Improvement of a high risk category source buried in the grounds of a hospital in Cambodia

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Abstract

This paper describes the improvements to the site of a high activity Cobalt-60 source buried in the grounds of the Khmer Soviet Friendship Hospital in Phnom Penh, Cambodia. The characterisation of the buried source and the options available to improve the area amenity, safety and security are described. The implementation of the preferred option of improving the site's shielding and access control is discussed, including the criteria to be satisfied for the site improvement and radiation protection and occupational health and safety considerations.

Key Words

Radioactive source control safety and security, health physics, Cambodia

1. Introduction

Since 2005, the Australian Nuclear Science and Technology Organisation (ANSTO) Regional Security of Radioactive Sources (RSRS) Project has conducted activities to assist countries in South East Asia to improve the security of high-risk radioactive sources [1]. As part of these efforts we have discovered situations of vulnerable legacy sources including a high activity Cobalt-60 (Co-60) source buried in the grounds of the Khmer Soviet Friendship Hospital (KSFH), also known as the Preah Bat Norodom Sihanouk Hospital, in Phnom Penh, Cambodia [2].

In early 2005, a hospital medical physicist observed localised elevated radiation levels arising from outside the oncology department building during a routine survey. Further investigation revealed a surface radiation hot-spot was identified about two metres from the building. In March 2005 the hospital staff partially excavated this hot-spot and upon measuring significant radiation dose rates placed a quantity of CerroBend shielding material within the excavation and five concrete blocks on the surface, so that the near-surface dose rate was less than a few tens of µSv/h. The area was fenced and a sign in Khmer erected warning of land mines (Figure 1). This was considered to be a temporary and unsatisfactory situation.

Figure 1: Buried source site in 2005 when first discovered and later fenced, including Khmer sign warning of mines.

Subsequent investigation, including interviews with former hospital staff, indicated that the buried orphan radioactive source is most likely one or more Co-60 teletherapy sources used at the hospital before the Cambodian civil war of 1975-1981. The KSFH dates to around 1960 when the Soviet Union was actively providing development assistance and technical cooperation in South East Asia, including building radiotherapy facilities and supplying radioactive sources which at the time were referred to as cobalt "bombs" for cancer treatment [3].

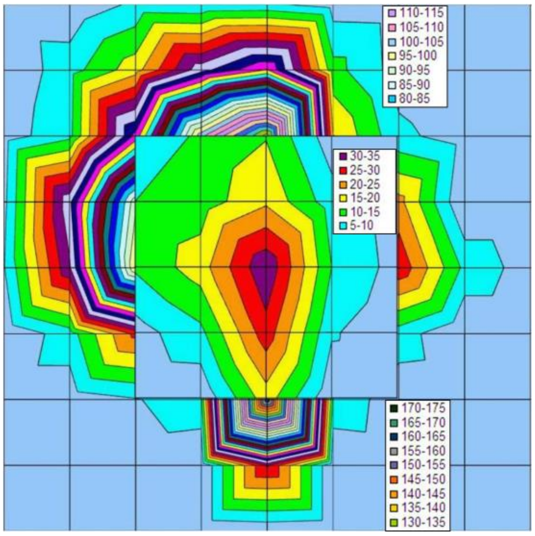
This paper describes the efforts conducted since 2005 to characterise the buried source and its conditions, the options considered to retrieve the source or remediate the situation, and the selection and implementation of the preferred option of improving the area amenity, safety and security without source retrieval. Health physics measurements and radiation protection considerations have been documented in ANSTO technical reports [4] - [12] and some of this work has been presented at the Australasian Radiation Protection Society annual conferences in 2006 and 2011 [13], [14], and at the International Radiation Protection Association Conference in 2008 [2]. The site improvement work has been conducted in collaboration with the New Zealand National Radiation Laboratory as part of the New Zealand Government contributions to the Global Initiative to Combat Nuclear Terrorism. The United States National Nuclear Security Administration Global Threat Reduction Initiative represented by the Pacific North West National Laboratory has provided security upgrades to the hospital's radiotherapy facility and a CCTV camera to monitor the buried source.

2. Characterising the buried source

Figure 2: Buried source site with and without the concrete block shielding in place.

Gamma radiation dose rate and surface contamination surveys of the buried source site have been conducted with and without the concrete block shielding in place (Figure 2). When the CerroBend and concrete shielding was removed high radiation levels were measured, up to a maximum of 60 mSv/h at a few centimetres above the ground surface near the hot-spot.

In November 2005 and 2010 the maximum radiation dose rates measured at the gaps in the concrete shielding blocks were approximately 375 μSv/h and 165 μSv/h, respectively. This change in dose rate is consistent with the radioactive decay of the buried source with all other conditions, such as shielding and measurement location, being the same. Generally the radiation dose rates on top of the two layers of shielding blocks were between 15 to 35 μSv/h, see Figure 3. Radiation dose rates at 1 metre above ground level at the old barbed wire fence location varied between 1 and 8 μSv/h. A radiation survey at 1 metre and 1.8 metres above ground level along the perimeter of the proposed new fence line indicated dose rates of less than 3 μSv/h, with the majority being less than 1.5 μSv/h.



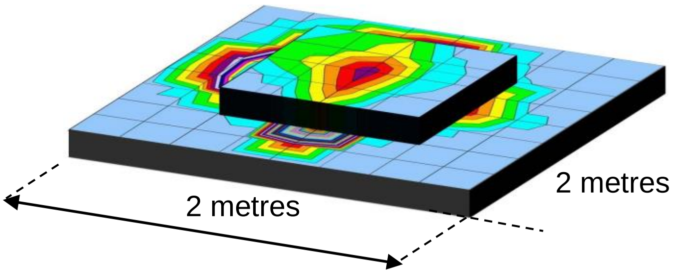


Figure 3: Contour plot in μSv/h of the dose rate survey measurements on the original concrete block shielding (plan and angled views). The asymmetry of the surface radiation field is probably due to partial shielding of the buried source.

Ground penetrating radar was used to determine if shielding was in place, and if so its size. However with a mix of materials including a rusted lid of an ammunition box (Figure 4) and residual shielding from when the source was discovered, the ground penetrating radar results were not definitive. The rusted ammunition box lid was recovered during partial excavation of the site, indicating the source may have been placed in such a box.

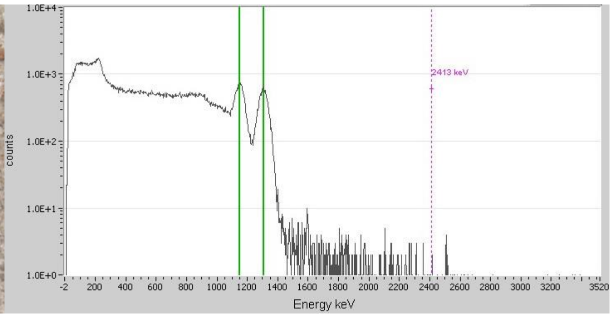


Figure 4: A rusted ammunition box lid recovered from the hospital buried source site from ground penetrating radar measurements.

Figure 5: GR-135 spectrum measured on 7 November 2010 at the hospital buried source site confirming Co-60.

Portable gamma spectroscopy measurements conducted at the buried source site confirmed that the source is Co-60, as shown by the characteristic gamma peaks of 1173.2 keV and 1332.5 keV appearing in the measured spectra shown in Figure 5 [15].

The activity of the buried source was estimated using dose rate measurements gathered from a small borehole drilled close to the source. Using a model AMP-200 high range gamma dose rate survey meter measurements were recorded at various depths around the maximum dose rate observed, as shown in Figure 6. The selection of the exact location to drill the borehole was within a few centimetres of the localised surface hot-spot. The distance between the probe and the source at which the maximum dose rate of 13.4 Sv/h was measured could not be accurately known but was estimated to be no further than 30 cm.

Using conservative assumptions for shielding and geometry, we concluded the source is buried between 30 cm and 50 cm below the ground surface. Various soil and shielding geometry scenarios were modelled using Microshield software and the activity of a Co-60 source in these variable conditions was conservatively estimated to be a few TBq up to a maximum of 12 TBq. This would represent a Category 2 source according to International Atomic Energy Agency (IAEA) criteria which if improperly handled could be "very dangerous to the person: it could cause permanent injury to a person who was in contact with it for a short time (minutes to hours); possibly fatal if in contact for hours to days" [16].

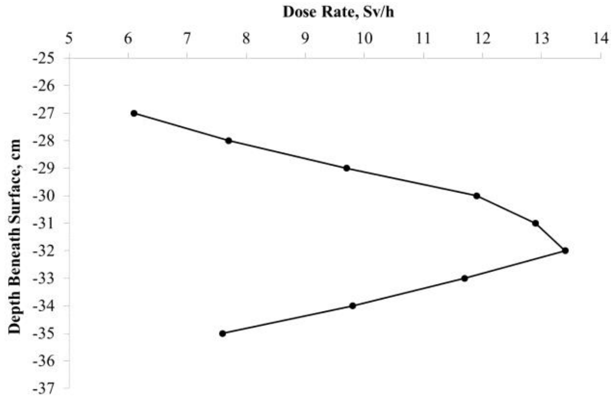


Figure 6: Dose rate-depth profile measured on 21 June 2007 at the hospital buried source site with a maximum dose rate of 13.4 Sv/h at a depth of 32 cm.

The results of the gamma radiation dose rate and surface contamination surveys since late 2005 are consistent with each other and there is no evidence that the buried object has moved or that conditions have significantly altered in that time. Surface and borehole gamma dose rates show that the radiation is non-uniform in distribution, implying partial shielding (Figure 3), possibly from the ammunition box. During the extent of these characterisation works at no point was any contamination found. This indicates there has been no degradation of the source encapsulation material.

In addition to conducting characterisation of the high-activity buried source we conducted a comprehensive radiation survey of a 5000 m^2 area surrounding the KSFH oncology department building in 2006 and discovered 31 low-activity Co-60 brachytherapy sources scattered through the area (total activity 18 MBq, Category 4 - unlikely to be dangerous to the person). These are believed to have been abandoned at the same time as the buried source and were probably scattered due to surface soil turnover. They were found within 15 cm of the ground surface, recovered, characterised, documented and placed into shielded storage at the hospital [7].

3. Options considered for site improvement

In July 2006 the Cambodian Ministry of Industry Mines and Energy sought ANSTO assistance and resources to remove the radioactive source from the hospital [17]. To improve the site's safety, security and area amenity ANSTO recommended that the preferable option was to retrieve the buried source from the hospital grounds, place it in a suitable shielded container, and transport it to either another country's storage facility or locate a suitable storage place in Cambodia. In order to store and manage the source outside of Cambodia, the sources country of origin was needed. While there is some evidence that the source was supplied by the former Soviet Union a request for investigation via the IAEA of available sale or export records now held by Russian authorities did not definitively confirm this. While it may have been possible to confirm the origin of the source if it was excavated, this would not necessarily assist in identifying a satisfactory end-of-life management pathway as there is almost certainly no contractual obligation to take the disused source back. The ability of many countries, including Australia, to provide a long-term storage or other disposition option for radioactive material is often restricted by their legislation prohibiting import of other's radioactive waste. As a result, we recommended that the Cambodian Government take responsibility for the source when retrieved and identify a suitable location for long-term safe and secure storage. The United States Department of Energy provided a suitable storage flask and ANSTO investigated techniques to safely excavate the source.

Various retrieval techniques were identified, partially developed and trialled at ANSTO facilities, with each technique evaluated for its effectiveness, any associated risks, and costs. The best option involved the use of a remote-controlled excavator typically used in buried landmine remediation, and placing the source into a water tank that provided shielding for further manual manipulation. Suitable filtering and mud settling techniques prior to recovery of the source from the water tank would allow examination and identification of the source prior to transfer and storage in the flask.

However, a suitable location for long-term safe and secure storage of the recovered source was not identified by the Cambodian Government and nor was there any indication that there would be a responsible Cambodian authority to manage the recovered source's safety and security. Also the area surrounding the buried source site was becoming a higher occupancy area both by the hospital and the surrounding land use (Figure 7). We therefore considered improving the hospital site with the buried source *in situ*.

Figure 7: 360º panorama of the hospital and the surrounding land use including new housing (the buried source site is circled).

In determining the best practicable option we relied on our experience gained over a number of years working closely with the key stakeholders in Cambodia. It was important to tailor a practicable solution taking account of the local technical infrastructure, the lack of clear authority and roles and responsibilities for the situation, competing resources and priorities of the hospital, and other risks and hazards prevalent in Cambodia. From a cost - risk - benefit perspective it was considered that improving the site without excavating the source was the preferred option. The reasons for not excavating the source were:

a) It would be an extensive and expensive operation to perform;
b) It would be highly hazardous to personnel involved and require careful planning and control of each step of the operation, under difficult local circumstances;
c) A long-term safe and secure storage site within Cambodia was not identified; and
d) There is no radiation safety or regulatory infrastructure in Cambodia and there was no responsible authority forthcoming to manage the retrieved source.

4. Improvement *in situ*

In November 2010 an assessment was performed with the aim to improve the radiation safety, security and area amenity of the site while leaving the source buried. The assessment concluded that a long-term, low-maintenance solution for improving the site is to install a more robust fence, place additional surface shielding and landscape the area. The relatively short 5.27 year half-life of Co-60 means that the site improvement needs to ensure satisfactory radiation protection and access control for several tens of years [15]. The design and installation of these works would satisfy public radiation protection criteria based on the radiological assessment for occasional uncontrolled occupancy at the new fence, maintain security and improve area amenity.

4.1. Public radiation protection criteria

All personnel, including hospital staff, patients and carers, are considered members of the public from a radiation safety point of view with respect to any exposure from the buried source. Considering the principle of ‘As Low As Reasonably Achievable’ (ALARA) a dose constraint of three-tenths of the IAEA recommended dose limit [18], or 300 µSv/year was used as the criteria for the design of the shielding and fencing location for public radiation protection of the buried source site. This also allowed for error in the assumed exposure time and is consistent with international best practice. As the buried source is within the hospital grounds and the amount of time spent in the surrounding area by an individual can be reasonably controlled if required, a conservative occupancy of 200 hours per year or about 4 hours per week for a full year was assumed. To satisfy the design dose constraint of 300 µSv/year, the maximum dose rate is required to be less than 1.5 µSv/h at the perimeter of the fenced area associated with the buried source.

4.2. Satisfaction of the public radiation protection criteria

To satisfy the public radiation protection criteria we conducted safety, security and area amenity improvement works at the site of the buried radioactive source in the KSFH grounds in February 2011. Agreement was obtained from the Director of the KSFH, the Cambodian Ministry of Health, and the Ministry of Industry, Mines and Energy (MIME) Energy Development Department to conduct these site improvement works. ANSTO and NZ NRL produced the technical specifications and contracted CPS Cambodia Co., Ltd. to complete the site works in accordance with developed safety assessments and procedures. The work included installing a security fence (Figure 8), constructing additional radiation shielding at the ground surface (Figure 9) and landscaping the area.

A radiation warning sign was installed in English and Khmer, along with the new ionizing radiation warning symbol (ISO 21482) on top of the existing concrete slab (Figure 10) [19]. The symbol is intended for IAEA Category 1, 2 and 3 sources and is a warning not to dismantle the enclosure or to get any closer. The signs are intended to warn any person attempting to disassemble the shielding enclosure, particularly those without knowledge of the buried radioactive source. As part of the shielding enclosure infill the signs were covered with sacking to ensure visibility if disturbed and then sand. The hospital buried source site after completion of the improvement works may be seen in Figure 11. The design life of the new construction is greater than 25 years with minimal ongoing maintenance.

Figure 8: Installing the security fence and gate around the hospital buried source site.

Figure 9: Brick work for the shielding enclosure and concrete infill up to the bottom concrete block.

Figure 10: Warning sign installation on top of existing concrete slab and sand infill.

Figure 11: Site after completion of improvement works.

To ensure that the area was left in a safe, secure and amenable condition, and to verify that the maximum dose rate met the requirement of less than 1.5 µSv/h at the perimeter of the fenced area, a final comprehensive radiological dose rate survey was conducted of the buried source site shielding enclosure and fence line. The effectiveness of the shielding enclosure is such that the highest dose rate at contact with the surface was less than 0.7 µSv/h. Therefore a member of the public would have to sit at this location for approximately 4 hours per day before reaching the IAEA recommended dose limit of 1 mSv/year whole body dose from all man-made sources of radiation [18]. The dose rates at the fence line were far below the design requirement and are at background levels (≤ 0.1 µSv/h). As such the improvement satisfies public radiation protection criteria for occasional uncontrolled occupancy at the new fence without any further monitoring, enhances security particularly access control, and improves area amenity.

4.3. Radiation safety management during the improvement works

We conducted external dose rate monitoring throughout all activities in all stages of the work and when necessary an evaluation of the situation was made by health physicists to ensure that the total dose and dose rates where personnel were located remained at an acceptable level. The dose constraints for the entire operation were set at 500 µSv for the health physics operations team personnel and 200 µSv for all other personnel by estimating expected cumulative dose using data from previous radiation surveys and task analysis. Electronic personal dosimeters (EPDs) were issued and recorded daily to everyone who entered the Controlled Area with dose rate alarm level of 100 µSv/h and cumulative dose alarm level of 100 µSv. The average accumulated dose received by individuals was about 7 µSv, which is well below the dose constraints indicating well planned and executed tasks, continuous dose rate monitoring and applying additional shielding controls when required. The maximum daily dose recorded was 18 µSv which is considered spurious since the crew member did not conduct any activities significantly different to those of the other crew members, and all other readings from that day were zero or one. However, for dose recording the reading was treated as "true". The EPD that recorded this result was removed from use during the work and used to record background readings. No further spurious readings were found (background ~ 1 µSv/day).

We conducted radioactive contamination monitoring of equipment, personnel, and items from the buried source site at all stages during the works and at no point was any contamination found.

5. Conclusions

Improvements to the security, safety and area amenity at the site of the high activity radioactive source buried in the grounds of a Phnom Penh hospital have been completed. The work was completed with minimal personnel radiation dose and well below the dose targets set in the ALARA assessment. The new shielded and access-controlled area ensures that radiation doses from the buried source to the public and hospital staff are well below internationally recommended dose constraints for members of the public. The site requires minimal ongoing maintenance and its design life of greater than 25 years will allow radioactive decay of the source to Category 3 without any further interventions.

The situation of this buried radioactive source highlights the need for continuous control, radiation protection and security considerations for radioactive sources throughout their lifetime. Following periods of conflict or societal breakdown, the international community must be prepared to assist countries to renew or re-establish local resources and the means to satisfactorily address the safety and security of vulnerable high activity radioactive sources. As in this case, the best solution of relocating the radioactive source to a well-managed storage facility may not always be achievable due to issues of local willingness, expertise and resources. International cooperation on the safety and security of radioactive sources is essential to provide support to ameliorate the impact of vulnerable radioactive sources.

6. Acknowledgments

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7. References

[1] *Report of the Third Regional Review Meeting of the Radiological Security Partnerships on Radioactive Source Security*, Philippines, January 2012, http://www.ansto.gov.au/__data/assets/pdf_file/0016/52126/201202_FINAL_Report_-_RRSP_Review_Meeting_2012.pdf.

[2] Mark Alexander and Allan Murray, *Managing the Risks of Legacy Radioactive Sources from a Security Perspective*, International Radiation Protection Association (IRPA) Conference, Buenos Aries, Argentina, October 2008.

[3] *Cambodia: The Neutral Harvest*, Time Magazine, 12 September, 1960, http://www.time.com/time/magazine/article/0,9171,897532,00.html.

[4] Allan Murray *et al*, *Characterisation of a Buried Radioactive Source at a Hospital, Phnom Penh, Cambodia,* S-RSRS-R-CAM-01.0, ANSTO, December 2005.

[5] Robert Blackley *et al*, *Further Characterisation of a Buried Radioactive Source at a Hospital, Phnom Penh, Cambodia,* S-RSRS-R-CAM-02.1, ANSTO, February 2006.

[6] Mark Alexander *et al*, *Investigation of the Plumbing System, and Discovery of Radioactive Sources, near a Buried Radioactive Source at a Hospital, Phnom Penh, Cambodia*, S-RSRS-R-CAM-03.1, ANSTO, October 2006.

[7] Mark Alexander *et al*, *Further Discovery of Orphaned Radioactive Sources and Preparations for Remediation of the Buried Source at a Hospital, Phnom Penh, Cambodia*, S-RSRS-R-CAM-04.1, ANSTO, January 2007.

[8] Mark Alexander *et al*, *Investigation of the Isolated Drainage System Near the Buried Source at a Hospital, Phnom Penh, Cambodia*, S-RSRS-R-CAM-05.0, ANSTO, September 2007.

[9] Mark Alexander *et al*, *Investigation of the Physical Attributes of the Buried Source at a Hospital, Phnom Penh, Cambodia,* S-RSRS-R-CAM-06.0, ANSTO, January 2008.

[10] Andrew Popp and Cris Ardouin, *Health Physics Survey Report in Support of the Assessment for Site Improvement of the Buried Radioactive Source Area at a Hospital, Phnom Penh, Cambodia*, S-RSRS-R-CAM-07.0, ANSTO, NRL, November 2010.

[11] Andrew Popp *et al*, *Report on Assessment for Site Improvement of the Buried Radioactive Source Area at a Hospital, Phnom Penh, Cambodia*, S-RSRS-R-CAM-08.0, ANSTO, NRL, US NNSA, November 2010.

[12] Andrew Popp and Cris Ardouin, *Health Physics Report for the Site Improvement at a Hospital, Phnom Penh, Cambodia, 31 January to 10 February 2011*, S-RSRS-R-CAM-11.0, ANSTO, NRL, March 2011.

[13] Robert Blackley *et al*, *Progress towards Remediation of an Orphan Source Situation in Cambodia*, ANSTO, Australasian Radiation Protection Society (ARPS) 31st annual conference, Sydney, Australia, October 2006.

[14] Andrew Popp *et al*, *Improvement of the Buried Radioactive Source situation at a Hospital in Cambodia*, ANSTO, NRL, Australasian Radiation Protection Society (ARPS) 36th annual conference, Melbourne, Australia, October 2011.

[15] G. Pfennig *et al*, CHART OF THE NUCLIDES, 6th Edition 1995, revised print 1998.

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, *Categorization of Radioactive Sources*, IAEA Safety Standards Series No. RS-G-1.9, IAEA, Vienna, 2005.

[17] Letter from Cambodian Secretary of State for the Ministry of Industry Mines and Energy to ANSTO, letter number 1486 MIME, July 27, 2006.

[18] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*, Safety Series No. 115, IAEA, Vienna, 1996.

[19] New Symbol Launched to Warn Public About Radiation Dangers, IAEA, 15 February 2007, http://www.iaea.org/newscenter/news/2007/radiationsymbol.html.