage is repaired with an error. Current theory is that some of these erroneous repairs can lead to cancer in somatic cells and genetic defects in reproductive cells. Furthermore it is assumed that this effect is linear with dose and independent of dose rate. This model for the long term effect of ionizing radiation is called the Linear No-Threshold Model (LNT). It is the most widely accepted model but there are many differing views. Many who accept it for use, do not believe it, but use it because the common view is that it does not underestimate the consequences. This is not the time and place to argue over differing views on this, that would require several more conferences. In a session on Thursday morning you will be able to hear some differing views.

The quantitative estimates of cancer risk are derived from the atomic bomb survivors. It is a probabilistic risk much like the risk of lung cancer from smoking or skin cancer from ultraviolet exposure. Not everyone who is exposed will get cancer. However the greater the exposure, the higher the probability will be of getting cancer. Currently, the accepted probability of cancer from a one rem exposure is one chance in two thousand using the LNT model. However, I have to add that empirically at doses below 10-20 rem increased incidence of cancer has not been demonstrated. In fact, there are a few parts of the world with a very high elevated natural background, where population groups receive lifetime doses of 50-100 rem or more with no observable health effects.

Genetic effect from ionizing radiation have not been seen in humans, quantitative estimates are based on animal studies. They are estimated to be 1 in 10000 per rem.



RADIATION DOSES IN PERSPECTIVE

Occupational Dose Limit	5 REM/Yr
Whole Body CAT Scan	2-4 REM/Scan
Special Public Dose Limit	.5 REM/Yr
Average Nuclear Med. Scan	.4 REM/Dose
Average Background	.3 REM/Yr
Public Dose Limit	.1 REM/Yr
NRC Decommissioning Limit	.025 REM/Yr

This slide presents typical radiation doses received by people along with some regulatory dose limits. I should note that most occupation workers (individuals working in the nuclear industry) receive doses well below the 5 Rem/yr dose limit. Typical annual occupational doses in the US are about 10 percent of the limit. NRC's dose limit for anyone who is not an occupational radiation worker is 0.1 Rem/yr except for special circumstances. A special circumstance would be a family member who is a care giver for a patient who has therapeutic radioisotopes in their body. While average US background is 0.3 Rem/yr, it can vary easily by a factor of 2 depending on elevation above sea level, radium concentrations in the ground and even the material used to build one's home. Like ultraviolet radiation from sunlight, natural radiation is hard to avoid.



INTERNAL DOSE (Sv/Bq)

Isotope	Ingestion	Inhalation
H-3	1.73E-11	1.73E-11
Co-60	2.77E-9	8.94E-9
Cs-137	1.35E-8	0.86E-8
Pu-239(Ox)	1.0E-7	833E-7

We have discussed differences in types of radiation, differences in specific activity, the effects of radiation and how much radiation people may routinely receive. We need to add chemical and biochemical properties. Just because a particular isotope is radioactive, its chemical properties are the same as stable isotopes. This means radioactive carbon can form carbon dioxide, krypton-85 is a noble gas and therefore forms no chemical species, and iodine-131 will collect in the human thyroid just like stable iodine.

This slide compares the effected dose to the human body from the same curie intake of several common radioisotopes. The doses shown here for the intake vary by as much as 100,000. Furthermore, in some cases, inhalation as compared to ingestion makes a big difference. Tritium, in the form of water, goes throughout the body. It is absorbed equally well by the lung or the GI track. For plutonium oxide, its relative insolubility makes a big difference. Ingested orally, very little is absorbed by the body and it is cleared rapidly. In the lung, its insolubility causes it not to be cleared from the body very fast. Tritium gives a much lower dose than the other three isotopes because it emits only a very low energy beta ray. Cs-137 emits a beta ray and a gamma ray of higher energy. Like tritium, Cs-137 is generally distributed throughout the body. Even though Co-60 has a higher energy gamma ray than Cs-137, the total absorption of the higher energy Cs-137 beta and its distribution in the body makes its dose higher. Pu-239 gives the highest dose because it emits a very high energy alpha particle and alpha particles are given a dose quality factor of 20 while beta and gamma radiation have dose quality factors of one.



EXTERNAL DOSE RATE (R/Hr per 1 mCi)

H-3	0
Co-60	1.32
Cs-137	0.33
Pu-239	0.08

Let us compare the same radioisotopes outside the body. In this case, alpha rays contribute nothing to the risk which is dominated by gamma ray intensity. In this exposure mode Co-60 dominates. Tritium emitting a very low energy beta has no external dose. Pu-239 emits very low energy gamma rays in addition to the high energy alpha which can not penetrate the skin. Cs-137 emits gamma radiation with an energy about one fourth that of Co-60.



EXPOSURE MODES

- Internal**
 - Plume**
 - Resuspension**
 - Contaminated food & water**
- External**
 - Plume**
 - Ground Shine – Contamination**
 - Direct**

What all this means is that we have to consider all exposure modes. Internal exposure can come from inhalation in a plume from an explosion or airborne release, resuspension from material deposited on the ground, again from an explosion or an airborne release, or direct spreading on the ground or the floor of a building. Ingestion can result from contaminated food or water.

External exposure can result from a plume. It can result from material deposited on the ground or an unshielded gamma emitting source concealed in a location where people can be irradiated.



**ALL CURIES ARE NOT
CREATED EQUAL**

- Can it become airborne?**
- Can it be inhaled?**
- Has it an adequate half-life?**
- Is it available in sufficient lump quantity?**
- Is it accessible?**
- Is it self-protecting?**
- Is it in a suitable form?**

Now let us put this together. There are a lot of things to consider. Widely varying internal doses, external doses, solubility, and intake path. However, there are a tools to help. We have computer codes, and I am sure such analyses will be presented at this meeting. These codes are useful for many analyses. In particular they help eliminate many sources from further consideration as credible RDD's.

However, more factors must be considered. Material must become airborne to be inhaled. It must also be in the form of sufficiently small solid or liquid particles or a gas in order for it to enter the respiratory system. The material must be sufficiently long-lived to permit construction and use of the device. This would suggest a half-life of at least several days. The most common diagnostic medical isotopes have half-lives shorter than this.

Depending on the dose, either external or internal, enough has to be available. Of the 2800 or more known radioactive isotopes only a small set are in commercial use. Of these a number of pure beta emitters such as C-14, S-35, Tritium, P-32, P-33, and Ni-63 are almost never available at one location to be significant. The number of radioisotopes available in relatively large quantities and with useful half-lives is limited.

Materials in heavy shields, such as teletherapy machines and large irradiators, are hard to take away, partly because of weight and mechanical complexity. A very large gamma source out of its heavy shield may be regarded as self-protecting. A terrorist may be willing to die but the dose rates from gamma emitting sources in the ranges of thousands of curies are acutely lethal at distances of a foot or two in a matter of minutes to an hour.

Many of the most common large gamma sources are in the form of encapsulated metal. To be dispersible such source must be converted to a different form. A calculation of the dispersion of such a metallic source using the computer code HOTSPOT in its default mode is not very reliable. To convert many sources to a dispersible form requires time and equipment



CONSTRAINTS ON MATERIAL

- Most Licensed Materials Do Not Meet Criteria**
- Some Do and Should Be Protected**
- Limit Time Available For Wrongdoer To Possess**
- Realistic Modeling for RDD's Could Help**

Where does this leave us. Most licensees do not possess material that meet the criteria. Some do and this material should be protected. Furthermore, some material is clearly not a problem and other material clearly is or could be. There are grey areas and the NRC is working cooperatively with other Federal Agencies and Agreement States to define the boundary.

There is a real need to be able to do realistic modeling just for dispersion. Models need to incorporate the actual physical and chemical form of the material.

In some cases, altering the chemical or physical form of the radioisotope used may make the material less attractive.

There is also a great need to be able to systematically identify the threat to material in the form that it is actually used and available. For example, large Co-60 sources are not easily stolen by a sneak thief. To use such a source a terrorist would have to have a lot of resources and have possession of the material for a relatively long period of time. Steps to increase the protection of material needs to consider ways in which a terrorist could actually obtain such material.

The NRC is studying the vulnerability of material in the ways that it is actually used and possessed. In a later presentation our actions to increase protection of material will be presented.



There is a lot more that I could go into but the purpose of this presentation is to establish boundaries for the problem that confronts us. Modeling of strong gamma emitters suggests that the highest doses are achieved by leaving the source intact rather than dispersing it. For the same curie content greater dispersal results in lower doses but over a larger area. RDD's are more weapons of mass disruption than mass destruction. Actions can be taken to minimize this disruption.

Prevention. Focused action is needed to prevent theft, diversion, sabotage and illegal importation of material that can actual do harm. If we try to protect every source regardless of source strength and radiological characteristics we risk dissipating our energies. I hope we hear a lot about focused prevention.

Planning. What actions will be taken in the event that a threat is identified or radioactive material is dispersed either with an RDD or some other mechanism needs to be established. How to do this planning is relatively well know. There are emergency plans for all of the operating nuclear power plants in the US as well as a number of other nuclear facilities. This includes Protective Action Guides on limiting exposure. This knowledge needs to be used.

Focusing on the likely radioisotopes that realistically might be encountered can aid planning. What type of radiation detectors are needed, what clean-up tools are available, how will contaminated material be disposed of, how will contaminated patients be treated?

Communication. How will we ensure that accurate information is given to the public before an event about what we are doing and why we are doing it. Have we accurately portrayed the risk? Is it worth revisiting the LNT model? I note again there is a session on this topic. How do we provide accurate information if such an event does occur?

I look forward to the information on topics such as these that our other speakers will present to us.