The Lessons to be Learned from Incidents and Accidents

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Abstract. The paper emphasises the important role that learning the lesson from accidents and incidents play in the cyclical process of improving operational safety and security of sources and emergency response arrangements. It reviews events that have provided "awakenings" and the initiatives that have stemmed from them particularly in respect of orphan sources, source security and emergency preparedness. It is noted that whilst terrorist driven issues are receiving well merited attention, conventionally failures in safety and security of radiation sources still regularly occur, sometimes with severe consequences. The paper reviews mechanisms for capturing the lessons to be learned, some common causes of accidents, with examples tracked through the life cycle of sources.

1. INTRODUCTION

Learning the lessons from accidents and incidents should be a fundamental element of all radiological protection programmes, both in respect of improving controls to prevent accidents and in improving emergency preparedness to respond to them should they occur. It feeds into the cyclical process of risk assessment, implementing controls and emergency arrangements, training, review and back to risk assessment. There are a number of dimensions to this. One is the level at which the learning process is taking place; from international and national levels down to the individual level. Other important dimensions are

- the extent of sophistication of the radiological protection infrastructure.
- the different sectors of use, eg, nuclear, industrial, medical, research etc and their respective safety cultures.
- the mechanisms for capturing information on accidents and incidents; assessment, analysis and dissemination.

This paper reviews some of the initiatives to improve the process of learning the lessons from accidents and incidents. It primarily focuses on the non nuclear sector. By its nature it cannot be exhaustive and is very much a personal view.

2. AWAKENINGS

The radiological accident in Goiania, Brazil in 1987 [1] provided something of a wake-up call on the potential serious consequences that can arise from the loss of control of radioactive sources. One of the positive outcomes from that accident was the start of a series of International Atomic

Energy Agency (IAEA) Accident Investigation publications that identified lessons to be learned [1–11]. Sadly many accidents are still either not reported in the open literature – or in some cases not even recognised.

Over the subsequent years there was an increasing stream of reports of sources either ending up in the metals recycling industry with serious economic consequences from smelting of the sources [12]; or in the public domain resulting in serious deterministic effects, environmental and socio-economic impacts. IAEA identified that globally a key root cause was the lack in many countries of an effective regulatory infrastructure and a critical mass of appropriate radiological protection expertise. To address this IAEA developed the Model Project [13]; and whilst there is clear progress, there is much to do.

The various issues were brought into focus in the International Conference on the Safety of Radiation Sources and Security of Radioactive Materials in Dijon in 1998 [14]. Arising from this was the development of IAEA's Action Plan to address the issues [15]. This was subsequently revised in 2000 and 2003 [16]. The term Orphan Source came into common usage being defined as "a source which poses sufficient radiological hazard to warrant regulatory control but is not under regulatory control, either because it never has been under regulatory control or because it has been abandoned, lost, misplaced, stolen or transferred without proper authorization".

A major element of IAEA's Action Plan was the development of an international "Code of Conduct on the Safety and Security of Radioactive Sources" [17]. Whilst not legally binding as an International Convention would be, it provided a vehicle for an 'international undertaking' that countries could commit to at a political level. Within the European Union (EU) the orphan source problem was also being addressed with the development of a (legally binding) High Activity Sealed Source (HASS) Directive [18]. Both these initiatives are examples of the international community learning the lessons from previous accidents and incidents, and seeking to improve controls over radioactive sources. However one has to say that the overall timescale for change and the pace in moving towards these international undertakings was not breath-taking – not for the want of effort by IAEA, EU and many others.

The tragic act of terrorism of 11 September 2001 in New York and Washington, gave a wake-up call to the world in more ways than one. It has impacted on all our lives in some way. This was followed by the distribution of Anthrax spores through the US postal service, which claimed 5 lives, caused significant disruption and spawned ongoing "white powder" incidents around the world. These events together with the earlier terrorist attack on the Tokyo underground in 1995 using the nerve agent Sarin, have fundamentally changed the credibility of a spectrum terrorist driven scenarios using different agents. To date there has been no serious attempt to utilise radiological or nuclear agents, however the global lessons from the terrorist events were recognised by the radiological protection community and, importantly, by governments and international bodies. The net result has been a significant focus of effort and political commitment to improve our collective ability to prevent, and if necessary, respond to Chemical, Biological, Radiological and Nuclear (CBRN) incidents.

3. IMPACT

3.1 Source security and orphan sources

The above had a significant impact on the various initiatives to improve the safety and security of radioactive sources worldwide and to address the issue of orphan sources. To the latter we now have to overlay the serious potential for terrorists to maliciously acquire radioactive sources and use them in some form of improvised radiological device. This is a significant change in that historically the emphasis in respect of source security has been on preventing inadvertent access or loss of control. Whereas now there is the added dimension of deliberate challenges to source security by terrorists. Getting the balance correct between security measures and maintaining the functionality and usefulness of radiological sources is not without problems. This issue is developed in the subsequent paper by Dodd [19] and it is anticipated that the solution to the issue will evolve, probably on a timescale of years rather than months.

Another impact of the global lessons, has been an acceleration of actions to address orphan source issues. The net effect has been that *inter alia* the IAEA Code of Conduct and the EU HASS Directive have been formally agreed faster than they would have otherwise have done. However there is still much to be done and lessons to be learned in the practical implementation of these documents. This acceleration has stemmed from the issue rising up the political agenda. In turn this is due to a recognition not only of the need to improve source security, but the need to bring back under control the many orphan sources that are either already lost from control and in the public domain or just one stage removed. This latter group is the large volume of disused sources, that are nominally still under control, but have been disused for many years and the record or knowledge of their existence is diminishing (see Section 8).

3.2 Emergency preparedness

As identified earlier the range of the credible has shifted dramatically and this provides an opportunity and a positive need for 'Getting Ahead of the Curve' – or ahead of the changing threat profile. As yet there has been no real example of the use of a terrorist driven Improvised Radiological Device (IRD), but it is known that terrorists have shown interest in these. This has caused emergency planners to ponder long and hard over how to plan for a radiological attack at an unknown location(s), with an unknown source term and an unknown dispersion/deployment mode. The latter could vary from the classical dirty bomb giving rise to plume dispersion and/or fragments, to a radiological emplacement device that is not announced and only becomes apparent when deterministic health effects are recognised. In essence the emergency planners are pondering the question of "how long is a piece of string". Here it is suggested that there is much to be learned from the lessons of dealing with previous accidents. In particular the accident in Goiania, Brazil in 1987 [1] has much to commend it as a design basis consequence to plan for. It has the elements of

- unrecognised health effects from external exposure to source fragments (as may be the case for an implacement device).
- widespread dispersion of radioactive contamination across an urban environment.
- a large range of intakes of radioactive material.
- disruption, fear and trauma (as may be associated with a terrorist attack).
- the production of a large volume of radioactive waste (3,500 m^3) – very few countries have addressed this lesson.

An attack resulting in an end effect such as Goiania would challenge even the most well developed national radiological protection infrastructures. To this we also have to add the lesson that recent experience has shown a predilection of the terrorists to coordinate multiple events. There are international assistance mechanisms in place that would help, for example

(a) the IAEA administered International Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency [20]

(b) the WHO Radiation Emergency Medical Preparedness and Assistance Network (REMPAN) [21]

Perhaps the immediate lesson is that there is an ongoing need for review and exercising of national and international arrangements.

A further conclusion to be drawn from the recent past is that terrorists may not just use one agent in an attack or a series of coordinated attacks. This has led a number of national authorities to look towards a coherent approach to CBRN issues, which also has implications for more routine aspects of radiological protection. For example, in the UK, the Chief Medical Officer for England, published in January 2002 a document entitled "Getting Ahead of the Curve" [22].

This was primarily targeted at improving the strategy for combating infectious diseases but "In its development the strategy has been shaped by experience and opinion which strongly supports the need for a broad based approach to health protection as a whole – infectious disease control as well as measures to address the risks posed by chemical and radiation hazards". This led to the establishment of the Health Protection Agency (HPA) which NRPB is working in partnership with and under a Bill currently going through Parliament, NRPB will become part of HPA. There have already been a number of positive elements to this; for example, collaboration with our chemical colleagues on dispersion modelling for radioisotopes and chemicals; and coordination of emergency response measures, one aspect of which is the development of a broader surge capacity base. It will be interesting to see at the IRPA12 meeting in 2008 what effects this and other coordination of public health issues will have had on the radiological protection community.

3.3 Other lessons continue

The current focus on CBRN issues is well merited, and has had a beneficial effect in dealing with some pre-existing issues such as those from orphan sources. However conventionally driven accidents and incidents still regularly occur, sometimes with severe consequences. It is important that we continue to investigate these and learn the lessons from them. The following sections concentrate on this ongoing aspect.

4. FEEDBACK MECHANISMS

The IAEA's reports of accident investigations have contributed significantly to the process of learning from accidents. By their very nature they have concentrated on the more important accidents that need to be reported in depth, often having many facets such as regulatory control, system failures, emergency response and medical treatment of the radiation casualties. However it is not only the big accidents from which we can learn, we can also learn from the smaller accidents and near misses. This feedback is relevant to suppliers in improving the safety aspects of design, the management in developing radiation protection measures and the training of their staff, and to national and international authorities in helping them prioritise issues and resources to deal with them. Some examples of feedback mechanisms are given in the following subsections.

4.1 IRID

In 1996 in the UK, NRPB, the Health and Safety Executive (HSE) and the Environment Agency (EA) jointly established the Ionising Radiations Incident Database (IRID) and published its specifications [23].

The database has 23 alphanumeric fields which categorise the incidents and allow navigation through the database. However the 24th field is the most important field being a text description of the incident, the causes, the consequences and the lessons to be learned. The description is anonymous and is designed to be used as training material.

In 1999 a first review of cases reported was published [24] and it is accessible on the web, http://www.irid.org.uk.

4.2 RELIR

The Qualified Expert Group of the French Radiological Protection Society has created an arrangement known as Retours d'Experience sur Les Incidents Radiologiques (RELIR) or in

English, Feedback Experience on Radiological Accidents. This has now been undertaken in collaboration with CEPN and the case reports can be found on their website http://www.relir.cepn.asso.fr.

4.3 EURAIDE

A pilot study is nearing completion for the creation of a European Union Radiation Accident and Incident Data Exchange (EURAIDE) system. The objectives of the study are

(i) facilitating the establishment of national radiation accident and incident databases where there are none, and to encourage the compatibility of such databases.

(ii) establishing a European network to exchange radiological protection feedback from accidents and incidents.

(iii) establishing summary reports of relevant accidents and incidents with the aim of identifying lessons to be learned, so that they can be included in radiation protection training programmes.

(iv) upgrading the radiological safety in the countries applying to join the EU by integrating them into the above feedback exchange system.

4.4 RADEV

The IAEA is informed of radiation accidents and incidents by a variety of routes. In order to bring these inputs together in a database to facilitate feedback it has developed the RADiation EVent (RADEV) database. This provides for the categorisation of accidents and provides summary descriptions of events, with lessons to be learned that can be used as training material. There has been significant international consultation on the design of the database and the software. It is currently in its final stages of international trialing and will be made available on the IAEA website. Importantly the software has been designed so that Member States can have their own copy and use it as the basis of their national database.

5. COMMON CAUSES OF ACCIDENTS

The causes for the loss of control of a source are many and varied. It may be due to a single catastrophic failure or more commonly a combination of events. Table 1 provides a list of some of the more common causes. Here 'loss of control of a source' is taken to include failure of safety systems to control exposures, as well as the physical loss of a radioactive source.

Table 1. Common causes of loss of control of radioactive sources

Root causes

- Lack of, or ineffective
  - regulatory bodies
  - regulations
  - regulatory enforcement
- Lack of
  - national radiation protection services
  - awareness or training of management and workers
  - commitment by management to safety
  - an effective radiological protection programme in the organization

Specific causes

- Lack of, or inadequate
  - prior risk assessment
  - security during storage, transport and use
  - radiation surveys, e.g. failure to monitor after a γ-radiography exposure
  - supervision
  - emergency preparedness plans
- Design or manufacturing fault
- Inappropriate maintenance procedures
- Human error
- Deliberate avoidance of regulatory requirements
- Abandonment
- Catastrophic event, e.g. fire, explosion, flood
- Theft
- Malicious act
- Loss of corporate knowledge, due to:
  - loss or transfer of key personnel
  - bankruptcy
  - long term storage of sources
  - decommissioning of plant and facilities
- Death of owner
- Inhibitions to legal disposal, such as:
  - no disposal route available
  - export not possible
  - high costs of disposal

An effective regulatory infrastructure will incorporate measures to eliminate or minimize the above problems. However it has to be recognised that it is not just a case of having an appropriate set of regulations. The regulators have to have an appropriate knowledge and skills base (in short be trained) and need the support of a radiation protection infrastructure with a critical mass. By their regulatory enforcement programme, the regulators can set the tone of user compliance. Together with input from Qualified Experts (from the radiation protection infrastructure) this strongly influences the development of the safety culture amongst users. Safety culture is an intangible but readily recognisable characteristic that takes time to develop. The consequence is that although many countries are making significant steps forward to develop a regulatory infrastructure, the development of a safety culture will lag behind and threats to the safety and security of sources will remain an issue for some time to come.

Even mature regulatory infrastructures cannot completely eliminate the threats. Periodically the effectiveness of the arrangements needs to be reviewed in the light of accidents and incidents that have occurred or might occur. One aspect of this might be to look at the possible threats through the life patterns of use of sources. Figure 1 provides a schematic representation of one such approach. In Section 6 examples are given of incidents and accidents that have arisen from the listed shortcomings.

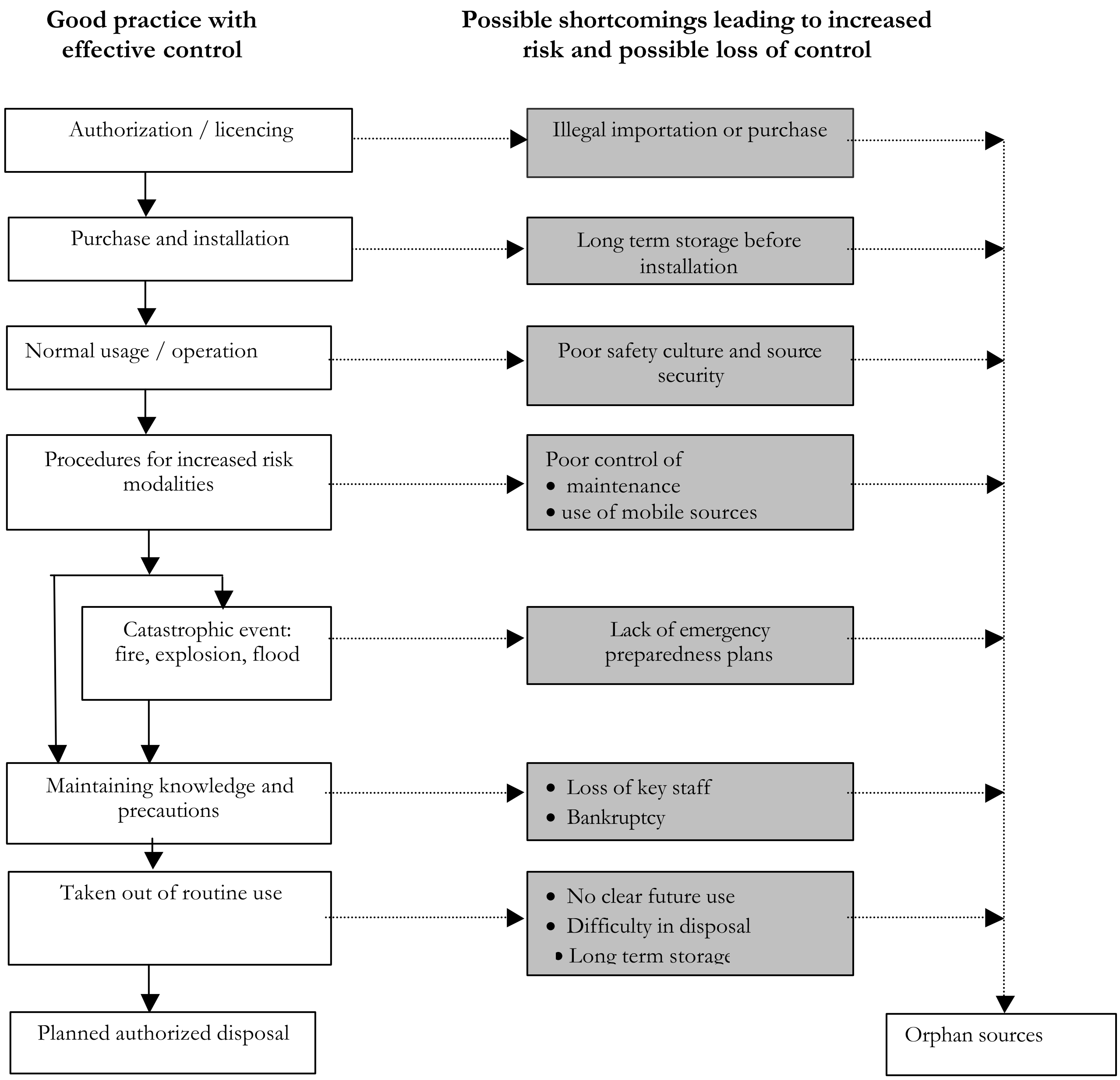

Figure 1. Challenges to good practice

6. EXAMPLES OF FAILURES IN SOURCE SECURITY

6.1 Illegal importation/purchase

In 1977 a 37 TBq ^{60}Co teletherapy unit was bought from a hospital in the USA by a hospital in Juarez, Mexico [25]. It was not imported legally and the authorities were unaware of it. The hospital did not have the resources to use it immediately and it was put into storage in a commercial facility without a clear indication of the hazards. The relevant senior staff left the hospital. In 1983 a junior member of staff who knew of its existence, but had no knowledge of the hazard, removed it to sell as scrap metal. During transport of the source it was ruptured and some small source pellets scattered along the road. The source was smelted in a foundry and was only discovered when a lorry carrying contaminated products set off the alarms at the Los Alamos nuclear facility.

Some 75 people received doses between 0.25 and 7.0 Gy: 814 houses with activity in the steel reinforcing bars had to be demolished, several foundries required extensive decontamination and the waste generated amounted to 16,000 m^3 of soil and 4,500 tonnes of metal.

This accident provides an example of a combination of causes: illegal importation preventing regulatory oversight together with long term insecure storage before use and loss of key staff. Had regulatory oversight been possible from the start ie, legal importation and authorisation, the other causes of the accident could have been prevented.

6.2 Normal usage

Table 1 includes many possible causes of loss of control of radioactive sources that provide challenges to source security during the normal usage of radioactive sources. Management commitment, training and overall safety culture are key elements in ensuring appropriate safety and security measures throughout the useful life of radioactive sources. However there are many instances of good systems being introduced at the beginning of usage, but not being maintained throughout the useful life of sources.

6.2.1 Brachytherapy sources in hospitals

There are different types of brachytherapy radioactive sources ranging from 50–500 MBq ^{137}Cs sources, used in interstitial manual techniques, to 400 GBq ^{192}Ir sources used in remote afterloading techniques. A major radiotherapy unit could have several hundred brachytherapy sources that are continually being moved and manipulated. This provides an increased potential for failures in following procedures and sources to be lost. There have been many reported instances of such sources leaving hospitals in refuse, still implanted in patients or cadavers. To address this countries often require hospitals to have installed radiation detectors at relevant exit points. Even so there are still reported instances of sources being lost. Typically this comes about from a combination of

- (i) complacency by those manipulating the sources – "familiarity breeds contempt" – leading to failure to follow procedures,
- (ii) poor maintenance of detector systems, either of the equipment itself or its positioning in what may be a changing environment, and
- (iii) lack of management oversight to recognise and address the problems.

6.2.2 Radioactive sources in the nuclear industry

Within a nuclear fuel cycle facility a high profile is given to the security of nuclear material and fission products. The same may not always be the case for radioactive sources. Following a minor incident at a nuclear facility in the UK involving the security of a conventional radioactive source, the company carried out a review of the security arrangements for such sources. They found that for the over 2000 sources they had on site these arrangements needed improving, particularly in respect of keeping inventories up to date. Although all the sources were accounted for, many were in different locations than the records showed;

having been moved from one location to another for operational reasons. In locating all the sources they realised that a visual image of each source or device was important. As a result they now have a policy of having an electronic image of all their sources to supplement the inventory record and to facilitate finding a source were it to be lost.

6.3 Increased risk modalities

Some types of use provide increased challenges to source security. Whilst maintenance of equipment is often an essential element of a radiation safety programme, it can also provide greater scope than normal usage for mishaps. This is because maintenance work often requires the overriding of installed safety systems or working in an environment where the operators may not be fully familiar with the local arrangements or hazards. If the work is not properly planned by well trained staff the net effect has in some cases been that the radioactive source has been left in an insecure manner.

Another increased risk modality is that of mobile sources. Common examples are sources used for industrial radiography (see Section 6.4) and those used in the oil exploration, mining industry and construction work for the determination of density, porosity and moisture or hydrocarbon content of geological structures or building materials. The sources in their containers are transported from site to site in cars or vans and may be left overnight in the vehicle or temporary storage facilities that may not be secure. There have been instances of the vehicles (with the device in them) being stolen. The thieves may or may not recognise the significance of the contents and often the devices with the radioactive sources in them are abandoned in the public domain.

6.4 Industrial radiography accidents

Industrial radiography is in wide spread use, and has a high hazard potential. The construction of petrochemical installations, for example, will involve the use of portable radiographic sources of up to 5 TBq for testing welds in pipes and tanks. Some years ago ^{137}Cs sources were used and some of these may still exist. Currently, sources will most often be ^{192}Ir or ^{60}Co, but ^{169}Yb, ^{170}Tm or ^{75}Se may also be used. The housings for these portable sources contain several tens of kilograms of shielding material, such as depleted uranium, lead or tungsten, which may be perceived as being potentially valuable. Also relevant is the fact that the portable nature of this equipment allows it to be used almost anywhere. Often this is in remote locations or under extreme working conditions. Couple this with often limited or non-existent supervision and there is a real potential for entire containers with their sources to be lost or stolen. They can end up in the metals recycling industry or lay dormant in random locations in the public domain.

However, perhaps the most significant threat comes from loss of the source on its own. Most remote-exposure radiography source containers have the same general design. The source capsule is physically attached to a short flexible unit often known as a ‘source pigtail’. This is designed to be coupled, often with a spring assisted ball and socket joint, to a flexible drive cable. When not in use the source is located in the center of the source container. In use, a guide tube is attached to the front of the container and the source is pushed down it to the required position by winding out the drive cable. Poor maintenance, incorrect coupling, obstructions in the guide tube or kinking it can all lead to extreme pressures being placed on the various linkages and eventually to the source becoming decoupled from the drive cable. This poses an immediate threat to the radiographer who must monitor after every exposure to ensure the source has fully returned to the safe shielded position. Failure to do so has lead to serious exposure of the radiographer and the source dropping out of the equipment unnoticed. To members of the public who find such radiography sources, they look like intriguing items and can easily be picked up and carried back to the family home; often with lethal effects as illustrated below.

6.4.1 Morocco, 1984

In this serious accident, eight members of the public died from overexposure to radiation from a radiography source. A 1.1 TBq (30 Ci) ^{192}Ir source became disconnected from its drive cable and was not properly returned to its shielded container. Later the guide tube was disconnected from the exposure device and the source eventually dropped to the ground, where a passer-by picked up the tiny metal cylinder and took it home. The source was lost from March to June, and a total of 8 persons (the passer-by, members of his family and some relatives) died; the clinical diagnosis was 'lung haemorrhages'. It was initially assumed that the deaths were the result of poisoning. Only after the last family member had died was it suspected that the deaths might have been caused by radiation. The source was recovered in June 1984.

6.4.2 Yanango, Peru, 1999

In this accident [10] gamma radiography using a 1.37 TBq ^{192}Ir source in a remote exposure container, was being carried out at the Yanango hydroelectric power plant. At some stage the 'source pigtail' became detached from its drive cable. A welder picked up the source, placed it in his pocket and took it home. The loss of the source was noticed the same day and it was recovered within 24 hours. However the dose received in this period was such that despite heroic medical treatment the welder lost one leg and had other major radiation burns. His wife and children were also exposed, but to a lesser extent.

6.4.3 Cairo, Egypt, 2000

This was a very similar incident to the one above. A farmer picked up a 3 TBq ^{192}Ir source, thinking it valuable and took it home. On 6 May 2000 the farmer and his 9-year-old son went to their local doctor complaining of skin burns. The doctor prescribed medication for a viral or bacterial infection. The youngest son died on 5 June 2000 and the farmer on 16 June. On 26 June a blood test was done on other family members who were showing similar symptoms. The blood test showed severe depression of the white blood cell count and radiation exposure was suspected. The source was located and recovered. Other family members were hospitalized. Four men were charged with gross negligence, manslaughter, and unintentional injury because they had failed to notify authorities that the source, used to inspect natural gas pipeline welds, was not recovered after the job.

6.5 Challenging events

During the life of some sources there may be some events that challenge the safety and security measures through abnormal situations, eg, fires, flood, explosions, transport accidents etc. The first requirement is recognition that an event may have a source security implication. This should then lead to the triggering of appropriate emergency preparedness plans. The greater the delay in implementing the emergency preparedness plan the longer there will be uncontrolled exposure and the greater area over which there may need to be searches for lost sources.

6.5.1 Accident in San Salvador, 1989

This accident [6] occurred in an industrial irradiation facility containing 0.66 PBq of ^{60}Co in the form of a source rack of two modules each containing a number of source pencils. At the time of the accident there was no relevant regulatory or radiation safety infrastructure and the country had been in a civil war for 10 years. The net effect was a degradation of the safety systems and the operators' understanding of radiation hazards. In the accident in 1989, three people gained entry to an irradiation chamber to free the source rack, whose movement to the safety of the water pit had been impeded by distorted product boxes. One person died and another had a leg amputated.

The occurrence was not recognised for two weeks, and during this time damage to the source rack from the accident caused the source pencils to drop out. Most fell into the water pit, but one fell onto the floor of the irradiation chamber. It is pure chance that none fell into one of the product boxes that could have transferred them out of the facility. The installed monitor on the product exit, designed to detect such an event, had long since failed. Some 6 months after the accident an IAEA team visited the plant to carry out an accident investigation. By that time the source pencil from the irradiation chamber had been recovered and shielded by the supplier, but the other source pencils were still at the bottom of the water pit awaiting recovery. Importantly no one had confirmed that the total inventory of source pencils had been accounted for and that none had left the plant. At the insistence of the IAEA team an underwater photograph was taken to confirm that all the source pencils were accounted for.

6.5.2 Tammiku, Estonia, 1994

In this accident [2] a cylindrical radioactive source in a metal frame was found in a consignment of scrap metal imported to Tallin, Estonia. The source, with an activity of up to 7.4 TBq ^{137}Cs was thought to be part, just a small part, of a seed irradiator (leaving the open question of where the rest of it was?). In this case the first part of the emergency preparedness plans worked and the source was successfully recovered and taken to the national waste disposal facility. Unfortunately this was just an underground concrete bunker with poor security. Three brothers broke into the facility and stole the source for resale as scrap metal. As a result one brother died from radiation exposure and the other two brothers, plus two other family members suffered significant deterministic effects.

The original find of the source in scrap metal imports had raised queries about other possible orphan sources being in Estonia and a Government Commission to assess the situation was set up. During its work it found a 1.6 TBq ^{137}Cs source in a container that had been abandoned close to a main road in the countryside.

7. MAINTAINING KNOWLEDGE AND PRECAUTIONS

Over the useful life of a radioactive source, which may be decades, there can be challenges to keeping the corporate knowledge of the source security requirements or even of the existence of the sources. For example

(i) The knowledge of the source security arrangements may be vested in one or two key staff, without it being properly covered in safety documentation or covered by management oversight. When those key staff leave the source security arrangements will degrade.

(ii) A sudden change in ownership can remove all corporate knowledge of the need for source security requirements. The accident described in 5.1 below provides an example of the change of ownership of a facility between nations where knowledge was not passed on.

(iii) Bankruptcy can also remove corporate knowledge. This can happen very suddenly with in some cases everybody walking away from the problem and leaving a derelict facility. Although the accident in Goiania described in 5.2 is not a case of bankruptcy it has the same characteristics eg, abandonment of responsibility.

7.1 Lilo, Georgia

In 1992, with the break up of the former USSR, the Soviet Army abandoned its former facilities in Georgia. One of these was a training camp in Lilo, which was taken over by the Georgian Army. In October 1997, eleven soldiers developed radiation induced skin lesions. A radiation-monitoring search of the facility revealed 12 abandoned ^{137}Cs sources ranging from a few MBq to 164 GBq [3]. These had been used by the previous occupants in Civil Defence Training; with the sources being hidden about the site and trainees having to find them. Many were still where they had been hidden. In addition, one ^{60}Co source and 200 small ^{226}Ra sources used on gun sights were also found on the site.

7.2 Goiania, Brazil

In 1987 in Goiânia [1], a private medical partnership specialising in radiotherapy broke up acrimoniously. No one took responsibility for a 50 TBq ^{137}Cs teletherapy unit that was left abandoned in the partially demolished building of the former clinic. After two years some local people dismantled the source and its housing and removed it for scrap metal value. In the process the source was ruptured. The radioactive material was in the form of compacted caesium chloride, which is highly soluble and readily dispersible. For over two weeks the radioactivity was spread over parts of the city by contact contamination and resuspension. Contaminated items (and people) went to other parts of the country.

The recognition of the existence of the problem was triggered by an increasing number of health effects. Overall some 249 people were externally contaminated, 129 internally, 21 people received in excess of 1 Gy and were hospitalized, of which 10 needed specialized medical treatment with 4 of these dying. The decontamination and clean up of the environment took 6 months of intensive effort and produced 3,500 tonnes of active waste.

In passing it is worth noting that although not an example of terrorism the Goiania accident provides a good example of the possible consequences of the use by terrorists of an improvised radiation dispersal device.

8. DISUSED SOURCES

There are a number of similarities between the issues identified in the previous section and the problem of disused or "spent sources". Both involve the loss of corporate knowledge or awareness of source security issues, but this section very much focuses on the end of life issues of radioactive sources. Perhaps the main characteristic here is that at some stage there has been a recognition that the sources, or the equipment they are in, have come to the end of their useful life or there is no clear future use for them. This can manifest itself in many ways.

(i) The sources can simply be removed to storage on site and through lack of management are not disposed off but simply left. Over time the safety and security arrangements degrade until eventually control is lost and the source may end up in the public domain, especially the metals recycling industry. The accidents described in 6.1 and 6.2 provide significant examples of this.

(ii) A variation on the above theme is that the sources are left in situ, eg, in level gauges on a disused part of a petrochemical facility. Eventually when that part of the plant is demolished, all the metal, including the sources, ends up in the metals recycling industry and the source may be smelted. There are many such recorded events which can be very costly: in the range US$ 1 to 100M [12].

(iii) In many cases the management takes a conscious decision not to dispose of the source, simply because the costs of disposal are very high. Whilst security arrangements may be maintained to a degree, the effect of this practice is to increase the potential for security to fail over time. It has been estimated that in the USA 500,000 of the two million sources may no longer be needed and thus could be susceptible to being orphan [26] – or a target for malicious intent. In the European Union some 30,000 sources are in a similar position [27].

8.1 Istanbul, Turkey

In 1993 a licenced operator loaded three spent radiotherapy sources into transport packages for their return to the original supplier in the USA [4]. However the packages were not sent and were stored in Ankara until 1998. Two were then transported to Istanbul and stored in a general-purpose warehouse. After some time the warehouse became full and the packages were moved to empty adjoining premises. After 9 months these premises were transferred to new ownership, and the new owners not knowing the nature of the packages, sold them as scrap metal. The family of scrap merchants broke open the source container and unwittingly exposed themselves to the unshielded 3.3 TBq ^{60}Co source. Ten people received doses between 1.0 and 3.1 Gy and showed signs of the acute radiation syndrome. Fortunately no one died.

The second source, 23.5 TBq ^{60}Co remains unaccounted for, despite an extensive search and monitoring programme.

8.2 Samut Prakarn, Thailand

One company in Bangkok possessed several teletherapy devices without authorization from the Thailand Office of Atomic Energy for Peace [5]. In the autumn of 1999, the company relocated the teletherapy heads from a warehouse it had leased to an unsecured storage location. In late January 2000, several individuals obtained access to this location and partially disassembled a teletherapy head containing 15.7 TBq of ^{60}Co. They took the unit to the residence of one of the individuals, where four people attempted to disassemble it further. Although the head displayed a radiation trefoil and warning label, the individuals did not recognize the symbol or understand the language. On 1 February 2000, two of the individuals took the partially disassembled device to a junkyard in Samut Prakarn. While a worker at the junkyard was disassembling the device using an oxyacetylene torch, the source fell out of its housing unobserved.

By the middle of February 2000, several of the individuals involved began to feel ill and sought assistance. Physicians recognized the signs and symptoms and alerted the authorities. After some searching through the scrap metal pile, the source was found and recovered. Altogether, ten people received high doses from the source. Three of those people, all workers at the junkyard, died within two months of the accident as a consequence of their exposure.

9. CONCLUSIONS

It is clear that there are many lessons to be learned from accidents and incidents which can help improve our control of radiation sources and in responding to radiation accidents.

During the 1980's and 1990's there was a growing awareness of a major issue over Orphan Sources and source security. As a result the international radiation protection community set in motion a number of initiatives to address the issue. These are now starting to bear fruit, but there is still much to do.

The tragic act of terrorism on 11 September 2001 in the USA fundamentally changed the credibility of terrorist driven scenarios that might include radiation sources. In particular it indicated that source security must now not only protect against inadvertent access to radiation sources but also the deliberate access challenge from terrorists trying to aquire radiation sources. Getting the correct balance between source security and maintaining the functionality and usefulness of radiation sources will be a challenge.

The current focus on CBRN issues is well merited, and has had a beneficial effect in dealing with some pre-existing issues such as those from orphan sources. However conventionally driven accidents and incidents still regularly occur, sometimes with severe consequences. It is important that we continue to investigate these and learn the lessons from them.

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