

# **A Review of the US National Academies Report on Radiation Source Use and Replacement**

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**Abstract.** In 2008 the US Congress asked the US National Academy of Sciences (NAS) to form the Committee on Radiation Source Use and Replacement. The NAS Committee was tasked with reviewing the prospects for replacing IAEA Category 1 and 2 radionuclide sealed sources with less dangerous alternatives. The NAS Committee found that non-radionuclide replacements existed for nearly all Cat 1 and 2 radionuclide sources, in varying degrees of readiness. However, after reviewing the overall risks associated with radioactive cesium chloride, the NAS Committee felt it was urgent to take near term action on cesium chloride sources. The Committee recommended that the U.S. Government should implement options for eliminating Category 1 and 2 cesium chloride sources from use. This paper will provide an overview of the risk based methodology that was used by the NAS Committee in formulating this recommendation.

## **1. Introduction**

The US National Research Council formed the Committee on Radiation Source Use and Replacement at the request of the US Congress. The Committee was tasked with reviewing the prospects for replacing IAEA Category 1 and 2 radionuclide sealed sources with less dangerous alternatives. The Statement of Task to the Committee is as follows [1]:

*The principal task of this study is to review the current industrial, research, and commercial (including medical) uses of radiation sources to identify uses for which: (1) the radiation source can be replaced with an equivalent (or improved) process that does not require the use of radioisotopes; or (2) the radiation source can be replaced with another radiation source that poses a lower risk to public health and safety if it is involved in an accident or used in a terrorist attack.*

This paper will review the key recommendation of the Committee, which was to begin the phase-out of CsCl. This recommendation was made after considering the radiological terrorism risk that is posed by those devices which employ CsCl.

## **2. Risk, RDDs, and Area Denial Consequences**

One of the main motivations for the NAS Committee study was to explore the feasibility of reducing the availability of high risk radionuclide sources and thereby reduce the potential for a terrorist group to illicitly acquire and use them for malevolent purposes. The consideration of risk was therefore a fundamental element to the study. In considering the risk of malevolent use, the Committee focused primarily on the risk of developing and deploying a radiation dispersal device (RDD). This was after consideration of the likelihood and impact of other types of radiological terrorism as presented in Table 1.

*Table 1: Options for Radiological Terrorism*

| Device Type                             | Dispersal Form  | Economic Effects                     | Health Effects  | Comments: Impact   |
|---|-----------------|--------------------------------------|---|--|
| <b>Radiation Exposure Device (RED)</b>  | N/A             | Low to Medium                        | Medium: Deterministic and stochastic health effects               | No lasting economic impact   |
| <b>Rad-Food Dispersal (RFD)</b>         | Dissolve or mix | Medium to High                       | Medium to High: Deterministic and stochastic health effects       | Other poisons more readily available?  |
| <b>Radiation Dispersal Device (RDD)</b> | Many            | Medium to Very High<br>"Area Denial" | Low: Latent cancer risk (stochastic) drives population relocation | Could impact ~ 10,000's;<br><b>Area Denial--Unique aspect of radiological material</b> |

The Radiation Exposure Device (RED) would, for example, involve simply taking a stolen radiation source and placing it in a public place with a high level of pedestrian activity. It is the least complicated scenario (no dispersal mechanism required) and a high activity (IAEA Cat 1 source) could cause serious radiation induced illness (including death) to those individuals that happen to pause near the source for a few minutes. More likely is that 100's to 1000's of individuals could be exposed to lower levels of radiation resulting in increased latent cancers. A large gamma ray emitting radiation source is readily detectable with hand-held radiation pagers and this scenario is likely to be detected quickly in any major US city where police officers and other first responders are equipped with radiation detection equipment.

Food and water poisoning are possible with certain forms of radioactive material but this is not unique and other common poisons are more readily available and easier to handle. Finally, there is the Radiation Dispersal Device (RDD) which involves the spreading of radiological material, most commonly with explosives. Studies and experiments [2, 3] have shown that it is quite difficult to cause serious health injury with RDDs, and that the hazard boundary for prompt, deterministic health effects for a realistic explosive RDD extends outward roughly to the order of 100 meters from the explosive device. The more serious consequence and a unique aspect of the RDD is its ability to cause economic damage due to the need to quarantine a much larger area and to clean up the contamination. The much larger quarantine area is determined not by the risk of prompt deterministic health affects but instead by the risk of latent stochastic effects, such as cancer.

Figure 1 shows a graphic depiction of a typical explosive RDD. Highlighted in the figure are the typical dose pathways to individuals that happen to be exposed to the radioactive debris cloud as it passes overhead. Beyond the "near field" zone (10's to 100 meters) for prompt health effects there will be a fairly large zone for late, stochastic health effects, extending for perhaps kilometres in range. Just how large this zone of area denial becomes will depend on the particulars of the RDD, wind speed and other weather conditions, as well as the interplay between the federal, state and local governments, whose job it will be to oversee the radioactive clean-up and the affected public. The public's perception of the risk of exposure to radioactive contamination and the responsible government's ability to communicate the true risks, as well as they are known, will factor into the clean-up decisions.

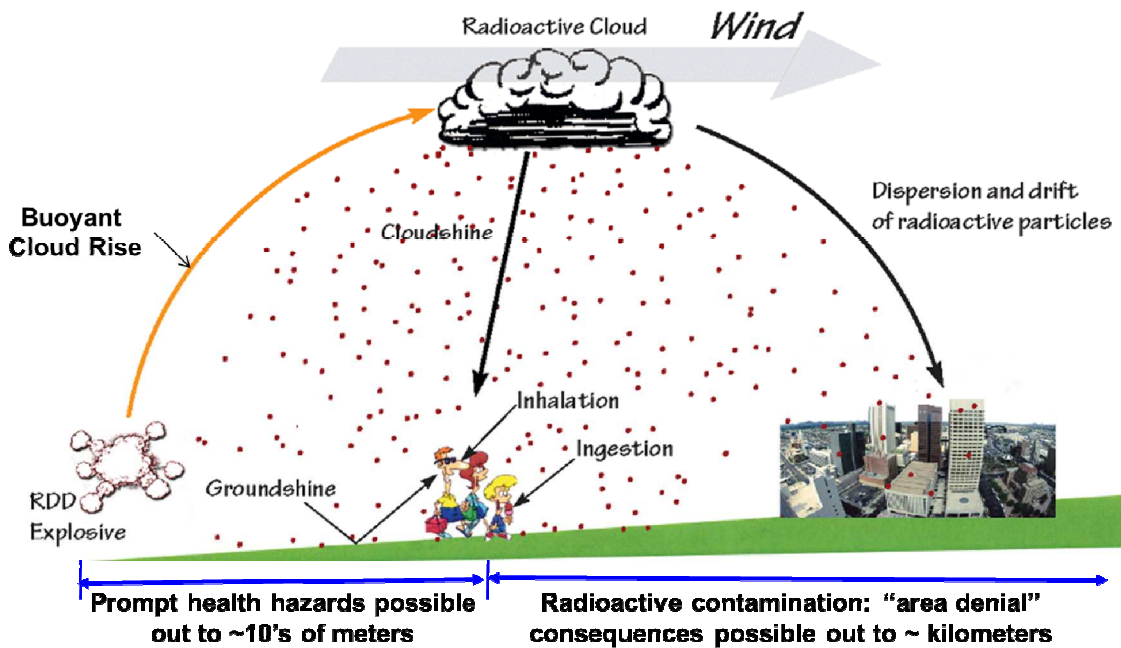


Figure 1: The RDD produces area denial consequences.

Indeed, it is this complex human interaction along with the fear and uncertainty as to the effects of low level chronic exposure to radiation that makes the RDD threat so pernicious and that could drive clean-up thresholds well below what would be scientifically and economically justified. Some of the qualitative factors that the public may consider in examining the risk of exposure to radioactive contamination are as follows:

- **Understanding of risk**
- **Trust in government information**
- **Short-term vs. long-term risk**
- **Personal control of risk**
- **Benefit/cost of risk**
- **Seen vs. hidden risk**
- **Equitable sharing of risk**

When examining the risk posed by an RDD, terrorism analysts will consider the factors as outlined below in Figure 2. In examining the risk posed by the Category 1 and 2 radiation sources the NAS Committee primarily considered, on the probability side, the "Source Material Acquisition" box. The probability of acquisition was explored qualitatively by the Committee by examining the availability and perceived vulnerability of the particular radiation source to illicit acquisition. On the consequence side, and based on the above discussions, the Committee focused primarily on the economic consequences resulting from the area denial consequence. This focus on the area denial consequences leads then to a consideration of the chemical/physical form of the source material as well as the total activity of the source.

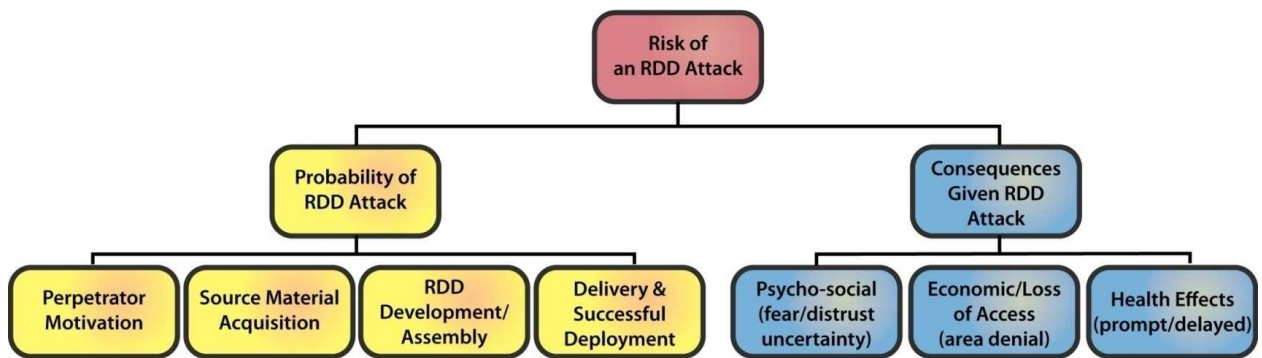


Figure2: RDD Risk Decomposition into Fundamental Factors.

### 3. IAEA Category 1 and 2 Devices and Radionuclides Examined in NAS Study

#### 3.1. Category 1 and 2 Devices

Figure 3, below presents a chart derived from the IAEA report [4] on the categorization of sources. The colored bars represent the activity range typical for the labeled devices with the black lines representing the typical activity. The radionuclide label applied to each bar is the most typical radionuclide used in the application. The blue lines overlaid on the chart depict the Category 1 and 2 thresholds for the particular radionuclide listed as the dominant radionuclide for that application. The Category 1 sources/devices include the large panoramic irradiators used for sterilization, the smaller self-contained irradiators, teletherapy and gamma knife devices, and radioisotope thermoelectric generators (RTGs). The most common Category 2 sources/devices are the calibration irradiators, well logging sources, and industrial radiography cameras.

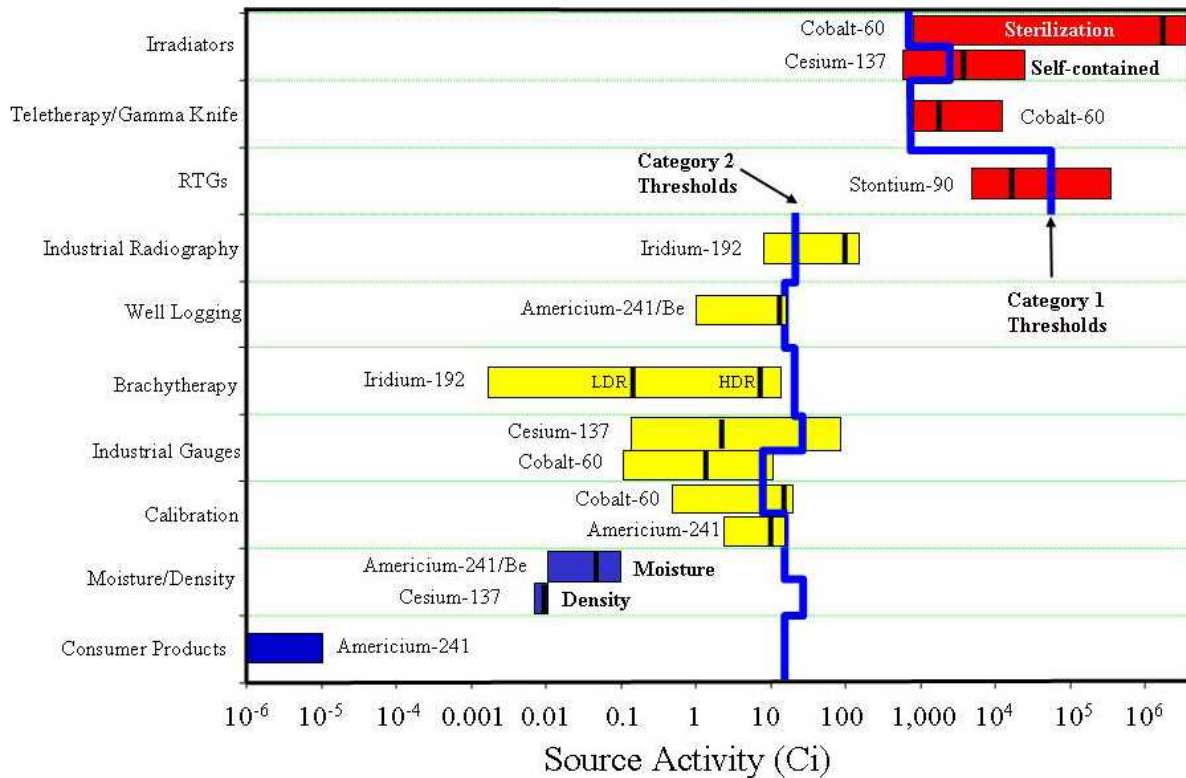


Figure 3: Radiation Source Applications, Radionuclides, and Activity Ranges. Note: 27 Ci ~ 1 TBq Source: Modified from IAEA [4].

Figure 4 presents images of some of the most common Category 1 and 2 devices and their sealed sources that the Committee examined for potential replacement. These are devices whose state of use and wide availability make them more likely candidates for illicit acquisition. The top row shows two Category 1 devices, a teletherapy machine which typically uses Co-60 and a self-contained irradiator which use both Co-60 and Cs-137. The teletherapy and self-contained irradiator sealed sources are also shown in Figure 4 alongside the device. These Cat 1 devices are found at facilities such as hospitals and universities. The two devices on the bottom row represent portable sources, an important factor to consider in terms of vulnerability to illicit acquisition. The radiography camera typically uses an Ir-192 source and the well logging source is usually Am-241 which, when mixed with beryllium (Am/Be) produces a neutron output.

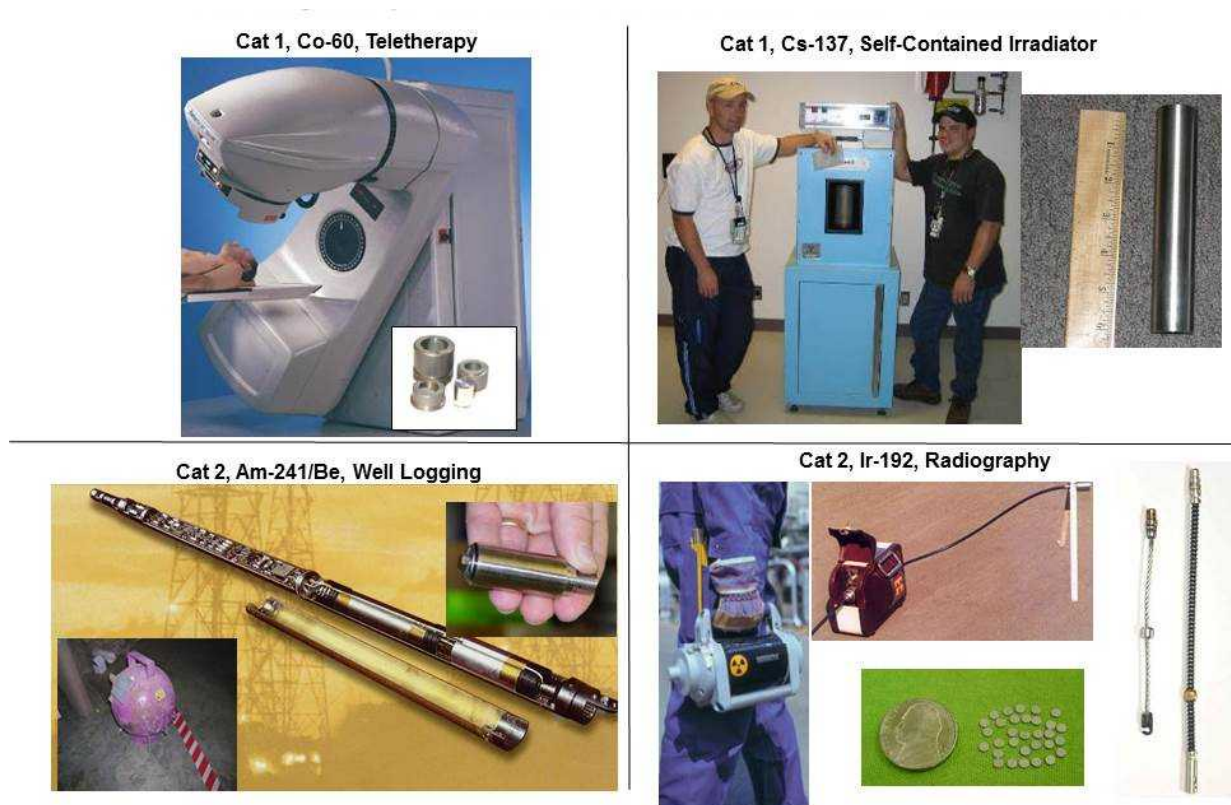


Figure 4: Sample of the Category 1 and 2 devices studied by the NAS Committee

Self-contained irradiators will be discussed in more detail below. They are used for performing radiobiology and medical research as well as for blood irradiation. Thus the basic application division for self-contained irradiators is between the research irradiators and blood irradiators, each having a separate and distinct user community. The difference in size and design between these two irradiator types is not significant and it often occurs that a hospital blood irradiator is donated to a university for use as a research irradiator.

### 3.2. Category 1 and 2 Radionuclides and Their Area Denial Properties

From the previous discussion it is clear that the radionuclides employed in the most common Category 1 and 2 sources/devices are: Co-60 and Cs-137 for Cat 1 devices, Ir-192 and Am-241 for Cat 2 devices. These were the principal radionuclides and applications considered by the Committee. Some of the key properties of these radionuclides are presented below in Table 2.

Table 2: Summary of the Most Common Radionuclides Used in IAEA Category 1 and 2 Sources and

Devices.

| Radionuclide and emission            | Half-life | Chemical Form (typical) | Power to Contaminate TBq/km <sup>2</sup> | Typical Application and Activity                     |
|--------------------------------------|-----------|-------------------------|--|--|
| <b>Co-60</b><br>( $\beta,\gamma$ )   | 5.3 yr    | Metal                   | 0.37                                     | Cat 1<br>Irradiators<br>Teletherapy<br>$\geq 37$ TBq |
| <b>Cs-137</b><br>( $\beta,\gamma$ )  | 30 yr     | Salt (CsCl)<br>Powder   | 1.5                                      | Cat 1<br>Irradiators<br>$\geq 37$ TBq                |
| <b>Ir-192</b><br>( $\beta,\gamma$ )  | 74 d      | Metal                   | 3.7                                      | Cat 2<br>Radiography<br>$\geq 3.7$ TBq               |
| <b>Am-241</b><br>( $\alpha,\gamma$ ) | 430 yr    | Oxide<br>Powder         | 1.5                                      | Cat 2<br>Well Logging<br>$\geq 0.37$ TBq             |

From the perspective of radiological terrorism risk, column 4 of Table 2, “Power to Contaminate” is an important parameter. This is the amount of source material activity that would need to be uniformly dispersed over one square kilometer in order to cause an exposed individual to receive a dose of 20 mSv in the first year, post dispersal, from either ground-shine or re-suspension/inhalation. This “20 mSv in the first year” is the recommended Protective Action Guideline (PAG) for population relocation as defined by the US Environmental Protection Agency [5]. The TBq/km<sup>2</sup> numbers presented in Table 2 are approximate. Of course an explosive RDD will not create a uniform dispersal so these values are an idealization of the dispersal problem but they are nevertheless useful because they present a threshold activity under perfect dispersal which removes the complexity associated with the mechanism of dispersal, the weather conditions, and other factors. They allow us to examine the quantity of radionuclide needed to cause an area denial condition over a square kilometer assuming “perfect dispersal”. This shows that, for these commonly used radionuclides, a quantity on the order of 1 TBq represents a significant quantity for area denial, which is in rough “order-of-magnitude” agreement with the threshold activities of an IAEA Category 2 source (for these radionuclides).

The difficulty of dispersal is a function of the chemical and physical form of the material, which is presented in the third column of Table 3. Here we see that Co-60 and Ir-192 are used in metal form while Cs-137 is used in the salt form as cesium chloride (CsCl) and Am-241 is an oxide powder that, as discussed previously, is mixed with beryllium powder and pressed into a pellet.

Finally, the half-life of the radionuclide is an important consideration from the area denial perspective. A relatively short half-life radionuclide, say a few days, would pose less of an area denial risk in that one could simply wait out the problem and not have to initiate decontamination, provided the daughter species is non-radioactive or is also short lived.

#### 4. Risks Factors Posed by Category 1 and 2 CsCl Sources

In Section 3 it was noted that Cs-137 applications involve Category 1 devices known as self-contained

irradiators, used in research and blood irradiation. These devices typically contain greater than 37 TBq of Cs-137 in the salt form, CsCl. It was also noted that the activity of a typical CsCl self-contained irradiator sealed source would possess an activity in excess of 37 TBq. This was one of the issues that concerned the Committee regarding CsCl RDD risk; the size of a typical CsCl source is 100 times the power to contaminate. A second issue concerning Cs-137 and CsCl in particular was the difficulty of decontamination that was known from past accidents involving this radionuclide. A review of past accidents is shown in Figure 5.

- **Chernobyl, USSR April 1986**  
 — 2 Million Ci, Cs-137



- **Goiania, Brazil Sept. 1987**  
 — 1400 Ci, Cs-137 (CsCl)



Figure 5: Past Accidents Involving Cs-137.

In order to form an appreciation of the potential effects of an RDD incident, two accidents involving the dispersion of Cs-137 are particularly relevant. They are the reactor accident at Chernobyl [6] and the dispersion accident in Goiania, Brazil [7]. At Chernobyl, Ukraine, in 1986 a nuclear power reactor suffered a loss of control accident during a test. The runaway reactor produced a large amount of hydrogen, which exploded and tore the roof off the reactor building. The reactor caught fire and burned for 4 days, spreading radionuclides for large distances. While much attention has been given to the spread of radioactive iodine isotopes, due to the delayed stochastic thyroid risk to children, another equally serious and persistent consequence has been the dispersion of Cs-137. Large areas were contaminated by this radionuclide and closed to the public. Soviet attempts at cleanup were unsuccessful. Confiscated zones were defined and over 200,000 inhabitants were forced to relocate from these areas. These zones are shown above in bright red. These areas were contaminated to a level of 40 Ci/km<sup>2</sup> or above, which is that same as that required by the US EPA for relocation, i.e. 20 mSv in 1-year. While 2 million Curies (70,000 TBq) of Cs-137, the amount released by the accident, is larger than any credible terrorist RDD, the issues involved are basically the same. Cs-137 by virtue of its chemistry (Group I of the Periodic Table of Elements) is an Alkali metal, a very reactive element that will chemically bond with many substances, thus making it very difficult to cleanup. Although the Cs-137 in the Chernobyl fallout was not CsCl, once it is deposited into the environment, the effects are similar.

The second accident, at Goiânia, Brazil, which occurred in 1987, is more representative of the scale of a terrorist RDD incident. A teletherapy machine containing 1400 Ci (52 TBq) of Cs-137 was left in an

abandoned medical clinic. Junk metal scavengers gained access to the facility and removed the therapy head containing the CsCl source. They sold the heavy metal therapy head (and source contained within) to a junk dealer, who later disassembled it and removed the CsCl source capsule, pierced the capsule window thus exposing the CsCl powder. A CsCl teletherapy machine similar to the one in the Goiânia accident is shown above in Figure 5 along with the source capsule being held in the figure. Not knowing what he had found, he was intrigued by the glowing blue powder and showed it to his family and friends who in turn spread it around to others. Due to its solubility, the CsCl became widely dispersed throughout the city, mainly by the motion of people, cars, etc., i.e. cultural dispersal. The CsCl became chemically bound to material surfaces resulting in large area destructive decontamination, as seen in the above picture.

It is instructive to note that a similar accident involving a teletherapy machine occurred in Juarez, Mexico in 1983 [8] only the teletherapy machine in Juarez contained a Co-60 source instead of CsCl. In this instance the source pellets that were accidentally scattered on the ground were found with a radiation detector and easily removed with no significant economic consequence. This clearly illustrates the significant area denial risk differences posed by a soluble powder (CsCl) in comparison to an insoluble hard metal (Co-60).

Another risk related issue of concern to the Committee was the widespread use of CsCl self-contained irradiators in the US. There are approximately 1000 CsCl self-contained irradiators in the US [1]. These are found in major cities of the US, at hospitals and universities. Universities in particular have a cultural mind-set of openness and academic freedom which is generally at cross purposes to the security culture one would like to instil with CsCl irradiator use. Hospital security is often better than at universities but the application of blood irradiation is a 24/7 operation which is conducted generally in an open floor of the hospital or blood bank with many other activities on-going; a difficult environment in which to impress physical security. Worldwide estimates (compiled by the author) obtained from data provided by CsCl device manufacturers and distributors indicate roughly an equal number of CsCl irradiators worldwide, that is, another 1000 machines with most countries having no more than 100 CsCl machines in use.

Thus it was the combination of these many risk factors that lead the NAS Committee to recommend near term phase out of CsCl, (1) the quantity of CsCl used in self-contained irradiators being large relative to the quantity needed for a significant area denial event, (2) the ease of dispersal of the CsCl powder relative to the hard metals used in other Cat 1 and 2 radionuclide applications, (Co-60 and Ir-192), (3) The deleterious consequences of past accidents involving Cs-137, (4) the wide availability of CsCl irradiators in the US and worldwide, and (5) the relative difficulty of providing security at the facilities where the CsCl irradiators are located.

## **5. Summary**

In the 5 years since the NAS report was published, the US Government is continuing to explore options to reduce the risk associated with CsCl. An outright ban on the use of CsCl has not been pursued in the US because many of the CsCl irradiator users believe that the available X-ray machine alternatives did not provide them with a viable option. The US Government has supported research into improved alternative technologies as well as funding side-by-side comparisons [9] between X-ray and CsCl irradiators for some research applications. In the interim, the US Federal Departments of Energy and Homeland Security and the US Nuclear Regulatory Commission have collaborated in developing a special security retrofit to the CsCl irradiators in use in the US.

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