Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

TRANSPORT OF RADIATION SOURCES USED FOR OIL WELL LOGGING: RADIATION SAFETY ISSUES FOR OFF-SHORE OPERATIONS

Igor Gusev
International Atomic Energy Agency

Christopher Bajwa
International Atomic Energy Agency

Tony Colgan
International Atomic Energy Agency

Brian Waud
International Atomic Energy Agency

ABSTRACT

In accordance with IAEA safety standards, many radiation sources and generators for well logging operations are categorized as category 3 ($10 > A/D \geq 1$). These sources, if not safely managed or securely protected, could cause permanent injury to a person who was to handle them or who was to otherwise be exposed to them for some time. The IAEA transport regulations are accordingly applied for transportation of well logging sources. In practice, the danger categories of well logging sources and generators are in the range of 3-4 (examples of such sources are discussed in the paper). The practices of well logging often include operations in remote areas including off-shore work. In such cases the transport of well logging sources is usually carried out via helicopter, where the application of transport rules is complicated due to the lack of space in the aircraft, transport of several sources in one cargo, and minimal distances between the transport containers and people. The paper presents a brief description of well logging sources and generators and typical transport conditions in the case of off-shore operations.

BACKGROUND

Devices with radioactive sources are used for a wide range of beneficial applications. These include cancer therapy, irradiation of blood for transplant patients, sterilization of medical equipment, non-destructive testing of structures, and petroleum exploration and production. In the petroleum industry, such sources are used in applications ranging from radiography of platform and equipment for flow monitoring to down-hole measurements for reserves estimation. In addition, naturally occurring radioactive material (NORM) containing potassium, thorium and uranium can deposit on walls of pipes carrying fluids from the reservoir and has to be disposed of. Many pipes or casings may also be coated by deposits containing radon progeny [1].

INTRODUCTION

The mining industry and the petroleum industry make extensive use of radioactive sources, and in some cases radiation generators, for the purposes of characterizing wells and boreholes. The term ‘well logging’ is used to include all such uses. A need has been identified, at the international level, for specific, detailed operational information to ensure the safe use of well logging sources and fracking pack monitoring sources. National and regional guidelines on this subject exist, e.g. [2], but as yet there is no international harmonization of national approaches. Safety Guides on industrial uses of ionizing radiation, e.g. for industrial irradiators, industrial radiography, nucleonic gauges and isotope production facilities are available [3, 4]. A Safety Guide is under development (DS419, *Radiation Protection and Safety in Well Logging*) to address well logging sources.

Despite the strict protocols mandated in utilizing radioactive sources in the petroleum industry and other industries, contamination from industrial use of sources may cause serious health effects and even death [5]. According to the IAEA, millions of radioactive sources have been distributed in the past 50 years for the variety of applications cited, but they were not well catalogued. The IAEA noted that companies have lost track of nearly 1500 radioactive sources since 1996 with more than half of these never recovered [6,7]. The same IAEA report cites a study which estimated that, annually, operational control of up to 70 sources is lost.

RADIATION SAFETY RELATED CHARACTERISTICS OF WELL LOGGING SOURCES

Most sources exhibit low activity and thus are unlikely to cause harm; however, according to the IAEA, there are over 20,000 operators of sources with significant activity [6]. While the potential for harm from industrial use of such sources is significantly greater in some other sectors, sources used in the petroleum industry may pose certain unique hazards. Such sources are highly mobile, are widely transported and are used in remote locations. There are approximately 9000 well logging sources in the field [8] and hundreds of such sources have been lost down-hole or have been cemented in place over the years. For example, according to an inventory taken by the IAEA, more than 40 Am–Be (~592 GBq of activity) sources and a similar number of Cs-137 (~74 GBq of activity) sources were lost down-hole in Gulf of Mexico offshore operations alone before 1992 [9].

There are numerous types of sources that are employed for a variety of well logging activities. Some of the characteristics of these various sources are provided in Table 1.

Table 1. Selected Petroleum Industry Applications, Corresponding Radioisotopes, A/D Ratios and IAEA Category[1]

Application	Radioisotope	Half-life	Typical Activity	D Value (GBq)	A/D Ratio	Category (A/D-based)	IAEA Assigned Category
Well logging-neutron porosity	Am-241(Am-Be)	433 a	8-23 Ci	74	4–11.5	3 to 2	3
Well logging-density	Cs-137	30.2	2 Ci	111	0.67	High 4	3
Well logging – capture lithology	Am-241(Am-Be)	433 a	16 Ci	74	8	High 3	3
Well logging- neutron porosity	Cf-252	2.65 a	0.11–0.027	18.5	0.22–0.054	4	3
Well logging- in D-T tools	H-3	12.33 a	1.6 to < 10 Ci	185×10^{4}	$< 2\times10^{-4}$	5	–
Nuclear gauges-pipeline or vessel	Cs-137	30.2 a	0.135–2.7	111	0.05 to ~0.9	4 to nearly 3	3
Nuclear gauges-vessel or pipeline	Co-60	5 a	0.25 to 2.6	29.6	0.31 to 3.3	4 to 3	3

Level gauges-pipe-wall profiling	Cs-137	30.2 a	Several mCi	111	<0.05	4	4
Frack-pack monitoring	Am-241 (Am-Be) (Vendor A)	433 a	16 Ci	74	8	High 3	3
	Am-241 (Vendor B)	433 a	300 µCi	74	0.15	4	-
Inter-well tracer	Kr-85	10.76 a	1000	29600	1.25	3	-
Moisture gauge in insulation-pipe wall gap	Am-241 (Am-Be)	433 a	0.05–0.1	74	0.031–0.062	4	4
[1]From: Radioactive Sources in Petroleum Industry: Applications, Concerns and Alternatives, A. Badruzzaman. Asia Pacific Health, Safety, Security, and Environment Conference and Exhibition held in Jakarta, Indonesia, 4–6 August 2009							

Technical characteristics of nucleonic well logging sources in the coal and petroleum industries are also provided for the gamma-gamma (Table 2) and the neutron activation (Table 3) techniques.

Table 2. Nucleonic Well Logging in Coal and Petroleum Industry: Technical Characteristics of Sources (Gamma-Gamma Technique)

Source content	Radioactive isotope	Half-life, years	Neutron energy, MeV		Neutron yield, $10^{6} \cdot s^{-1}$	sizes, mm	
			Average	maximum		Dia.	height
Cf	^{252}Cf	2.64	2.13	11	1-100	7	14
Po-Be	^{210}Po	0.379	4.3	11	1-100	20	40
Po-Be	^{210}Po	0.379	2.7	5	1-10	20	40
Pu-Be	^{238}Pu	86.4	5.0	11.3	1-50	12-21	16-40

Table 3. Nucleonic Well Logging in Coal and Petroleum Industry: Technical Characteristics of Sources (Neutron Sources for Neutron Activation Techniques)

Initial isotope	Dissemination %	Reaction product	Reaction threshold, MeV (effective cross-section of activation, conditional units)	Half-life	Gamma energy , MeV (yield, %)
Fast neutrons: (n,p) and (n,α) reactions					
^{16}O	99.76	^{16}N	10.0 (90)	7.35 s	7.12(4.90), 6.13(68)
^{19}F	100	^{16}N	3.2 (15)	7.35 s	- „ -
^{28}Si	92.27	^{28}Al	3.9 (380)	2.31 min	1.78 (100)

Initial isotope	Dissemination %	Reaction product	Reaction threshold, MeV (effective cross-section of activation, conditional units)	Half-life	Gamma energy , MeV (yield, %)
Thermal neutrons (n,γ) reaction					
^{23}Na	100	^{24}Na	-(534)	15 h	2.75(100),1.37(100), 3.85 (9)
^{27}Al	100	^{28}Al	-(210)	2,31 min	1.78 (100)
^{48}Ca	0.185	^{49}Ca	-(1100)	8,75 min	4.68 (3), 4.05 (8), 3.1 (8.9)
^{55}Mn	100	^{56}Mn	-(13170)	2,59 h	2.11(17.5), 1.81(33.3), 0.85 (98.6)
^{63}Cu	69	^{64}Cu	-(4500)	12,88 h	1.32 (0.53)
^{65}Cu	31	^{65}Cu	-(1800)	5,1 min	1.09 (9)

TRANSPORT OF RADIOACTIVE SOURCES

Transport of well logging sources and generators should conform to national regulations inside the State and IAEA regulations for international transport [10].

Movement within the worksite

When radiation devices and sources are to be moved within a site for well logging work, they should be kept in the storage facility until they are to be moved to the new location.

The sources should be moved only in shielded containers, and these should be locked and the keys should be removed. If a vehicle or trolley is used to move the container, it should be securely fastened inside the separate compartment of the vehicle. The shielded container should be kept under surveillance for the duration of the movement on the worksite. Keys of the container should be kept by the authorized person.

Transport to another site

When well logging sources are to be transported to another worksite for site operation purposes, they should be kept in the storage facility until they are to be moved to the new site.

The sources should be moved only in shielded containers, and these should be locked and the keys should be removed. The operating organizations should ensure that the transport and the transport packages comply with the IAEA Regulations for the Safe Transport of Radioactive Material [10] or equivalent national or international regulations.

Where applicable, consideration should also be given to binding international instruments for specific modes of transport, such as the Technical Instructions for the Safe Transport of Dangerous Goods by Air [11] of the International Civil Aviation Organization (ICAO), and the International Maritime Dangerous Goods (IMDG) Code [12] of the International Maritime Organization (IMO).

Regional agreements such as the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [13] the Agreement of Partial Reach to Facilitate the Transport of Dangerous

Goods, Signed by the Governments of Argentina, Brazil, Paraguay and Uruguay (MERCOSUR/MERCOSUL) [14] and the European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) [15] may also apply.

The IAEA Transport Regulations [10] assign responsibilities for individuals involved in the transport of radioactive material: the consignor (a person, organization or government that prepares a consignment for transport), the carrier (the person, organization or government that undertakes transport of radioactive material) and the consignee (the person, organization or government that receives a consignment). In many cases, for site well logging work, the operating organization will perform all three functions and is required to discharge the responsibilities associated with each function.

Transport of radioactive material, and specifically of well logging sources, is a complex activity.. Guidance on how to meet transport requirements is provided in Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material [16].

Security of sources during transport

The transport time of radiation sources and generators is the period when sources are the most vulnerable to theft. The comprehensive recommendations on nuclear security are provided by IAEA Security Series Publication related to transport of radioactive materials [17].

ISSUES IN TRANSPORT OF SOURCES

According to IAEA observations the following issues were identified for the transport of well logging sources:

- transport of well logging sources to geographically remote areas (e.g. oil platforms);
- transport of well logging sources to areas with problematic regulatory infrastructure (e.g. operations in countries without radiation safety regulatory authorities); and
- transport of well logging sources containing "dual-use" materials and potential proliferation concerns.

As mentioned previously, the IAEA is developing a Radiation Safety Guide, where the above issues will be addressed.

CONCLUSIONS

Well logging sources belong to significant danger categories established by the IAEA. The transport of well logging sources under the existing framework developed by the IAEA for transport of radioactive materials and generators of ionizing radiation provides sufficient radiation safety of routine operations; however, as discussed in this paper some issues remain to be addressed. Special considerations including increased safety and security measures should be applied in cases of transport of well logging radiation sources and generators to remote geographical areas, countries of insufficient national regulatory infrastructure, and if "dual-use" materials are present.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Naturally Occurring Radioactive Material (NORM V). Proceedings of an international symposium Seville, Spain, 19–22 March 2007.

[2] US NRC Regulations NRC, March 17, 1987, 10 CFR Part 39, Licenses and Radiation Safety Requirements for Well Logging, US Nuclear Regulatory Commission, 52 FR 8225.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of radiation generators and sealed radioactive sources, IAEA, Vienna, (2006).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation safety in industrial radiography, specific safety guide, IAEA safety standards series. IAEA, Vienna (2011).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of radioactive sources, IAEA Safety Standards Series No. RS-G-1.9, IAEA, Vienna (2005)

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and the Management of Radioactive Waste in the oil and gas industry, Safety Report Series No.34, IAEA, Vienna (2003).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Inadequate Control of World's Radioactive Sources, IAEA Press Release 2002/09, IAEA, Vienna (June 24, 2002) http://www.iaea.org/newscenter/pressreleases/2002/prn0209.shtml

[8] A. BADRUZZAMAN, Radioactive Sources in Petroleum Industry: Applications, Concerns and Alternatives, Asia Pacific Health, Safety, Security, and Environment Conference and Exhibition, Jakarta, Indonesia, 4–6 August 2009.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Inventory of accidents and losses at sea involving radioactive material, IAEA-TECDOC-1242, IAEA, Vienna (2001).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material - 2012 Edition, Specific Safety Requirements, IAEA Safety Standards Series SSR-6, IAEA, Vienna (2012).

[11] INTERNATIONAL CIVIL AVIATION ORGANIZATION, Technical Instructions for the Safe Transport of Dangerous Goods by Air, 2007–2008 edition, ICAO, Montreal (2007).

[12] INTERNATIONAL MARITIME ORGANIZATION, International Maritime Dangerous Goods (IMDG) Code, 2006 Edition including Amendment 33-06, IMO, London (2006).

[13] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, INLAND TRANSPORT COMMITTEE, European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR), 2007 Edition, UNECE, Geneva (2006).

[14] The MERCOSUR/MERCOSUL Agreement of Partial Reach to Facilitate the Transport of Dangerous Goods, Signed by the Governments of Argentina, Brazil, Paraguay and Uruguay (1994).

[15] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, INLAND TRANSPORT COMMITTEE, European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN), 2007 Edition, UNECE, Geneva (2006).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series No. TS-G-1.1 (Rev. 1), IAEA, Vienna (2008).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Security in the Transport of Radioactive Material, IAEA Nuclear Security Series No. 9, IAEA, Vienna (2008).