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Lack of international consensus on the disposition and storage of disused sealed sources

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ABSTRACT

A lower-activity analogue of the trans-national problem of spent fuel management and disposal is the global problem of radioactive sealed source [source: The IAEA definition of a sealed source is "Radioactive material that is permanently sealed in a capsule or closely bonded and in a solid form." Taken from glossary of Nuclear Waste Data Management found at http://www-ewmdb.iaea.org/showhelp.asp?Topic=8-1-1.] disposal. Sources are found in almost every country in the world because of their beneficial medical and commercial or industrial applications. Some of the isotopes used have short half-lives—iridium-192 (Ir-192), 73.8 days—while others have very long half-lives—americium-241 (Am-241), 432 years or plutonium-239 (Pu-239), 24,130 years. It is critically important, particularly for longer-lived isotopes, to find final disposition pathways. Lack of a permanent disposition pathway such as recycling or irretrievable disposal creates numerous problems, including the potential loss of regulatory control, which increases the risk of inadvertent or deliberate misuse of the material.

The misuse of radioactive materials has the potential for substantial public health and economic damage. Disused sources also pose an inherent risk to the end-users from a liability, safety, and public health perspectives. This paper examines various disposition pathways employed by several key source manufacturing or possessing nation-states for disused sources. Examples of source disposition pathways include long-term storage, deep geological disposal, borehole disposal and shallow land burial. The Off-Site Source Recovery Project (OSRP), part of the office of Global Threat Reduction Initiative (GTRI), acts as an intermediary in the recovery and ultimate disposition of US origin sealed radiological materials. Several concepts that could help mitigate the challenge of a lack of long-term disposition options for sources are available, but these tools have not yet been applied by most nation-states. For example, regional consolidation and repatriation of sources to the country of manufacture would ease or eliminate the need for in situ disposal or storage in a number of developing nation-states.

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1. Background

The difficulty of developing disposal alternatives for disused sources has offset many of the benefits of their use. Sources are used in numerous industrial, research, and medical applications and are currently used in nearly every country in the world. The wide availability of sources, including several with relatively long-lived isotopes, makes their collection and disposal very challenging. End-of-life disposition pathways for sources are few and vary widely from nation-state to nation-state; therefore, long-term-surface or near-surface storage remain the most commonly applied options. This paper investigates various nation-states current methods and future plans for storage and the permanent disposition of disused sources. For the purposes of comparison, nation-states with more advanced disposal methodologies are illustrated alongside a select few developing nation-states with scarce infrastructure for source disposal. Table 1 presents current and past national deep geologic repositories of which several store sealed sources. Not all of these deep geologic repositories are operational and, even though much of the waste taken at these sites fits into the same category of waste of most sources, some of these sites do not accept sources. Table 2 shows nation-states that are researching sites for the development of a national deep geologic repository, which may or may not include source disposal.

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Table 1
Active and non-active deep geological radioactive waste repositories[a]

Repository	Host rock	Operation
Hostim (CZ)	Limestone mine	1959–1965
Russian injection (RUS)	Clastic sediments	Since 1963
Richard (CZ)	Limestone mine	Since 1964
Asse (D)	Salt/potash mine	1967–1978
Bratrstvi (CZ)	Uranium mine	Since 1974
Morsleben (S)	Salt/potash mine	1978–1998
Forsmark (S)	Crystalline basement	Since 1998
Olkiluoto and Loviisa (FIN)	Crystalline basement	Since 1992/1997
WIPP (USA)	Salt	Since 1999

[a] Norbert Rempe, 2007. Permanent underground repositories for radioactive waste. (Science Direct) 367;Progress in Nuclear Energy (London: Elsevier) 49.

As the definition of disposal differs from nation-state to nation-state, the International Atomic Energy Agency (IAEA) definition of disposal was used.[1] In addition, waste category definitions for low-, intermediate-, and high-level-waste (LLW, ILW, HLW) tend to overlap or differ from nation-state to nation-state. Therefore, the definitions are the following: LLW is non-heat generating with low activity and a short half-life; ILW generates none to negligible heat and has low to intermediate activity with short to long half-life; and HLW is heat generating and has high activity with short to long or both half-lives.[2]

2. Europe

2.1. European Union nation-states

Currently, the European Union (EU) has four repositories that hold sources, two operational and two non-operational.[3] The operational repositories consist of one in Sweden and another in Czechoslovakia. Two closed and scheduled-to-be-closed repositories are located in Germany and in Czechoslovakia.

2.2. Finland

In Finland, sources are consolidated at a laboratory in Helsinki called Nuclear Waste and Materials Regulation (STUK). Finland has two LLW/ILW repositories, but both of them handle operational waste from nearby nuclear reactors and do not accept sources. These two repositories are mentioned simply as an example of what a repository might look like for the same categories of waste that sources typically fall under (LLW/ILW). One site, the VLJ Repository, is located less than 1 km from the Olkiluoto nuclear power plant on the island of Olkiluoto. This repository is a crystalline bedrock silo site with vertical tunnels located 70–100 m underground that began taking waste in 1992. The VLJ Repository can take radioactive material with up to 400 gigabecquerels (11 Ci) of activity, but cannot dispose of radium-226 (Ra-226), which is temporarily in near-surface storage on-site. The other site is called Loviisa, and it has also been accepting LLW/ILW since 1992. Loviisa has half the disposal capacity (4000 m^3) of the VLJ Repository (8000 m^3), but is sited in the same geologic setting. As of 2004, the VLJ Repository had reached half of and Loviisa just over a quarter of each of their disposal capacities, and they are both estimated to reach their limits in 2032.[4] A HLW and spent fuel repository site, which might have future implications for disused sources meeting specific activity levels, is currently being characterized and will likely be located near the ONKALO underground research laboratory, which is also located on the island of Olkiluoto. This repository is scheduled to begin taking HLW in 2020.

Table 2
Nation-states planning or researching the possibility of development of a national repository

Nation-State	Repository	Status
European Union	SAPIERR II Project (multinational regional repository	Under research
Latvia	Deep geologic site (consolidation at Baldone Site)	Planned
Lithuania	Near-surface repository (Stabatiske)	Planned
Russia	Sosnovy Bor (underground repository)	Under research
China	Gobi desert Beishan Granite Site (underground research laboratory)	Under research
Belarus	Ecores (expansion of current site)	1963 to present
Brazil	Borehole/deep geologic disposal	Under research
Argentina	Borehole/deep geologic disposal	Under research
United Kingdom	Underground repository	Planned
France	Deep geologic repository	Planned
Germany	Former iron ore mine	Planned
India	Deep geologic repository (crystalline rock)	Under research
Japan	Deep geologic repository	Under research

2.3. Sweden

Sweden has one repository, called the Swedish Final Repository (SFR), which is located 50 m below the seabed in the Baltic Sea in metamorphic bedrock. This repository has four chambers for LLW and one for ILW. Its disposal capacity is 63,000 m^3 with possible expansion, through further excavation, adding another 130,000 m^3. This site began disposing of disused sources in 1987 and adds around 1000 m^3 of radioactive material yearly.[5] Studsvik AB, a private company in Sweden, has plans for construction of the Swedish Deep Rock Repository (KBS-3). The KBS-3 repository will be subterranean and composed of solid crystalline rock. It will have tunnels and shafts down to a depth of between 400 and 700 m and horizontal deposition holes that will use bentonite clay and crushed rock as a buffer to reduce water erosion and potential leakage of radioactive waste. This site will provide for the disposal of disused sources not originating from nuclear activities.[6]

2.4. Germany

Until 1998, a repository at Morsleben, called Endlager für Radioaktive Abfälle Morsleben (ERAM), stored 6621 sources.[7] In 2001, disposal of sources at this site was discontinued by the government and backfilling of the site had begun. Similarly, a salt mine called Asse was used to dispose of LLW/ILW from 1967 to 1978 by placing drums 500–750 m below the surface. Since 1995, chambers have been backfilled with salt with a projected closure date of 2013.[8] Underground exploration of the Gorleben salt dome as a potential new disposal site was indefinitely suspended by the federal government in 2000, initially for only 3–10 years, but it now

[1] The IAEA definition of disposal is "Emplacement of waste in an appropriate facility without the intention of retrieval."
[2] Rempe, Norbert T., 2007. Permanent underground repositories for radioactive waste. Progress in Nuclear Energy 49 (5), 365–374.
[3] The IAEA definition of a repository is "A nuclear facility where waste is emplaced for disposal."
[4] Rempe, Norbert T. Permanent underground repositories for radioactive waste.
[5] Rempe, Norbert T. Permanent underground repositories for radioactive waste.
[6] The KBS-3 Method.
[7] Rempe, Norbert T. Permanent underground repositories for radioactive waste.
[8] Rempe, Norbert T. Permanent underground repositories for radioactive waste.

appears to be an indefinite suspension. The Gorleben site was designed for HLW with heat- and non-heat generating waste, and the possibility of this site accepting LLW/ILW, which includes many sources, has not been excluded.[9] Another possible site for future disposal in Germany is a former iron ore mine called Konrad. The Konrad mine was approved to accept sealed sources with negligible heat generating potential in 2002, and after a long appeal process from 2002 to 2007 against the approval of the license for the site, as of this writing, the license had been approved and the site is scheduled for operation in 2013. Germany also has three companies that offer source recycling with particular expertise using cobalt-60 (Co-60), Am-241 and krypton-85 (Kr-85), which are often imported from other countries.[10]

2.5. France

The French National Agency for Radioactive Waste Management (ANDRA) is the sole organization responsible for the disposal or storage of sources in France. As of this writing, France has no operational deep geological waste repository. However, in 2004, it was estimated that France had enough options available to cover 75% of the volume of its existing radioactive waste.[11] Since 1992, LLW and ILW from the Centre de la Manche Waste Disposal Facility has been sent to the Centre de l'Aube (Aube) Waste Disposal Facility for near-surface storage.[12] Other sources are stored by the Commissariat a l'Energie Atomique (CEA) at Saclay. As of 2005 there were 32,500 sources, which occupy 60% of the facility's storage limit, stored at Saclay. Sources such as Am-241, Am-241/Be (Beryllium), and Pu-238 are sometimes recycled at Marcoule. France also has an underground research laboratory (called the Meuse/Haute-Marne in Bure), which has been conducting a feasibility study for a permanent deep geological waste repository (in clay) for ILW and HLW sources. Unlike Finland's ONKALO site, French regulations prohibit the siting of a deep geologic waste repository at the underground research laboratory (Meuse/Haute-Marne) and so a different site will have to be selected.[13] Almost 30 boreholes in various geologic settings had been excavated with 14 more scheduled for 2009 in order to determine the optimal host rock for the final site. An application for the planned deep geologic site is scheduled to be delivered no later than 2015. France has cooperated internationally with the Mont Terri and Äspö projects in determining the appropriate site.[14]

2.6. Czechoslovakia

From 1959 to 1965, the Hostim repository located 30 m below the surface in a limestone mine took about 400 m^3 of LLW and ILW. This site was closed in 1997. Another repository, called the Richard site has more promising prospects, as far as longevity is concerned, and is also sited in a limestone mine. The Richard site provides for disposal or long-term storage with 6500 m^3, with the possibility of expansion to 9300 m^3, for sources and other "institutional" waste.[15] The Bratrsvi site that is shown in Table 1 only takes naturally occurring radio-nuclides and therefore does not dispose of isotopes usually associated with sources that have industrial, medical or agricultural applications.

3. Remaining EU and non-EU nation-states

Before 1982, several European states, mainly Belgium and the Netherlands, disposed of sources by dumping them into the sea. No other EU states have national repositories, and few have plans for research in developing deep geological repositories. No EU member state, nor any nation-state in the world, has a final disposal route that encompasses all forms of disused sources.[16] With the exception of Ireland, Greece, and Luxembourg, most EU states, depending upon the level of activity and half-lives of the sources, have some form of temporary storage for sources. As with much of the rest of the world, many EU and regional nation-states have agreements with source supplier states for the repatriation of sources to the manufacturer.

Latvia is an exception and has demonstrated interest in creating a long-term storage facility for disused sources and is also preparing to conduct a feasibility study on domestic or regional deep geological disposal.[17] Latvia also has a near-surface permanent disposal site with 80% of the capacities of its seven vaults occupied by disused sources. This site is called the Baldone site, and it has been operational since 1962. One vault remains operational, but pending a decision on a final national or regional repository site, the vault is used temporarily for long-term storage.

From 1964 to 1989, Lithuania had a Radon (Russian enterprise in charge of regional disposal sites)-designed near-surface disposal site, called Maisiagala, which was partially filled with legacy sources from the Soviet Union. Government efforts are underway to determine the feasibility of converting this site into a deep permanent repository.[18] Romania and Hungary have similar Soviet legacy Radon-designed sites. Radon sites are of Soviet origin and encompass all of the former Soviet states and their satellites. Radon sites were originally planned to be permanent disposal sites, but after the fall of the Soviet Union and the rapid weakening of regulatory control over sources, most Radon sites are now considered to be temporary and should be considered as short-long-term storage sites because they now permit the retrieval of sources.

The United Kingdom (UK) has a governmental entity called the Nuclear Decommissioning Authority, which through its Radioactive Waste Management Directorate examines the prospects for a geological repository for LLW and ILW. A design was created for a deep underground repository that might include sources. This underground repository is scheduled to open in 2040; however, the siting of the facility has not yet been resolved. Since 1952, the UK has been disposing of LLW in concrete vaults at a LLW repository near Drigg, Cumbria, but this does not include sources. By 2050, construction of all the vaults should be complete, and this site will have a total capacity of 1.7 million m^3.[19] Sources are temporarily

[9] Rempe, Norbert T. Phone Interview. 8 January 2008.

[10] Disposal of Radioactive Waste in Germany. German Company for the Construction and Operation of Waste Repositories (DBE). 8 November 2007; http://www.dbe.de/en/final-disposal/final-disposal-of-waste/index.php and Angus, M.J., et al., 2000. Management and Disposal of Disused Sealed Radioactive Sources in the European Union. Oxfordshire, United Kingdom, Safeguard International Ltd.

[11] Grévoz, A. Statement. Proceedings of an International Symposium. IAEA, 13–17 December 2004, Cordoba, Spain.

[12] National Radioactive Waste Management Agency (ANDRA). The Aube Waste Disposal Facility. 4 December 2007, Châtenay-Malabry, France. http://www.andra.fr/interne.php3?id_article=324&id_rubrique=112.

[13] Angus, M.J., et al. Management and disposal of disused sealed radioactive sources in the European Union.

[14] Ouzounian, Gerald., et al. The French Program: A Development Plan for a Geological Repository for High-Level and Long-Lived Waste. Waste Management Symposia. 24–28 February 2008, Phoenix, AZ.

[15] Rempe, Norbert T. Permanent underground repositories for radioactive waste.

[16] Angus, M.J., et al. Management and disposal of disused sealed radioactive sources in the European Union.

[17] European Commission. Inventory of Radioactive Wastes: Deliverable D-1, Comp. Vladan Stefula. SAPIERR Slovakia, Septemper 2004.

[18] Witherspoon P.A., G.S. Bodvarsson, (Eds), 2006. Geological Challenges in Radioactive Waste Isolation: Fourth Worldwide Review. Ernesto Orlando Lawrence Berkley National Laboratory, University of California.

[19] Nuclear Decommissioning Authority (NDA). Our Sites: LLWR, Future Plans. Cumbria: United Kingdom. 7 January 2008. http://www.nda.gov.uk/sites/llwr/llwrplans.cfm

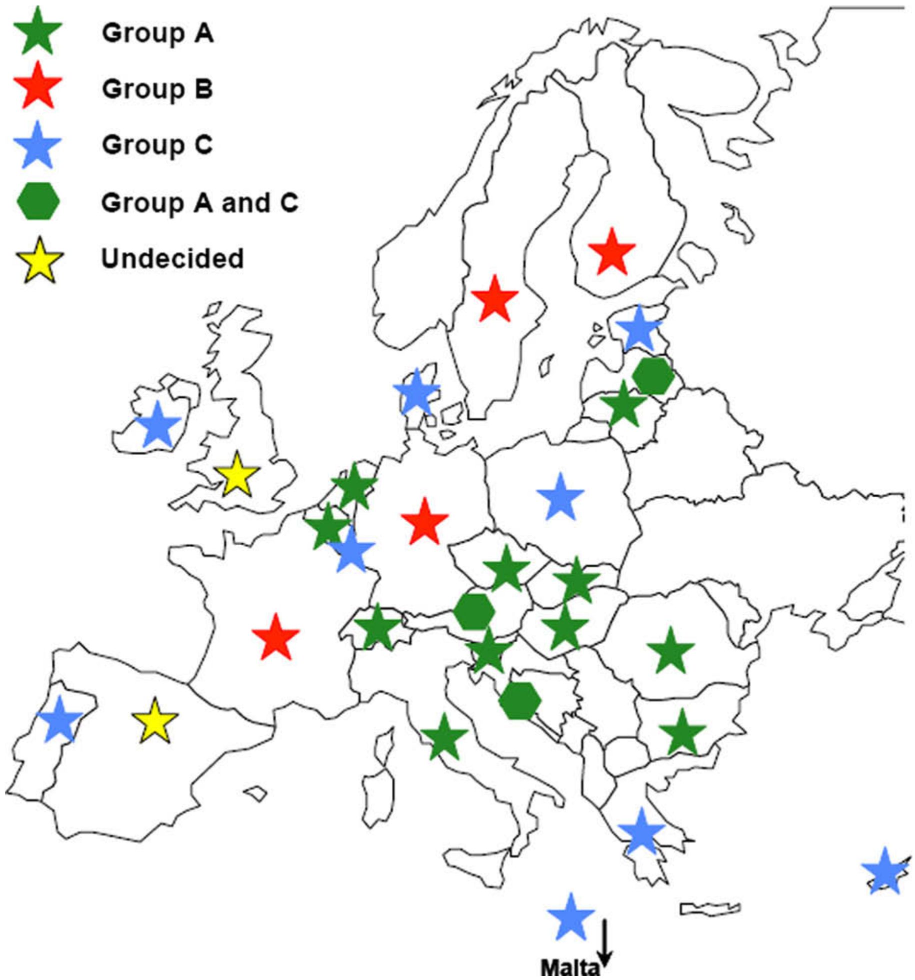

Fig. 1. Group A = Interest in regional repository; Group B = Interest only in national repository; Group C = States with small quantities of long-lived wastes that need a repository; Groups A and C = Austria, Croatia, and Latvia.[22]

stored in above-surface storage at the Harwell site in South Oxfordshire.

The Netherlands has followed a consistent policy since 1984: all types and categories of waste (including sealed sources) are stored above-ground in storage buildings for a period of at least 100 years. After this period of long-term storage, deep geologic disposal is planned either nationally in salt or clay formations or in an international context. COVRA (Centrale Organisatie Voor Radioactief Afval) is responsible for all steps in the waste management cycle. When waste is handed over to COVRA ownership and full liability are transferred as well. COVRA manages the capital growth fund that will be used to cover all future costs including the costs of a deep geologic repository. Sources are treated and stored in principle the same as any other radioactive waste. Sources are stored in their shielding capsule and cemented in 200 or 1000 l drum. Combined with other radioactive waste they are horizontally stacked on pallets and stored in concrete buildings.[20]

From 2003 to 2005, 21 organizations representing 14 European states participated in a European Commission funded project called SAPIERR I (Support Action on a Pilot Initiative for European Regional Repositories). The main goal of this project was to gradually develop plans for the creation of a multinational regional radioactive waste repository in Europe, and it was soon followed by the SAPIERR II project. It is too early in the stage of this project to ascertain proposed siting for the repository, but as shown in Fig. 1, there is significant interest by most European states to develop such a site. Although the focus of this project is mainly on spent fuel and HLW, the scope might also include most, if not all, types of sources.[21]

General guidelines for these projects focused initially on a single horizontal disposition in granite and clay, but SAPIERR II now includes other geologic media such as salt and investigates multiple repository sites in several countries. The IAEA has supported this project as a possible regional repository concept for other parts of the world.[23]

4. Former Soviet Union (FSU)

4.1. Russia

As of 2004, Russia had 16 sites dedicated to source storage. As discussed earlier, Radon sites were originally meant to be permanent

[20] Codee, Hans, et al. No Time Wasted! 25 Years COVRA: Radioactive Waste Management in the Netherlands. Waste Management Symposia. 24–28 February 2008, Phoenix, AZ.

[21] Chapman, Neil. Arius Association for Regional and International Underground Storage. Email interview. 16–26 November 2007.

[22] Possible Options and Scenarios of Regional Disposal and Future RTD Recommendations. Map. Slovakia: SAPIERR/European Commission, 2005.

[23] Ewoud, Verhoef. Birds of a Feather & Developments towards Shared, Regional Geologic Disposal in the EU? Waste Management Symposia. 24–28 February 2008, Phoenix, AZ..

disposal sites and they now allow for the retrieval of waste and so they do not fit the IAEA definition of a repository or disposal site. An enterprise called Radon is the sole entity in charge of each regional storage site. As of 2006 all of these sites had nearly met their maximum capacities for radioactive waste storage, and the next few years will be a critical period in Russia's determination of a methodology for the disposal of waste.[24] Russia has not agreed to recycle or repatriate sources, which has significant repercussions for other nation-states because Russia is a major manufacturer of several key isotopes (Am-241, Cs-137, etc.) actively used in radioactive sources.

The All-Russia Scientific Research Institute for Energy Technology (VNIPIET) and Sweden's SKB IC have researched the possibility of creating two variants of repositories. Underground and surface repository types are being explored with the siting of the underground repository suggested near the town of Sosnovy Bor, in the Leningrad Oblast region.[25] The siting of either repository type will likely be in the Northwest or Ural sections of Russia, because of a severe lack of storage space in the region from the 2001 closure of the Arkhangelsk Radon facility.[26] According to the director of the Arkhangelsk facility, as of 2006, only 1000 m^3 of the allotted 81,000 m^3 of storage space at the site remains and the site will be completely filled in just a few years.[27]

4.2. Belarus

After the fall of the Soviet Union, 20 repositories consisting of layers of disused military sources in filled concrete and sand wells were located throughout the country. One LLW/ILW facility called Ecores has been in operation since 1963. Its original design incorporated two reinforced near-surface concrete trenches. In 1977, the facility was reconstructed into a repository that included four storage wells for disposal of sources. This site did not meet internationally recommended safe storage and disposal protocols, primarily because of expected barrier failures leading to groundwater contamination. In 1997, the Council of Ministers of the Belorussian government adopted a resolution to reconstruct this facility to meet international standards and to construct an additional repository, specifically for sources, with a capacity of 3000 m^3. As of 2004, the site accepted 3000–4000 metric-tons of disused sources per year with each well storing sources based upon their emission type. The capacity of the wells is expected to be exceeded within the next eight years.[28]

5. South and east Asia

5.1. China

As of 2005, China has 25 operational urban radioactive waste temporary storage sites. This verifies China's long-term plan for the creation of urban temporary storage in each municipality and province throughout the country until siting is finalized for a permanent repository.[29] Although China currently only has a policy of temporary source storage, it is important to look at regional sites slated for spent fuel and HLW, because these sites may also be used for more permanent source disposal in the future. Of the five sites being surveyed for deep geological disposal of radioactive waste, the Gobi desert is considered the preferred site.[30] The underground research laboratory (URL), with planned operation around 2030 and the Beishan granite site in the Gansu province (Western China) are two possible sites for a disposal of radiological materials.[31] By October 2004, four boreholes had been completed at the Beishan site.[32] The Shandong storage site in the Gansu province is also the region where all sources are currently sent to and consolidated for long-term storage when urban temporary storage facilities have exceeded their activity limits.[33]

5.2. India

India's future disposal plans for sources, as with spent fuel and HLW, focus on deep geological repositories. Crystalline rock is the preferred geological setting under research. Sites near Kalpakkam with its granite foundation and proximity to the Indira Gandhi Centre for Atomic Research (IGCAR), the Kalpakkam Reprocessing Plant (KARP), and abandoned mines are being considered by the Bhabha Atomic Research Centre (BARC) as preferred disposal sites.[34] The criteria for determining which sites will be chosen are low-rainfall, minimal groundwater, and no deep-seated faults or fractures.[35] In the meantime, near-surface storage or repatriation is the only method available in India for dealing with disused sources.

6. Australia

Australia exists as a federation of states and each state is responsible for the sources within its jurisdiction. Some states have more storage sites than others. In Australia, the source owner is responsible for the storage of disused sources until a more permanent route is determined for disposal. This may include return to manufacture, commercial recycle, and radionuclide decay of short-lived waste (which can then be disposed conventionally as non-radioactive waste).

The only planned disposal site is near-surface and will be called the Mt Walton East Waste Disposal Facility. This facility is the only near-surface land burial site in Western Australia, where there are very few sources in use, and will be used for disposal of LLW/ILW. The method of disposal at the Mt Walton East site will be encasing

[24] Chuen, Cristina. Radiological Materials in Russia. July 2004. Nuclear Threat Initiative. 28 November 2007 http://www.nti.org/e_research/e3_51b.html#fnB2.

[25] Ponomoreva, Vera. Nuclear Experts Discuss Radwaste Repository Options for Russian Northwest. 3 October 2006. Bellona. 10 March 2006. Google. 28 November 2007. http://www.google.com.

[26] Chuen, Cristina. Radiological Materials in Russia.

[27] Chuen, Cristina. Radiological Materials in Russia.

[28] Shiryaeva, N.M., et al. Management of Radioactive Waste in Belarus. Proceedings of an International Symposium. IAEA, 13–17 December 2004, Cordoba, Spain.

[29] China Atomic Energy Authority. Nuclear Security in China Strengthen International Efforts in Nuclear Security and Promote International Cooperation. International Conference on Nuclear Security. IAEA, 10 March 2005, 29 September 2006. http://www.caea.gov.cn/n602670/n621894/n621898/32161.html

[30] Li, Zhongliang, 2001. Radioactive Waste and Spent Fuel Management in China. Proceedings of GLOBAL 2001: Back End of the Fuel Cycle Conference, 10–13 September 2001, Paris, France.

[31] Department of Energy. Office of Civilian Radioactive Waste Management. China's Radioactive Waste Management Program. June 2001, Las Vegas, Nevada Yucca Mountain Project. http://www.ocrwm.doe.gov/factsheets/doeymp0409.shtml (accessed 8.12.2006).

[32] Anonymous Official. Personal interview. 25 May 2007. The current status of these developments is unknown. However, the World Nuclear Association site does give reference to two borehole sites: http://www.world-nuclear.org/nb/nb02/nb0249.htm under the heading [NB02.49-11].

[33] McAlpin, Jerry. Off-site Source Recovery Project. Personal Interview. 4 January 2008.

[34] Department of Energy, 2001. Yucca Mountain Information Office. The Nuclear Waste Dilemma: An International Perspective. Fall ed. 29 November 2007, Eureka, Nevada: Nuclear Waste Office. http://www.yuccamountain.org/international.htm.

[35] Bhaba Atomic Research Centre. Back End Technology Development Division. Natural analogue study of Resubelpara Group of thermal springs at Garo Hills, Meghalaya for demonstration of safe geological disposal of nuclear waste. Comp. Bajpai, R.K., Narayan, P.K., 2005. Current Science. 88 (6); Bangalore, India. http://www.ias.ac.in/currsci/mar252005/986.pdf (accessed 29.11.07).

drums in concrete and then cementing, backfilling, and capping them in one of two (28 m deep and 2 m in diameter) shafts.[36]

As a result of the refusal of the Australian states to accept the creation of national waste repositories in each respective state, in 2011, the Australian Federal Government plans on opening the Commonwealth Radioactive Waste Management Facility (CRWF) for LLW and ILW, which will include disused sources.[37] The only manufacturer of sources in Australia is the Australian Nuclear Science and Technology Organization (ANSTO). Most of the sources it manufactures, primarily Ir-192, are short-lived and can thus be stored for decay. Higher activity sources that ANSTO produced in the past are gradually being returned for long-term storage at CRWF. All other sources in use are imported and thus when considered excess and unwanted, most sources are exported back to the manufacturer or nation-state of origin. There does not appear to be a need nor do any plans exist for deep geologic disposal of sources.

7. Africa

7.1. South Africa

While there are plans being considered in South Africa for disposal of long-lived waste in deep geologic repositories, only short-lived waste is currently disposed of in near-surface facilities. Most disused sources are stored by the South African Nuclear Energy Corporation (Necsa) in covered trenches at a site in Pelindaba called the Thabana repository. This includes disused sources generated by hospitals and industrial users that Necsa manages. However, long-term plans exist for the future transfer of all radioactive waste at Pelindaba to an as of yet undetermined storage site(s).[38] Another site called Vaalputs, which places LLW and ILW into concrete drums that are then covered and compacted with clay in near-surface earthen trenches, is operational and is capable of taking disused sources.[39] However, as of this writing, using Vaalputs for source disposal had not been fully evaluated.[40] Naturally occurring radioactive materials (NORM) wastes are stored in several locations in the mining and minerals industry.[41] The disposal sites of NORM waste may impact the determination of sites for future storage or disposal of a limited set of sources.

South Africa's National Radioactive Waste Management Policy and Strategy of 2005, similar to many other nation-states, explicitly prohibits South Africa from importing and disposing of nuclear waste from other countries. However, like Brazil, the South African government and Necsa are considering accepting and consolidating radioactive sources from other African countries as long as they have a predetermined repatriation path to their country of origin. This primarily includes sources of US origin that would allow rapid repatriation to the US.[42] Regional consolidation and repatriation of sources by stable developed regional nation-states in partnership with the source manufacturing nation-states helps to alleviate the urgency for the creation of disposition pathways and storage sites for sources in developing nation-states.

South Africa is at the forefront of the African continent in the development of source storage, dismantling and transport, and disposal technologies. With IAEA support, Necsa developed the cost-effective advanced borehole disposal technology and assisted in the recovery and conditioning of Ra-226 sources in several African states.[43] Borehole disposition is flexible and allows for the site to be between a few to several hundred meters deep and tens of centimeters to over a meter in diameter. Boreholes are expected to be located in an area with a low water table and then backfilled. This technology has already been implemented in several developing and developed states for disposal of a minimal number of sources.

South Africa and the IAEA have also provided the world with a unique mobile hot cell facility for dismantling devices with high-activity sources in remote locations. The mobile facility is intended to be shipped and assembled at an international work site where high-activity sources can then be removed from disused teletherapy heads or irradiators and consolidated in an attached long-term storage shield (LTSS). Some nation-states have expressed interest in the certification of the LTSS as a transportation container, because this would ease the costs and transport regulations required for repatriation of sources from developing states to their nation-state of origin. The process of this certification should be expedited and supported by source manufacturing nation-states as a confidence building measure for developing states that have agreed to become regional source consolidators. This will demonstrate the manufacturing states commitment to take back its sources once they have been consolidated. Rapid approval of the LTSS as a transportation container would also help remove the highest risk categories of sources that would likely be used in an RDD. The mobile hot cell facility would also enable safe long-term storage of high-activity sources for developing nation-states that currently lack storage or disposal sites. From 2004 to 2007, the mobile hot cell facility was manufactured and successfully test-run by Necsa with support from the IAEA.

Unfortunately, the unwillingness of most source producing nation-states to repatriate sources has impeded their rapid and safe disposition. The large lag time in determining a final disposition route for many sources makes unclear whether or not it is cost effective to remove the sources in the field or to ship the teletherapy head or irradiator to a regional consolidation site for costly storage for an undetermined amount of time. The lack of certified shipping containers for high-activity sources and high transportation costs also severely hamper repatriation efforts. If repatriation and consolidation of these types of sources could be achieved, the mobile hot cell facility and LTSS would reduce transportation and storage costs and eliminate the need for in situ disposal or storage of an entire category of at-risk sources in developing states.

7.2. Egypt

In Egypt, roughly 800 disused sources are currently stored unconditioned and in their original devices in 18 near-surface storage pits. Some sources, such as Ir-192, are conditioned through encapsulation in stainless steel leak-tested capsules, which are then placed in storage shields and concrete-lined drums for decay in storage. These pits are sited in Inshas (North of Cairo) at the Hot Lab

[36] Hartley, M.B., et al., 1998. The Establishment of a radioactive waste disposal facility in western Australia for low level waste. Applied Radiation and Isotopes. 49 (3), 260–264. Elsevier Science Ltd., Great Britain.

[37] Australian Government. Australian Radiation Protection and Nuclear Safety Agency. Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management: Australian National Report. October 2005, Commonwealth of Australia.

[38] South African Nuclear Energy Corporation Ltd. Nuclear Liabilities Management. Our Work: Liabilities Management at Pelindaba. 29 November 2007 http://www.radwaste.co.za/our_work.htm.

[39] Vaalputs: The National Radioactive Waste Disposal Facility. Springbok, South Africa.

[40] Liebenberg, Gert. Necsa. Email interview. 27 November 2007.

[41] South African Nuclear Energy Corporation (Necsa), 2007. Nuclear Waste: Mining and Process Industry Waste. http://www.necsa.co.za/default.asp?pageid=791.

[42] Liebenberg, Gert. NECSA. Email interview. 27 Nov. 2007.

[43] Our Work: International Involvement.

and Waste Management Center, which is subordinate to the Egyptian Atomic Energy Authority (AEA).

Another LLW and ILW disposal site near Inshas has also been constructed and is currently obtaining a license. It houses four near-surface concrete trenches with a cap. The Egyptian government began a collaborative effort, entitled the Integrated Management Program for Radioactive Sealed Sources (IMPRSS), with Sandia National Laboratory and the U.S. Agency for International Development to locate an ideal site for an intermediate-depth borehole facility. Of the six original sites considered, one site has recently been selected and studies are still being conducted for selection of a second borehole disposal site in the western desert region. Egypt's 96% land area consisting of arid desert provides an ideal climate for geologic disposal, and sites were chosen based upon criteria similar to those used for choosing the Yucca Mountain Project in the United States. An example of how a developed state can assist regional developing states is the use of South African technology provided by the IAEA, through a Technical Cooperation Project, which assisted Egypt in investigating the use of the mobile hot cell technology, ensuring quality assurance of waste management, and creating a safety assessment for borehole disposal.[44] This case also exemplifies the useful role the IAEA has played in mitigating the disposal issue by sharing new disposal technologies and best practices with developing nation-states.

Egypt and South Africa both demonstrate the benefits of using multilateral cooperation for resolving their own and other nation-states' barriers to disposal of sources. South Africa also is unique in that it is not a source manufacturing state, yet it has developed innovative methods for the transport and storage of sources despite the absence of a final disposition route.

8. South America

With one site in Brazil and the other in Argentina, South America has only two LLW disposal sites and no disposal option for ILW and HLW. Source repatriation from South America is an example of one way that source manufacturing states can assist developing nation-states by reducing the inventory of disused sources that require disposal. This also eases the urgency for nation-states development of a disposition pathway such as a national repository or other disposal method for disused sources. Nevertheless, the lack of disposal sites in most supplier countries coupled with the high cost of repatriation prevents this solution from being routinely and efficiently achieved. Additionally, without the commitment by a select few governments of source manufacturing states to accept the liability for long-term storage or disposal of sources, most manufacturers are not in a position to conduct source repatriation.

8.1. Brazil

Currently, disused sources are collected, conditioned, and stored at Brazilian Nuclear Energy Commission (CNEN) institutes. The CNEN is responsible for the planning and construction of a national repository for radioactive waste. The concept calls for a dual repository located at one site: a surface structure for conditioned wastes and a borehole for disused sources.[45] Based upon the possibility for future repatriation (see below) of IAEA Category 1, 2, and 3 sources, there is now internal discussion among authorities responsible for waste disposition about the necessity for the creation of a borehole site[46] (Photo 1).

Photo 1. Abadia de Goias Facility: section of radioactive waste generated and disposal site as a result of dispersal incident in Goiânia, Brazil.[47]

Brazil previously disposed of some LLW at its Abadio de Goias Facility (above photo) from 1997 to 1999. However, these dispositions were limited solely to the Cs-137 contaminated materials resulting from an incident involving widespread contamination from an orphaned Cs-137 source in Goiânia, Brazil.[48] Sites like the Abadia de Goias Facility and disposal sites for contaminated materials resulting from the Chernobyl incident may be useful for characterization and siting of future sealed source disposal repositories.

8.2. Source consolidation and repatriation

A cooperative project is underway between the US Department of State, the GTR, and the IAEA, using Brazil as a regional partner to demonstrate the feasibility of cooperative efforts to return unwanted, vulnerable radiological sources to their country of origin. In principle, Brazil has agreed to license the temporary import of sources from all countries in the region for consolidation and later repatriation. The consolidation effort would be achieved through bilateral agreements between Brazil and the exporting states; these agreements, followed by agreements by the manufacturing states to accept the sources, would be monitored by the IAEA. Given the preponderance of US origin sources in many countries in the region, this project may significantly reduce the inventory of disused sources that will require disposal in many of these South American states. Argentina and Brazil both have national laws that prohibit them from importing radioactive waste from other states.[49] However, because the material being consolidated in Brazil will not be classified as waste, Brazil can temporarily store and then re-export the sources.

The IAEA is also working to develop an implementation plan that would address an inventory of obsolete teletherapy heads and an irradiator in Uruguay. The plan involves working with the regional partner, source device and transport container suppliers, US government agencies and contractors, and regulatory authorities to develop a cost-effective method to repatriate these sources. It is hoped that this regional concept could then be applied to similar inventories of disused high-activity sources in other countries.

The IAEA held a training consultancy at Center of Nuclear Technology Development (CDTN) at Belo Horizonte in September of 2007 during which the Brazilian team was trained by members of the OSRP, to remove sources from various devices and to package

[44] Cochran, J.R., et al., 2006. Borehole Disposal and cradle-to-grave management program for radioactive sealed Sources in Egypt. Waste Management Conference. 26 February to 2 March 2006, Tuscon, Arizona.

[45] Vincente, R., et al., 2004. Management of Spent Sealed Radiation Sources. Health Physics. 86 (5) 497–504.

[46] Mourao, R.P. Center for Nuclear Technology Development (CDTN/CNEN). Email interview. November 2007.

[47] Greater Confinement Disposal of Radioactive Waste in Borehole Facilities. Photo. Proceedings of an International Symposium. IAEA, 13–17 December 2004, Cordoba, Spain. Q9

[48] Maset, E., Andresik, R., 2005. The Present Situation of the Low Level Waste Repository in Argentina and the Necessity of Developing a New Site. IAEA-TECDOC-1553, Workshop, Vienna, IAEA, 9–11 November 2005.

[49] Leonard, Shelby. IAEA. Email and phone interview. 16 January 2008.

sources for transport to the US. During the consultancy, 127 US origin sources were packaged for later repatriation to the US in December 2007. The sources included Am-241, Pu-238, Pu-239, Cf-252, Cs-137, and sources containing combinations of isotopes. As detailed in subsequent sections, some bilateral repatriation operations based upon cooperation between GTRI and Ecuador and Chile are also underway.[50]

8.3. Argentina

From 1971 through 2001 Argentina disposed of LLW at a near-surface storage site called Ezeiza Radioactive Waste Management Area in the province of Buenos Aires, on the site of the Centro Atomico Ezeiza. A safety re-assessment was initiated at Ezeiza in 2001 and operation of all radioactive storage systems was suspended because of the age of the facility, suspected leakage of radioactive waste, and more frequent heavy rains that had raised the local water table.[51] The suspected contamination was disproved during re-assessment of the site. A new site for radioactive waste storage of LLW and ILW is currently under consideration by the Argentine government, but no information on siting or plans for the site has been developed.

8.4. Ecuador

Ecuador, like most other developing states, has no formal disposal site or plan. A government-operated Comision Ecuatoriana de Energia Atomica (CEEA) facility has inventoried and consolidated devices containing Am-241, Cs-137, and Co-60. The CEEA participated in Ecuador's first source repatriation to the US in 2007, also under the GTRI.

8.5. Chile

The Comisión Chilena de Energía Nuclear (CCHEN) does not have a LLW and ILW disposal facility. The CCHEN has a storage facility sited at Lo Aguirre, a government-operated site where sources have been inventoried and consolidated since 1998. Similarly organized as the bilateral GTRI project with Ecuador, the CCHEN will be participating in a repatriation effort of sources containing Cs-137, Am-241, Pu-238, and Ra-226 to the US in January 2008. Repatriation of US origin sealed sources in Chile and Ecuador exemplify how repatriation reduces the inventory of disused sources that will require a LLW and ILW disposal facility.

South America and Africa both demonstrate how bilateral or other multilateral partnerships, either in isolation or in unison, combined with regional agreements, can facilitate effective source consolidation and repatriation and thus ease some of the stress on finding an immediate disposal solution for developing states.

9. North America

9.1. Canada

For more than 55 years, Atomic Energy of Canada Limited (AECL) has made radioisotopes. One company, MDS Nordion, uses Cs-137 and Co-60 from AECL as one of the largest manufacturers of teletherapy heads in the world. MDS Nordion is unique in that it offers removal and recycling services for the sources it supplies. Once sources are returned, MDS Nordion assesses whether the sources are in condition for reuse or recycling. If they cannot be reused or recycled sources are then temporarily stored on site until they can be forwarded for storage at an AECL waste management facility.[52]

Historic LLW was handled in three different ways at Area B of Chalk River Laboratories Waste Management: (1) unlined soil trenches from 1953 to 1963; (2) asphalt lined and capped trenches for solid ILW in the 50's (rectangular concrete structures until 1979 and cylindrical thereafter); and (3) tile holes used to store HLW. Canada's Low-Level Radioactive Waste Management Office was established in 1982 to carry out the responsibilities of the federal government for management of historic LLW. In 2001, after public consultation, the AECL constructed a new modular above-ground storage facility (MAGS) that uses tagged steel containers for compacted LLW.[53] The MAGS facilities are designed to receive up to two years of waste and are meant to provide temporary storage until a decision is made on a final disposal site. Although they have the potential, MAGS facilities have never been used for source disposition.

9.2. Mexico

The Instituto National de Investigaciones Nucleares (ININ) is the authority responsible for the disposition of radioactive waste in Mexico. As in many other countries, until an ultimate disposal pathway is found, interim storage is used to manage sources. The ININ either cements conditioned sources or leaves larger unconditioned disused sources in their original packaging. Long-term storage of waste is managed at the Centro de Almacenamiento de Desechos Radiactivos (Radioactive Waste Storage Center (CADER)) located near Maquixco. As of 2003, this site received over 20 drums per year, which were stored on the surface and in below-surface trenches (200 m long and several meters deep). As a result of public and political pressures the CADER site has been scheduled for decommissioning and has led to the investigation of other sites that could dispose of LLW and ILW. While a small fraction of the waste at CADER is ILW requiring long-term storage, most of it is LLW and will need a final disposal solution.[54] Mexico, like many other nation-states, intentionally designs sites for the easy retrieval of sources allowing for more permanent disposition at a later date. Therefore, under the IAEA definition of disposal and repository, Mexico and most other nation-states do not have a permanent disposal site for sources.

9.3. United States

In the US, disposition options for sources vary depending upon the classification of the source. Most commonly used sources are classified as either transuranic (TRU) waste or LLW. Sources containing US-defense-origin TRU isotopes, such as Am-241, Pu-239, Pu-238, and Np-237, are accepted by the aforementioned OSRP, which disposes of these materials at the Waste Isolation Pilot Plant (WIPP). The DOE's WIPP geologic repository is sited in a 1000-m thick series of salt beds. WIPP disposal rooms are situated 655 m below the surface. The WIPP repository has a capacity of 175,600 $m^{3,}$ and as of the end of 2007 it was about a third full.[55]

[50] Leonard, Shelby. IAEA. Email and phone interview. 16 January 2008.
[51] IAEA-TECDOC-1553. Workshop, Vienna, IAEA. 9–11 November 2005.

[52] Martell, E.S, 2004. Safety of Sealed Source Disposal. Radiation Physics and Chemistry. 71, 575–578.
[53] Atomic Energy of Canada Ltd. Chalk River Laboratories. Ecological Effects Review of Chalk River Laboratories. Comp. Hart, Donald, et al. Ontario: Ecomatrix Inc.; C Wren & Associates Inc, January 2005.
[54] Newell, Dennis, Sinkule, B.J., 2003. Los Alamos national laboratory's sister laboratory collaborations on low and intermediate level radioactive waste management. Waste Management Conference. 23–27 February 2003, 3 December 2007, Tuscon, AZ. www.wmsym.org/abstracts/2003/pdfs/336.pdf.
[55] Department of Energy. Carlsbad Field Office. National TRU Waste Management Plan: Corporate Board Annual Report. DOE/NTP-96-1204, rev. 3 July 2002.

Photo 2. TRUPACT-II and RH-TRU 72B casks used to transport TRU and remote handled waste to WIPP. Source: Los Alamos National Laboratory and Waste Isolation Pilot Plant.

In 2005, the OSRP was given an expanded scope of operation that included all of the IAEA isotopes of concern (Cs-137, Co-60, Sr-90, Ra-226, etc.). Since the inception of the OSRP in 1999, it has recovered over 16,000 sources. US origin sources have been and are currently being recovered from numerous countries around the world including Italy, Ecuador, Chile, Denmark, and Sweden. Joint efforts between the OSRP and the IAEA have also resulted in the removal of US origin sources in South Africa, Australia, and Brazil. The OSRP, in conjunction with WIPP, have disposed of over 3400 TRU sources at the WIPP site. Whenever possible, the OSRP also returns sources to the original manufacturers for recycle.

There is a legal mandate from the 1992 WIPP Land Withdrawal Act that prohibits private source owners from disposing of sources directly at WIPP. Three DOE defense determinations have made it possible for the OSRP to take possession, ownership, and title of the sources held by the licensed sector (private owners).[56] This has allowed the OSRP and WIPP to implement final disposition to lower the inherent risk associated with disused sources.

Other common sources in the licensed sector (i.e., Cs-137) that meet certain activity specifications may be disposed of at commercial LLW disposal facilities. Currently, only two commercial facilities are available in the US for disposal of non-TRU and small quantities of TRU disused sources: the Barnwell LLW Disposal Facility in South Carolina and the Hanford Site operated by U.S. Ecology in Richland, Washington. There are a total of ten compacts that were developed by the NRC to deal with LLW as a result of the Low-Level Waste Policy Act of 1980. Previously, states without a storage option were required by the 1980 act to take possession and title to the waste until a disposition pathway is determined. This was meant to encourage the construction of storage facilities at host sites for the compacts. However, a Supreme Court ruling removed this requirement, which encouraged the construction of very limited and few storage sites. The Hanford Site handles waste from the 11 states that make up the Rocky Mountain and Northwest Low-Level Waste Compacts (Alaska, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming). The Barnwell Site is scheduled to halt acceptance of waste from out-of-compact states in 2008. This will result in the Barnwell Site being able to accept waste only from the three states that comprise the Atlantic Compact (South Carolina, Connecticut and New Jersey). The closure of Barnwell to non-compact states will leave 36 states that generate an average of 425 m^3 of waste per year devoid of a storage facility.[57]

The Central Midwest Compact (Illinois and Kentucky) has projected the opening and operation of a storage site, but not until 2032 (Photo 2).

A new potential LLW storage site called Waste Control Specialists Texas (WCS) near Andrews, TX is presently under regulatory evaluation. The site is approved for uranium byproduct waste disposal and is currently only permitted to transport and temporarily store waste.[58] If found acceptable, this site will be the first new LLW disposal site in the US in 30 years, but it remains unclear if this site will be licensed to allow for the storage of sources. Oak Ridge National Laboratory and Frontier Technology Corporation both recycle small quantities of Californium-252. Recycling sources can have enormous up-front costs, but may be more economical in the long run when compared to long-term storage or disposition.

A new program, sponsored by the Conference of Radiation Control Program Directors (CRCPD) and DOE/NNSA with support from the OSRP, called the Source Collection and Threat Reduction (SCATR) program, is intended to remove smaller sources from the licensed sector by using state agencies and commercial brokers to consolidate sources from their respective geographic area.[59] The SCATR program is also unique in that it either funds the disposition or notifies source owners of possible disposition options. Similar to the remediation provided to nation-states by repatriation, removal of sources from the private sector through consolidation provides a safe, secure, and efficient route toward their eventual disposition.[60]

10. Conclusion

The survey of disposal options and issues of source disposal as presented in this paper, mostly for long-lived isotopes, underscores the need for all nation-states to consider and plan for the repatriation, consolidation, and disposition of sources from which they derive significant benefits. Several developed nation-states are researching deep geologic repositories and other permanent disposal options, but only a few have implemented these plans with operational sites, even fewer which dispose of sources, and none of which cover every category of source.

While it is true that recipient countries receive benefit from the multitude of industrial, medical, and research uses of sources, developing nation-states often do not have the national physical, regulatory, and security infrastructures necessary to manage these materials at the end of their useful lives, which results in the

[56] Each defense determination differs in its coverage: 1. LA-OS-NA-01 covers all domestic sources originating from DOE's weapons program; 2. LA-OS-NA-02 covers all DOE origin sources located in foreign countries; and 3. LA-OS-NA-03 covers all sources located at DOE sites.

[57] Zacha, Nancy J., 2007. Low-level radioactive waste disposal: are we having a crisis yet? Nuclear News. 50 (9),29–33.

[58] WCS Receives License for Disposal of Fernald Waste, 2008. Weapons Monitor Complex. 19, (25 and 26) 10.

[59] In order to qualify for the SCATR program sources must be less than 10 Ci (37E10Bq) and non-transuranic.

[60] More information on the SCATR program can be found at the following websites: http://www.crcpd.org/SCATR/SCATR.html and http://osrp.lanl.gov/CRCPDSCATR.shtml.

sources becoming a liability from a safety, health, and security standpoint.

For the most part, barring return of sources to supplier or until an ultimate disposition pathway is identified, most nation-states condition their waste in cement-matrixes, which are then stored in near-surface interim storage facilities. Although not ideal, this approach may be the only means available to many nation-states for managing disused sources.

Source producing states and the IAEA should continue working together to assist manufacturing and developing states in ensuring that end-of-life options for disused sources are realistic for each state's unique circumstances. The IAEA effort should be premised upon United Nations Security Council Resolution 1540 (UNSCR 1540), which requires that states take "effective measures to account for, secure, and physically protect sensitive materials (radioactive sources)" and IAEA Information Circular 663 (INFCIRC 663), which requires international cooperation in harmonizing national policies, laws, and regulations in assuring proper regulatory control of radioactive sources from manufacture to disposal. INFCIRC 663 also encourages recycling and repatriation of sources. UNCSR 1540 focuses on the prevention of the proliferation of nuclear weapons, which necessarily includes Pu-239 that has been used and distributed in source applications such as in neutron howitzers at research institutes or calibration devices. Therefore, an effort should be initiated by the IAEA with support from its member states to create a universal and harmonized system for source disposition for all source owners. The Group of Eight (G-8) encompasses the most prominent source manufacturing states. Therefore, it should not be beyond the G-8 scope of purpose to propose and support an international disposal endeavor through the same action plan they issued in support of INFCIRC 663. Source disposition should also be addressed regionally and multilaterally through similar agreements that have addressed radioactive waste in the past. Cooperation through consolidation, repatriation, and effective disposal pathways would help alleviate concerns from developing states that they not forego their right to receive their full share of peaceful nuclear technologies from developed states and would help alleviate the inherent threat these sources pose should they fall out of regulatory control and into malicious hands.