Safety and Security of Radioactive Sources

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Abstract. The evolution of the safety and security of radioactive sources is discussed in the context of a series of global eras. The first era was the 'golden' era when radioactive sources were pro-actively distributed to any that had need. Their benefits to humankind and especially developing countries were clear and largely undisputed. The second era started when it was recognized that some of these same radioactive sources were not being managed as safely as they ought to be and every year a few people were accidentally getting hurt or killed by them. The third era followed the terrorist attacks on the USA in 2001, when an urgent need was felt to try and prevent any attempts to maliciously use radiation and radioactive materials. The fourth and final era is beginning as the efforts to mandate the replacement of radioactive sources with alternatives is gaining momentum.

1. Introduction

Radioactive sources have been used for a large variety of applications for many years. The degree of hazard from unshielded radioactive sources is primarily a function of the radioactivity of the source and the radionuclide and these are reflected in the categorization. Category 1, 2 and 3 sources are regarded as being potentially dangerous if not under control [1]. For those less familiar with the uses of radioactive sources, the following are examples of some major applications typically using sources of the following categories:

Category 1:	Self-contained, radioisotope thermoelectric generators; irradiators for sterilization or radiation damage effects; beam cancer treatment; gamma-knife cancer treatment of brain tumours.
Category 2:	Weld, casting and pipeline integrity examination; cancer treatment with sources inserted into the tumour.
Category 3:	Industrial gauges to measure flow, tank and feedstock levels; oil or water exploration.
Category 4:	Cancer treatment with radioactive seeds; industrial gauges to measure thickness of paper and metal sheets; gauges to measure product filling; bone density measurement; static eliminators.
Category 5:	Eye treatments and permanent implant sources; devices for specific research applications using small sources; check sources.

Radioactive sources have been of great benefit to humankind, particularly in the fields of medicine, agriculture and industry. Consequently there are likely hundreds of thousands of radioactive sources throughout the world and in most countries. To ensure that every one of them is managed in a safe and secure manner is a difficult task that has changed over the years. It is postulated that the history of radioactive sources can be divided up into four global eras.

2. Era of Promotion and Provision

Following the discovery of radioactivity and the development of the main applications of radioactive sources, there was a long, 'golden' era when radioactive sources were actively promoted for their benefits. In particular, they were provided to developing countries as part of the effort to improve the human condition. Many of the initial applications were in health and agriculture, but they were soon extended to industrial uses such as oil exploration and mining to help local and national economies.

This era can be regarded to have started in the 1950s. While U.S. President Eisenhower's "Atoms for Peace" speech in 1953 focused on nuclear weapons, it also marked the beginning of the transition from secret, government uses of radioactive material to commercial applications. The era flourished following the establishment of the International Atomic Energy Agency (IAEA) in 1957 because it meant that there was now a co-ordinated international effort to promote the peaceful uses of nuclear power, radiation and radioactive materials, particularly for developing nations.

During this era, knowledge of radiation effects and radiation safety guidance were evolving along with the applications themselves. The primary focus was on ensuring that the radiation doses to those using the radioactive sources did not exceed regulatory limits. As sources were mostly being used by those qualified to do so, and then placed in storage when not in use, the exposure of the public was minimal and of little concern. Nevertheless, it was certainly factored into regulations such as the transport regulations [2], which were being developed during this time. Internationally, the IAEA not only developed applications, and provided radioactive sources and training but it also developed consensus guidance and regulations [3] for their safe use.

3. Era of Safety Concerns

The watershed accident in Goiânia [4] in 1987 was the beginning of a slow, 10-15 year awakening of the international consciousness that there might be some serious safety issues related to radioactive sources. This was most clearly first enunciated at the IAEA's Conference on *Safety of Radiation Sources and Security of Radioactive Materials* in Dijon [5] in 1998. At this meeting it was recognized that there was a global issue, not just a few isolated problems with sources. Several people a year, especially members of the public, were dying or being severely injured by sources that were not under regulatory control. These orphan sources became the focus of the first IAEA *Action Plan for the Safety of Radiation Sources and the Security of Radioactive Materials* [6] approved in October 1999. There were subsequent conferences [7] and action plans [8], [9], but the international support for the efforts to better manage, regulate and control sources was generally quite low…until the beginning of the next era.

4. Era of Security Concerns

4.1. Deliberate Intent

The terrorist attacks on the USA in September 2001 ushered in the next era because it suddenly made all of those involved with radioactive sources worry about the potential for deliberate, malicious use of such sources. The security of radioactive sources became a new and immediate priority, particularly for some influential, potential "target" countries such as the USA. The IAEA's Action Plans were not only revised [9], but they were suddenly given much more support and resources. Human nature being what it is, this resulted in some competition and conflict between the safety professionals and the security professionals that was not "our finest hour". (The author's paper presented at IRPA11 in Madrid explains and expands on this issue [10].

4.2. Prioritization and Principles

Attempts to prioritize efforts on sources had begun during the safety era with the IAEA's first Categorization of Radiation Sources [11]. Similarly, attempts to assemble common international principles for good radioactive source control had begun with the first Code of Conduct on the Safety and Security Radioactive Sources [12]. However, each of these had flaws and was fairly weak, largely because of the low level of interest and minimal involvement of many nations. The events of September 11, 2001 changed all of this and the new, high degree of concern and interest by many countries resulted in the rapid development of a new Categorization of Radioactive Sources [1] based on dangerous quantities [13], interim guidance on Security of Radioactive Sources [14] and a significantly revised Code of Conduct [15].

The revised categorization enabled all those in the field to have a common basis for prioritizing their efforts. The interim guidance on Security of Radioactive Sources provided a simple and common basis for security and prevented a divergence of security measures amongst different countries. The revised Code of Conduct provided an agreed, minimal, de-facto standard for the management of radioactive sources. It also outlined the basis for more secure international trade in radioactive sources [16].

Following these initial, frenzied efforts based on available and quickly derived information, much more effort, including some substantial research has been put into better determining the factors for consideration with regard to dirty bombs [17], [18]. In addition, much more thinking has gone into the development of radiological emergency response to radiological events and radiological dispersal devices specifically [19], [20], [21], [22], [23], [24], [25].

4.3. International Action

While the initial IAEA Action Plan had begun under the safety era, most of the work was actually performed during the security era. Clearly, many of its actions contributed to both safety and security. The major topic areas for the action plans were:

- Regulatory Infrastructure
- Source Management and Control including the Management of Disused Sources
- Categorization of Sources
- Response to Abnormal Events
- Information Exchange
- Education and Training
- International Undertakings
- Enhancing Security of High-Risk Radioactive Sources and Protecting them against Malicious Acts

The three IAEA action plans on the safety and security of radioactive sources have a combined total of 88 actions in them, almost all of which have been completed. The following is a brief listing of their major accomplishments:

- A Code of Conduct for the Safety and Security of Radioactive Sources was developed [15] and 92 States (as of March 2008) have made a non-binding, political commitment to move towards its implementation.
- Guidance on the Import and Export of Radioactive Sources [16] was published in support of the Code and 46 States (as of March 2008) have made a similar commitment to it.
- A Categorization of Radioactive Sources [1] was developed and is now an integral part of IAEA guidance and many national regulations.
- An electronic database called the "International Catalogue of Sealed Radioactive Sources and Devices" consting of several thousands of entries has been made available to regulatory authorities. In addition, a publically available, limited information manual entitled "Identification of Radioactive Sources and Devices" [26] has been published.
- A new, inherently understandable, supplemental radiation warning sign [27] for Category 1 and 2 sources was developed in conjuction with the International Organization for Standardization.
- Major conferences relating to the safety and security of radioactive sources were held in Buenos Aires (2000) [7], Vienna (2003) [28] and Bordeaux (2005) [29].
- A major tripartite initiative between the IAEA, the Russian Federation and the USA has resulted in the securing of many high-risk radioactive sources in the former Soviet Union [30]. Over 2,000 TBq of sources were recovered and secured in 13 countries under this project. There have

also been significant source recovery projects completed since then under an ongoing cooperation agreement between the IAEA and the European Union.

- A mobile hot cell and long term storage container for the conditioning and management of disused high activity sealed sources have been designed, constructed and demonstrated.
- A large number of standards and guidance documents relating to the safety and security of radioactive sources have been published (See the References and Bibliography).
- A complete suite of training materials on radioactive source safety and security has been developed.
- A comprehensive, IAEA regulatory infrastructure review service has been developed and implemented with modules covering all aspects of radiation safety and security of radioactive materials.

4.4. National Implementation and Regulation

Once the prioritization and principles were agreed upon at the international level, it then became the task of each country to implement them at the national level. As might be expected there has been a large variation in the degree of this implementation, ranging from nothing at all to an almost completely new regulatory infrastructure and framework for security of radioactive sources. The IAEA has been providing international forums [29] for the discussion of implementation issues and updates on progress. In my own country, there have been substantial changes in radioactive material regulations relating to security, to the point where background checks and fingerprinting are now required for certain applications. There are also indications that some members of the U.S. Congress want to make even more changes in a desire to further reduce the possibility of a dirty bomb. This brings us to the next era.

5. Era of Alternatives

Soon after the terrorist events of September 11, 2001, concern about radioactive sources potentially being used for malicious purposes led many people to begin thinking about alternatives [31], [32]. However, for many of those working in the field and particularly for national and international bodies, the priority was with remediation of past problems by collecting and securing disused sources and securing high-risk vulnerable sources. So it has taken a while to seriously start looking at alternatives to radioactive sources.

From the beginning of the security era, it was clear that ^{137}Cs sources and devices that contain ^{137}Cs were of concern because of the dispersibility and solubility of the ^{137}CsCl used in the sources. The Goiânia event [4] has often been cited as an illustration of what can happen. In 2004 the International Atomic Energy Agency held a meeting [32] with source manufacturers, regulators and others to examine what could be done to minimize the attractiveness of radioactive sources potentially being used for malicious purposes. Again ^{137}CsCl was identified as the most significant problem, but alternatives to other sources were also considered. In the USA, after the imposition of significantly increased regulatory controls for security reasons, many organizations and facilities started looking at alternatives to ^{137}CsCl, particularly for its main application in biomedical self-shielded irradiators.

5.1. National Academies' Study

In the USA, the Energy Policy Act of 2005 (EPAct) [34] had several provisions for the Federal Government to evaluate alternative technologies for replacing radiation sources that may pose a national security risk. One of these provisions, EPAct Section 651(d), directed the U.S. Nuclear Regulatory Commission (NRC) to work with the National Academies (NA) to review current industrial, research, and commercial uses of radiation sources and identify technically and economically feasible replacements for these sources. Concerns about the safety and security of radioactive sources that could be used in a radiological dispersal device and radiological exposure device prompted Congress to direct this study. Data from the U.S. NRC show that out of the thousands of manufactured and natural radionuclides, ^{241}Am, ^{137}Cs, ^{60}Co, and ^{192}Ir account for nearly all (over 99 percent) of the Category 1 and 2 sources, which were the focus of the study. The findings and recommendations of this study [35] are reproduced below *(in italics)* because they have not been widely distributed internationally and they are informational for all countries. In particular, in the context of this paper, they typify the era of alternatives. Particular attention should be paid to Recommendation 3.

Finding 1: The radiation sources examined in this study are used in applications that are important to the nation's health, safety, and economic strength.

Recommendation 1: Replacement of some radionuclide radiation sources with alternatives should be implemented with caution, ensuring that the essential functions that the radionuclide radiation sources perform are preserved.

Finding 2a: The U.S. NRC ranks the hazards of radiation sources primarily based on the potential for deterministic health effects (especially death and severe bodily harm) from direct exposure to the radiation emitted by the bare (unshielded) sources. The U.S. NRC's analyses that support the commission's security requirements for nuclear materials licensees are based only on these potential consequences.

Finding 2b: Factors other than the potential to cause deterministic health effects are important when evaluating hazards from radiation sources, especially the potential to cause contamination of large areas resulting in economic and social disruption (area denial).

Recommendation 2: For prioritizing efforts to reduce risks from malicious use of radiation sources, the U.S. NRC should consider radiation sources' potential to cause contamination of large areas resulting in economic and social disruption (area denial) to determine what, if any, additional security measures are needed.

Finding 3a: Because of its dispersibility, solubility, penetrating radiation, source activity, and presence across the United States in facilities such as hospitals, blood banks, and universities, many of which are located in large population centres, radioactive cesium chloride is a greater concern than other Category 1 and 2 sources for some attack scenarios. This concern is exacerbated by the lack of an avenue for permanent disposal of high-activity cesium radiation sources, which can result in disused cesium sources sitting in licensees' storage facilities. As such, these sources pose unique risks.

Finding 3b: In view of the overall liabilities of radioactive cesium chloride, the committee judges that these sources should be replaced in the United States and, to the extent possible, elsewhere.

Finding 3c: In most (and perhaps all) applications, radioactive cesium chloride can be replaced by (1) less hazardous forms of radioactive cesium, (2) radioactive cobalt, or (3) non-radionuclide alternatives. However, not all of these alternatives are commercially available now, and all are currently more expensive than radioactive cesium chloride for the users.

Finding 3d: Government action is required to implement replacement of radioactive cesium chloride sources because the alternatives cost more and the liabilities or social costs of the sources currently are not borne by the end users.

Recommendation 3: In view of the overall liabilities of radioactive cesium chloride, the U.S. government should implement options for eliminating Category 1 and 2 cesium chloride sources from use in the United States and, to the extent possible, elsewhere. The committee suggests these options as the steps for implementation:

— *Discontinue licensing of new cesium chloride irradiator sources.*
— *Put in place incentives for decommissioning existing sources.*

— *Prohibit the export of cesium chloride sources to other countries, except for purposes of disposal in an appropriately licensed facility.*

Finding 4a: Non-radionuclide replacements exist for nearly all applications of Category 1 and 2 radionuclide sources (not just radioactive cesium chloride). At this time, these replacements may not all be practical or economically attractive, but most of them are improving.

Finding 4b: Neither licensees nor manufacturers now bear the full cost of liabilities related to misuse of Category 1 and 2 radiation sources, nor do they bear the costs of disposal of cesium and americium sources.

Recommendation 4: In addition to actions related to radioactive cesium chloride, the U.S. government should adopt policies that provide incentives (market, regulatory, or certification) to facilitate the introduction of replacements and reduce the attractiveness and availability of high-risk radionuclide sources.

Finding 5: Accelerator neutron sources and californium-252 sources show promise as potential replacements for americium-beryllium sources in neutron well logging tools. However, there are technical obstacles for these replacement sources and they are at a disadvantage based on the extensive experience and data accumulated with americium/beryllium sources.

Recommendation 5: The Society of Petrophysicists and Well Log Analysts should task an industry working group, called a Special Interest Group (SIG) such as the Nuclear Logging SIG, to address the technical obstacles to implementing replacements for the americium-beryllium sources used in well logging and the challenges of data interpretation. The group should decide what obstacles are most important, but the issues might include development of new reference standards for these replacement tools, examination of the response of these tools relative to the americium-beryllium tools, and exploration of any differences in response when the replacement tools are used in combination with other nuclear and nonnuclear well logging tools.

5.2. Caesium, the New Radium?

While the NAS study recognized the importance of the beneficial use of radioactive sources, six of the ten findings and two of its five recommendations relate to ^{137}Cs [35]. If these recommendations were enacted into U.S. law, as some are proposing, then ^{137}CsCl sources would no longer be licensed and there would be incentives for decommissioning existing sources. Caesium-137 self-shielded irradiators have been used for many years for blood, biomedical and small animal irradiations. Approximately 10% of donated blood [36] is irradiated in a production mode by blood centres and medical institutions largely to prevent transfusion associated graft versus host disease for certain patients [37]. Biomedical and small animal irradiations are performed mostly for research purposes at universities and hospitals. The author and a colleague at the Mayo Clinic performed a small independent study looking at the specifics of replacing the ~1000 blood, cell and small animal ^{137}Cs irradiators in the USA with x-ray devices. In addition to conducting a literature search and to contacting some manufacturers and suppliers, several x-ray owners were interviewed about their experiences. The conclusions of this study were:

— It is possible to replace ^{137}CsCl blood, biomedical and small animal irradiators with cabinet x-ray machines with little or no loss of performance. Once the ^{137}Cs sources have been dispositioned, the administrative overhead for the irradiator is likely to diminish. Replacement costs are similar to purchase costs of ^{137}Cs irradiators, but routine maintenance costs, especially if an annual service contract is signed, are significantly greater. Contingency planning for the potential for being off-line for several days should be made for those with critical supply needs.
— Newer and better x-ray machines are likely to become commercially available in the near future to fill the gap left by ^{137}Cs irradiators.
— The question of replacement may become moot before too long, because the ability to make a choice may be taken out of the users hands. Within a year or two, purchasing or licensing a new

^{137}Cs irradiator may not be an option and the decommissioning of existing ones may be required, or at least actively encouraged with incentives.

For these reasons, it would seem that the era of the ^{137}Cs irradiator may be drawing to a close and the renaissance of its currently most feasible alternative, the x-ray machine is beginning. This is but one example of a trend that is likely to continue in this new era of alternatives. As an aside, it is worth noting that this is not the first time this has happened. Radium-226 is a radioisotope that has almost completely gone out of use for safety reasons. An IAEA program has resulted in the disposition or secure long-term storage of all disused radium sources in about 50 developing countries around the world. Interestingly, in a recent historical *Radium Tales* article in Health Physics News [38], Lubenau states "*The states…accomplished a great deal in upgrading the radiation protection programs of radium users. In addition, the Bureau of Radiological Health encouraged medical radium users to convert to alternative, less hazardous radioactive sources [39], A measure of success of that effort is that today there are no medical radium users in Pennsylvania.*" This statement is probably true of many more states and not just for medical users.

6. Conclusions

From a review of the history of the safety and security of radioactive sources it can be concluded that we have moved through a number of eras, from the innocent distribution of sources for the benefit of humankind, to safety concerns about the deaths and injuries that poorly controlled sources can unintentionally cause, to concerns that security of sources is insufficient to prevent them falling into the hands of terrorists, and finally on to its extreme 'logical' conclusion when Category 1, Category 2 and perhaps Category 3 radioactive sources may ultimately be replaced entirely by non-radioactive alternatives, beginning with ^{137}Cs.

To amend the famous quotation by Sir Winston Churchill: "Now this is not the end (of the use of radioactive sources). It is not even the beginning of the end. But it is, perhaps, the end of the beginning."

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