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Radiation Safety in Well Logging

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. As stated in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1]: "The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation." Paragraph 2.1 of SF-1 [1] states that:

> "This fundamental safety objective of protecting people – individually and collectively – and the environment has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks."

1.2. Paragraph 2.2 of SF-1 states that [1]:

> "The fundamental safety objective applies to all facilities and activities and for all stages over the lifetime of a facility or radiation source, including planning, siting, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure. This includes the associated transport of radioactive material and management of radioactive waste."

1.3. Mining, ground engineering and water industries and oil and gas exploration and production (conventional and unconventional (e.g. fracking)) make extensive use of radioactive sources, and in some cases radiation generators, for characterizing and evaluating geological formations and borehole and well constructions. The term 'well logging' is used in this Safety Guide to include all such practices.

1.4. Well logging work can be performed with a device (often referred to as a 'logging tool') containing one or more gamma and/or neutron sealed radioactive sources or a neutron generator. The location for well logging work will normally be at the premises of a client company (e.g. at a mine, or at an offshore oil and gas exploration platform). There are many thousands of radioactive sources and radiation generators used in well logging around the world [2].

1.5. IAEA Safety Standards Series No. RS-G-1.9, Categorization of Radioactive Sources [3] provides a relative ranking of radioactive sources in terms of their potential to cause severe deterministic effects (i.e. how 'dangerous' they could be if misused). The categorization is composed of five categories, with Category 1, 2 and 3 sources being the most hazardous. Well

logging sources generally fall into Categories 3 and 4; however, the aggregation of sources at a particular well logging site might fall into Category 2.

1.6. This Safety Guide is one of a number of Safety Guides on topics related to safety in industrial uses of ionizing radiation, for example radiation generators and sealed sources, industrial radiography, industrial irradiators and nuclear gauges: see Refs [4–7].

1.7. Unless otherwise stated, terms are used with the meanings ascribed to them in the IAEA Safety Glossary [8].

1.8. It is assumed in this Safety Guide that an effective governmental, legal and regulatory infrastructure for radiation safety that covers the practice of well logging with radiation sources is in place (see Section 2). In the case that well logging activities are to be conducted in a State in which regulations on radiation protection are not yet in place or do not meet the relevant international standards, the recommendations in this Safety Guide will provide general guidance on ensuring radiation safety in well logging.

OBJECTIVE

1.9. The objective of this Safety Guide is to provide recommendations on how to meet the relevant requirements of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [9], with regard to the use of radioactive sources and radiation generators in well logging.

1.10. The guidance in this publication is aimed primarily at operating organizations that are authorized to undertake well logging with radiation sources, as well as their employees and radiation protection officers. The guidance will also be of interest to regulatory bodies, and to designers, manufacturers, suppliers, and maintenance and servicing organizations of well logging equipment that contains radiation sources.

SCOPE

1.11. This Safety Guide provides recommendations on the use of radioactive sources and radiation generators in well logging, including in the manufacture, calibration and maintenance of well logging tools. It provides recommendations on radiation protection and safety for the storage, use and transport of such radiation sources.

1.12. This Safety Guide is concerned with radiation safety issues and does not address non-radiation related risks associated with well logging.

1.13. This Safety Guide also provides information on the need for appropriate nuclear security measures and provides recommendations on their interface with safety measures, but does not provide specific guidance on aspects of nuclear security. Additional guidance on nuclear security can be found in the IAEA Nuclear Security Series.

1.14. Radiation protection and safety in respect of radionuclides of natural origin and for the use of radiotracers in the mining and petroleum industries are outside the scope of this Safety Guide. Recommendations on protection and safety in respect of radionuclides of natural origin are provided in IAEA Safety Standards Series No. WS-G-1.2, Management of Radioactive Waste from the Mining and Milling of Ores [10]. Radiotracer techniques are addressed in Ref. [11].

STRUCTURE

1.15. The various duties and responsibilities of organizations and individuals are described in Section 2. Recommendations on the preparation of a safety assessment and on the radiation protection programme are provided in Sections 3 and 4, respectively. Recommendations on training and qualification of personnel are provided in Section 5. Sections 6 and 7 provide recommendations on individual monitoring of workers and workplace monitoring, respectively. Section 8 provides recommendations on the control of gamma and neutron sources. Section 9 describes security considerations for gamma and neutron sources. Sections 10 and 11 provide recommendations on the safe use of neutron and gamma sources in well logging facilities[1] and on a site, and Section 12 provides recommendations on the safe transport of radioactive sources. Preparedness for and response to emergencies involving well logging sources is described in Section 13.

1.16. An overview of well logging sources and equipment is provided in Annex I. The elements of a safety assessment for well logging is given in Annex II. Annex III provides information relating to the safety of neutron generators and Annex IV provides information on

[1] In this Safety Guide, well logging facilities include any area in which well logging equipment is kept or used.

radiation shielding for gamma and neutron radiation. Annex V provides a suggested structure for local rules for well logging. Annex VI provides illustrative examples of typical incidents that occurred with well logging sources, including a description of the successful recovery of a source stuck down a well.

2. DUTIES AND RESPONSIBILITIES

GENERAL

2.1. IAEA Safety Standards Series No. GSR Part 1, Governmental, Legal and Regulatory Framework for Safety [12] establishes requirements for the governmental, legal and regulatory infrastructure for safety of facilities and activities, including those associated with well logging with radiation sources, and attributes duties and responsibilities to all relevant parties. GSR Part 3 [9] provides the general framework for these duties and responsibilities, and this Section provides further guidance in the context of well logging using radioactive sources and radiation generators.

THE GOVERNMENT AND THE REGULATORY BODY

2.2. Paragraph 2.15 of GSR Part 3 [9] states that:

”The government shall establish legislation that, among other things:

(a) Provides the statutory basis for requirements for protection and safety for all exposure situations;

(a) Specifies that the prime responsibility for protection and safety rests with the person or organization responsible for facilities and activities that give rise to radiation risks;

(b) Specifies the scope of its applicability;

(c) Establishes and provides for maintaining an independent regulatory body with clearly specified functions and responsibilities for the regulation of protection and safety;

(d) Provides for coordination between authorities with responsibilities relevant to protection and safety for all exposure situations.”

A sound legal and governmental infrastructure, including a national regulatory body with well-defined responsibilities and functions is vital for the achievement and maintenance of a high level of safety in the use of radiation sources in well logging.

2.3. Paragraph 2.16 of GSR Part 3 [9] states that:

> "The government shall ensure that the regulatory body is effectively independent, in making decisions relating to protection and safety, of persons and organizations using or promoting the use of radiation and radioactive material, so that the regulatory body is free from any undue influence by interested parties and from any conflicts of interest; and shall ensure that it has functional separation from entities having responsibilities or interests that could unduly influence its decision making."

The regulatory body should have no stake in the development and utilization of the technology that it is regulating.

2.4. Paragraph 2.17 of GSR Part 3 [9] states that:

> "The government shall ensure that the regulatory body has the legal authority, competence and resources necessary to fulfil its statutory functions and responsibilities."

2.5. Requirement 3 of GSR Part 3 [9] states that:

> "The regulatory body shall establish regulations and guides for protection and safety and shall establish a system to ensure their implementation."

Many States have decided to adopt the IAEA's standards for use in their national regulations.

2.6. Paragraph 2.30 of GSR Part 3 [9] states that:

> "The regulatory body shall establish a regulatory system for protection and safety that includes:
>
> (a) Notification and authorization;
>
> (b) Review and assessment of facilities and activities;
>
> (c) Inspection of facilities and activities;
>
> (d) Enforcement of regulatory requirements;

(e) The regulatory functions relevant to emergency exposure situations and existing exposure situations;

(f) Provision of information to, and consultation with, parties affected by its decisions and, as appropriate, the public and other interested parties."

2.7. Paragraph 2.31 of GSR Part 3 [9] states that:

"The regulatory body shall adopt a graded approach to the implementation of the system of protection and safety, such that the application of regulatory requirements is commensurate with the radiation risks associated with the exposure situation. "

The graded approach should ensure that the application of regulatory resources is optimized while effectively verifying regulatory compliance.

2.8. Paragraph 2.32 of GSR Part 3 [9] states that:

"The regulatory body shall ensure the application of the requirements for education, training, qualification and competence in protection and safety of all persons engaged in facilities and activities relevant to protection and safety."

2.9. Paragraph 2.33 of GSR Part 3 [9] states that:

"The regulatory body shall ensure that mechanisms are in place to ensure the timely dissemination of information to all relevant parties, such as suppliers of and users of sources, on lessons learned for protection and safety from regulatory experience and operating experience, and from incidents and accidents and the related findings. The mechanisms established shall, as appropriate, be used to provide relevant information to other relevant organizations at the national and international level."

In many States, the regulatory body periodically communicates with relevant parties, such as suppliers of and users of sources through newsletters that provide information – such as on safe work practices and details of incidents involving radiation sources that have occurred in the State or elsewhere – so that lessons learned can be implemented to improve protection and safety.

2.10. Paragraph 2.34 of GSR Part 3 [9] states that:

"The regulatory body, in conjunction with other competent authorities, shall specify requirements for acceptance and for performance, by regulation or by the application of

published standards, for any manufactured or constructed source, device, equipment or facility that, when in use, has implications for protection and safety."

2.11. Paragraph 2.35 of GSR Part 3 [9] states that:

"The regulatory body shall make provision for establishing, maintaining and retrieving adequate records relating to facilities and activities. These records shall include:

- Registers of sealed sources and radiation generators;
- Records of doses from occupational exposure;
- Records relating to the safety of facilities and activities;
- Records that might be necessary for the shutdown and decommissioning or closure of facilities;
- Records of events, including non-routine releases of radioactive material to the environment;"

Records relating to the safety of well logging facilities and activities should include inventories of sources in use and of disused sources.

2.12. The regulatory body should also make provision for establishing, maintaining and retrieving adequate records of:

- The transport of radioactive sources;
- The location of radioactive sources;
- Incidents involving radiation sources, such as loss of radioactive sources, damage to radioactive sources and theft of radioactive sources or radiation generators.

2.13. The regulatory body should carry out inspection activities relating to the use of well logging devices containing radiation sources by the operating organization [13]. Inspections should review a range of issues relating to the safe use of such devices, and should include the following:

(a) Review of compliance with the conditions of the authorization to possess and use radiation sources for well logging: for example, checking that the inventory includes all the authorized radiation sources and devices, and that well logging devices are used only for authorized purposes at authorized locations. If any authorized source is missing or if any source is found to be not properly authorized, the matter should be investigated and

appropriate actions implemented (an immediate search should be made for missing sources, and any unauthorized sources should be brought under regulatory control).

(b) Confirmation that radiation sources and well logging devices meet the acceptance criteria and performance criteria established by the regulatory body.

(c) Measurement of the radiation levels around the well logging devices and estimation of the doses to workers and members of the public.

(d) Review of the records of workplace monitoring and individual monitoring.

(e) Observing the use of well logging devices, including procedures for safe handling of radiation sources.

(f) Review of control measures, such as the conduct of periodic source inventory checks, controls to ensure that sources are only used by authorized individuals, the use of appropriate engineered controls, the storage of radiation sources (including disused sources) and emergency plans and procedures.

(g) Review of compliance with regulatory requirements for transport of radioactive material (see Section 12).

(h) On-site inspections at client facilities where well logging devices are being used, and observing the operations involving the well logging tools including procedures for safe use and the arrangements for the safety and security of each source.

2.14. Paragraph 2.38 of GSR Part 3 [9] states that:

> "The regulatory body shall establish, implement, assess and strive to continually improve a management system that is aligned with the goals of the regulatory body and that contributes to the achievement of those goals."

2.15. Requirement 19 of GSR Part 3 [9] states that:

> "The government or regulatory body shall establish and enforce requirements to ensure that protection and safety is optimized, and the regulatory body shall enforce compliance with dose limits for occupational exposure."

2.16. Paragraph 3.69 of GSR Part 3 [9] states that:

> "The government or regulatory body shall establish the responsibilities of employers, registrants and licensees with regard to application of the requirements for occupational exposure in planned exposure situations."

2.17. In accordance with para. 3.72 of GSR Part 3 [9], before authorization of a well logging facility or activity the regulatory body is required to review the design criteria and design features relating to the exposure and potential exposure of workers in all operational states and in accident conditions. Only well logging tools that meet the design standards stipulated by the regulatory body should be permitted to be used. Individual monitoring, including estimation of neutron dose and gamma dose, as appropriate should be mandatory for well logging workers. In addition, the regulatory body should verify that the operating organization complies with workplace monitoring requirements (See paras 3.96–3.98 of GSR Part 3 [9]) for all well logging facilities and activities.

2.18. The regulatory body should establish requirements concerning the use of well logging devices at client facilities. The use of well logging devices at client facilities should be specifically authorized, for example through licence conditions.

2.19. The regulatory body should require the operating organization to conduct periodic checks on the inventory of radioactive sources that it possesses and to provide information, as appropriate, to the regulatory body for inclusion in a national register of radioactive sources, in accordance with IAEA Safety Standards Series No. SSG-19, National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources [14].

Communication and reporting mechanisms

2.20. Paragraph 2.33 of GSR Part 3 states that:

> "The regulatory body shall ensure that mechanisms are in place for the timely dissemination of information to relevant parties, such as suppliers of and users of sources, on lessons learned for protection and safety from regulatory experience and operating experience, and from incidents and accidents and the related findings. The mechanisms established shall, as appropriate, be used to provide relevant information to other relevant organizations at the national and international level."

In many States, the regulatory body periodically communicates with relevant parties, such as suppliers of and users of sources, through newsletters that provide information on topics such as safe work practices and details of incidents involving radiation sources that have occurred in the State or elsewhere so that lessons learned can be implemented to improve protection and safety.

2.21. Paragraph 2.36 of GSR Part 3 states that:

"The regulatory body shall establish mechanisms for communication and discussion that involve professional and constructive interactions with relevant parties for all protection and safety related issues."

2.22. The regulatory body should ensure that arrangements are put in place for the safety and security of radioactive sources, including financial provisions, where appropriate, for the disposal of radioactive sources once they have become disused. Specifically, the regulatory body should attach conditions to authorizations that require the operating organization to make arrangements for the safe and secure management of disused sources, including, where applicable, agreements regarding the return of disused sources to the supplier, in accordance with the Code of Conduct on the Safety and Security of Radioactive Sources [15].

THE OPERATING ORGANIZATION

2.23. The operating organization responsible for well logging facilities and activities has the prime responsibility for safety (see Requirements 4 and 9 of GSR Part 3 [9]). The operating organization is required to ensure that protection and safety is optimized (Requirement 11 of GSR Part 3 [9]). For well logging, the operating organization is normally the well logging company, i.e. the company that employs workers (or contracts self-employed workers) to undertake well logging activities involving radioactive sources and/or radiation generators. The manufacturers and suppliers of well logging equipment that contains radiation sources are also operating organizations with their own responsibilities for protection and safety.

2.24. The operating organization is required to demonstrate commitment to protection and safety at the highest levels within the organization for which they are responsible (Paragraph 2.47 of GSR Part 3 [9]).

2.25. The operating organization is required to submit an application to the regulatory body for authorization to operate a facility or conduct an activity involving radiation sources for well logging (Requirement 7 of GSR Part 3 [9]). Consequently, for an authorized well logging facility or well logging activity, the operating organization is normally also the registrant or licensee as defined in GSR Part 3 [9].

2.26. As stated in para. 2.42 of GSR Part 3 [9], the operating organization:

"Shall establish and implement a protection and safety programme that is appropriate for the exposure situation. The protection and safety programme:

(a) Shall adopt objectives for protection and safety in accordance with the requirements of [GSR Part 3];

(b) Shall apply measures for protection and safety that are commensurate with the radiation risks associated with the exposure situation and that are adequate to ensure compliance with the requirements of [GSR Part 3].”

2.27. The well logging company should have a source storage facility at its main base and on-site storage facilities, as necessary, which comply with regulatory requirements.

2.28. As stated in para. 2.43 of GSR Part 3 [9], the operating organization:

“Shall ensure that, in the implementation of the protection and safety programme:

(a) The measures and resources that are necessary for achieving the objectives for protection and safety have been determined and are duly provided;

(b) The programme is periodically reviewed to assess its effectiveness and its continued fitness for purpose;

(c) Any failures or shortcomings in protection and safety are identified and corrected, and steps are taken to prevent their recurrence;

(d) Arrangements are made to consult with interested parties;

(e) Appropriate records are maintained.”

Recommendations on establishing a radiation protection programme for well logging are given in Section 4 of this Safety Guide.

2.29. Paragraph 2.44 of GSR Part 3 [9] states that:

“The relevant principal parties and other parties having specified responsibilities in relation to protection and safety shall ensure that all personnel engaged in activities relevant to protection and safety have appropriate education, training and qualification so that they understand their responsibilities and can perform their duties competently, with appropriate judgment and in accordance with procedures.”

Recommendations on the training and qualification of persons undertaking well logging with radiation sources are given in Section 5 of this Safety Guide.

2.30. The operating organization is required to allow access by authorized representatives of the regulatory body to carry out inspections of their well logging facilities and activities and of

their protection and safety records, and should cooperate in the conduct of inspections (Paragraph 2.45 of GSR Part 3[9]).

2.31. The operating organization is required to ensure that qualified experts (see paras 2.43–2.47) are identified and consulted as necessary on the proper observance of regulatory requirements (Paragraph 2.46 of GSR Part 3[9]).

2.32. The operating organization is required to ensure that protection and safety is effectively integrated into their overall management system (Requirement 5 of GSR Part 3[9]).

2.33. As stated in paragraph 2.48 of GSR Part 3 [9], the operating organization:

> "Shall ensure that the management system is designed and applied to enhance protection and safety by:
>
> (a) Applying the requirements for protection and safety coherently with other requirements, including requirements for operational performance, and coherently with guidelines for security;
>
> (b) Describing the planned and systematic actions necessary to provide adequate confidence that the requirements for protection and safety are fulfilled;
>
> (c) Ensuring that protection and safety are not compromised by other requirements;
>
> (d) Providing for the regular assessment of performance for protection and safety, and the application of lessons learned from experience;
>
> (e) Promoting safety culture."

2.34. The operating organization is required to ensure that the protection and safety elements of the management system are commensurate with the radiation risks associated with the number and type of radiation sources in well logging tools in their possession, and the way in which these sources are used (Paragraph 2.49 of GSR Part 3[9]).

2.35. As stated in para. 2.50 of GSR Part 3 [9], the operating organization:

> "Shall be able to demonstrate the effective fulfilment of the requirements for protection and safety in the management system."

2.36. As stated in Paragraph 3.60 of GSR Part 3 [9], the operating organization:

> "Shall ensure that arrangements are made promptly for the safe management of and control over radiation generators and radioactive sources, including appropriate financial provision, once it has been decided to take them out of use."

Recommendations on the requirements relating to radiation generators and radioactive sources in well logging are provided in Section 10 of this Safety Guide.

Safety culture

2.37. Although the radiation sources and associated equipment used in well logging incorporate safety features, there is still a high reliance on safe working procedures to ensure protection and safety. In accordance with para. 2.51 of GSR Part 3 [9], the operating organization should promote and maintain safety culture by:

(a) Promoting individual and collective commitment to protection and safety at all levels of the organization, including staff from administration, security, storage facilities, operation, transport assembly and maintenance of well logging tools, as appropriate;

(b) Ensuring a common understanding of the key aspects of safety culture within the organization;

(c) Supporting individuals and teams in carrying out well logging activities safely and successfully, with account taken of the interactions between individuals, the well logging equipment and the well logging company and the client;

(d) Encouraging open communication and participation of operating staff, radiation protection officer(s) and other workers in the facility in the development and implementation of policies, rules and procedures dealing with protection and safety in well logging;

(e) Ensuring accountability of the organization and of individuals at all levels for protection and safety in the procurement, storage, installation, operation, maintenance, handling and safe management of well logging sources until their safe disposal after the end of their useful life;

(f) Encouraging a questioning and learning attitude, discouraging complacency and providing means by which the organization continually seeks to develop and strengthen its safety culture.

2.38. The operating organization should also ensure that personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment, or discrimination.

Human factors

2.39. Paragraph 2.52 of GSR Part 3 [9] states that:

"The principal parties and other parties having specified responsibilities in relation to protection and safety, as appropriate, shall take into account human factors and shall support good performance and good practices to prevent human and organizational failures, by ensuring among other things that:

(a) Sound ergonomic principles are followed in the design of equipment and the development of operating procedures, so as to facilitate the safe operation and use of equipment, to minimize the possibility that operator errors could lead to accidents, and to reduce the possibility that indications of normal conditions and abnormal conditions could be misinterpreted;

(b) Appropriate equipment, safety systems and procedural requirements are provided, and other necessary provision is made:

(i) To reduce, as far as practicable, the possibility that human errors or inadvertent actions could give rise to accidents or other incidents leading to the exposure of any person;

(ii) To provide means for detecting human errors and for correcting them or compensating for them;

(iii)To facilitate protective actions and corrective actions in the event of failures of safety systems or failures of protective measures."

RADIATION PROTECTION OFFICER

2.40. Paragraph 3.94(e) of GSR Part 3 [9] states that:

"Employers, registrants and licensees, in consultation with workers or through their representatives where appropriate: … shall designate, as appropriate, a radiation protection officer in accordance with criteria established by the regulatory body."

2.41. Paragraph 3.96 of GSR Part 3 [9] states that:

"Registrants and licensees, in cooperation with employers shall establish, maintain and keep under continuous review a programme for workplace monitoring under the supervision of a radiation protection officer or qualified expert."

2.42. The radiation protection officer is a person technically competent in radiation protection matters relevant for well logging operations with radiation sources, who is designated by the well logging company to oversee the application of relevant requirements. The appointment of the radiation protection officer should be in writing and the roles and responsibilities should be integrated into the job description.

2.43. The radiation protection officer should oversee the application of the safety requirements and should have the authority to intervene to stop an unsafe or non-compliant operation.

QUALIFIED EXPERTS

2.44. As stated in para. 2.46 of GSR Part 3 [9], the operating organization: "shall ensure that qualified experts are identified and are consulted as necessary on the proper observance of [GSR Part 3]".

2.45. A qualified expert is an individual who, by virtue of certification by appropriate boards or societies, professional licences or academic qualifications and experience, is duly recognized as having expertise in a relevant field of specialization [8], for example in radiation protection and the safe operation of well logging tools with radiation sources.

2.46. The government is required to establish requirements for the formal recognition of qualified experts (Paragraph 2.21 of GSR Part 3 [9]). 'Formal recognition' means documented acknowledgment or accreditation by the relevant authority that a person has the qualifications, training, education, experience and expertise required for the responsibilities that he or she will bear in relation to the conduct of well logging activities. The procedure for formal recognition may vary from State to State.

2.47. The operating organization may consult with one or more qualified experts on matters relevant to radiation safety, such as the design of well logging facilities, radiation shielding calculations, and testing and maintenance of workplace monitoring instruments. The responsibility for compliance with regulatory requirements cannot be delegated to the qualified expert and always remains with the operating organization.

2.48. Qualified experts do not have to be employees of the operating organization; they may be appointed on a part-time basis or for a specific period or project involving well logging. For example, a well logging company based in one State might appoint a qualified expert in another State where its operations are in progress. In such cases, the qualified expert should satisfy all

appropriate national qualification or certification criteria of the State where well logging operations are in progress. Qualified experts should have suitable experience, i.e. of facilities and activities involving well logging with radioactive sources and radiation generators. The qualified expert should work in close cooperation with the radiation protection officer to ensure that all the necessary duties and tasks are performed by workers.

WORKERS

2.49. A worker is any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection [8].

2.50. Workers are required to fulfil their obligations and carry out their duties for protection and safety (Requirement 22 of GSR Part 3 [9]). In particular, para. 3.83 of GSR Part 3 [9] states that:

> "Workers:
>
> (a) Shall follow all applicable rules and procedures for protection and safety as specified by the employer, registrant or licensee;
>
> (b) Shall use properly the monitoring equipment and personal protective equipment provided in working with well logging tools;
>
> (c) Shall cooperate with the employer, registrant or licensee with regard to protection and safety, and programmes for workers' health surveillance and programmes for dose assessment;
>
> (d) Shall provide to the employer, registrant or licensee such information on their past and present work that is relevant for ensuring effective and comprehensive protection and safety for themselves and others;
>
> (e) Shall abstain from any wilful action that could put themselves or others in situations that would not be in accordance with the requirements of [GSR Part 3];
>
> (f) Shall implement such information, instruction and training in protection and safety as will enable them to work with well logging tools in accordance with the requirements of [GSR Part 3]."

2.51. Paragraph 3.84 of GSR Part 3 [9] states that:

"A worker who identifies circumstances that could adversely affect protection and safety shall report such circumstances to the employer, registrant or licensee as soon as possible."

Employers should not take adverse or punitive actions against a worker who reports such circumstances.

COOPERATION BETWEEN EMPLOYERS AND THE OPERATING ORGANIZATION

2.52. Requirement 23 of GSR Part 3 [9] states that:

"Employers and registrants and licensees shall cooperate to the extent necessary for compliance by all responsible parties with the requirements for protection and safety."

The main example of such cooperation within the context of well logging is expected to occur between the well logging company (the operating organization) and the client (i.e. the owner of the site on which well logging is undertaken: see paras 2.58–2.63).

2.53. Paragraph 3.85 of GSR Part 3 [9] states that:

"If workers are engaged in work that involves or that could involve a source that is not under the control of their employer, the registrant or licensee responsible for the source and the employer shall cooperate to the extent necessary for compliance by both parties with the requirements of [GSR Part 3]."

For example, well logging might be undertaken on sites where there are already other sources of radiation exposure present. In such circumstances, the necessary protective measures should be implemented taking into consideration that the client (the operating organization in terms of the site) is responsible for protection and safety with regard to the radiation hazard associated with the site, and the well logging company is responsible for protection and safety with regard to the well logging sources.

2.54. Paragraph 3.86 of GSR Part 3 [9] states that:

"Cooperation between the employer and the registrant or licensee shall include, where appropriate:

(a) The development and use of specific restrictions on exposure and other means of ensuring that the measures for protection and safety for workers who are engaged in

work that involves or could involve a source that is not under the control of their employer are at least as good as those for employees of the registrant or licensee;

(b) Specific assessments of the doses received by workers as specified in (a) above;

(c) A clear allocation and documentation of the responsibilities of the employer and those of the registrant or licensee for protection and safety."

2.55. Paragraph 3.87 of GSR Part 3 [9] states that:

"As part of the cooperation between parties, the registrant or licensee responsible for the source or for the exposure as appropriate:

(a) Shall obtain from the employers, including self-employed persons, the previous occupational exposure history of workers … and any other necessary information;

(b) Shall provide appropriate information to the employer, including any available information relevant for compliance with the requirements of [GSR Part 3] that the employer requests;

(c) Shall provide both the worker and the employer with the relevant exposure records."

WORKERS ON SHORT TERM CONTRACTS (ITINERANT WORKERS)

2.56. If the operating organization hires self-employed workers on a short-term basis, it should ensure that they have the same level of protection and safety as workers employed on a permanent basis. Such short-term workers (sometimes called itinerant workers) typically work for a relatively short period of time (e.g. a few weeks) for the operating organization before leaving to work for another employer. It should be ensured that such working practices are in compliance with regulatory requirements.

2.57. The relevant responsibilities of the operating organization and the itinerant worker should be clearly specified in the contractual arrangements. The operating organization should request copies of the records of the annual effective dose received by the itinerant worker prior to their commencing work.

2.58. The operating organization and the itinerant worker should fulfil their respective responsibilities, as specified in regulations. The operating organization should clarify with the itinerant worker the allocation of responsibilities for matters such as:

(a) Individual dosimetry and dose record keeping (see Section 6);

(b) Health surveillance arrangements (see Section 4);

(c) Workplace monitoring arrangements (see Section 7);

(d) Local rules (see Section 4).

2.59. The operating organization should verify that the itinerant worker has the appropriate qualifications and has received adequate training in both radiation safety and safe handling and operation of well logging tools containing radiation sources. The operating organization should verify that all procedures and other relevant documents are provided in a language understood by the itinerant worker.

THE CLIENT

2.60. The client is the organization or person responsible for hiring the operating organization (the well logging company) to perform well logging work. The client is often the organization or person responsible for the well or drilling site or facility. The client should always use an operating organization that is authorized by the regulatory body in accordance with the regulatory requirements for well logging involving radiation sources.

2.61. The operating organization should insist on sufficient time to plan the work and to carry it out safely, and to enable compliance with any requirements to notify the regulatory body in advance of the work.

2.62. The operating organization should not accept conditions or limitations that would hinder them from performing well logging work in a safe manner. The client should ensure that well logging work is coordinated with other work on the site, to minimize the risks to workers arising from site specific hazards and to minimize radiation exposure of other workers on the site. There should be special coordination if more than one operating organization is working on the client's site at one time. A 'permit-to-work system' can facilitate communication and coordination of different activities on the same site.

2.63. The client is responsible for ensuring a safe working environment in the locations where access might be necessary by the well logging company. The client is also responsible for informing visiting workers about safety issues that are site specific, and should provide the visiting workers with any necessary training, in accordance with regulatory requirements.

2.64. If radioactive sources are to be stored temporarily on the client's site, both the client and the operating organization should ensure that the storage facilities are safe and secure, and that

any necessary authorizations are obtained from the regulatory body. Procedures for gaining access to the source storage facility should be clearly defined for the client and the operating organization and adhered to. (See also Section 8).

2.65. In the event of an incident involving the well logging tools with a potential for exposure of individuals to radiation, the client should extend all necessary cooperation to the operating organization to manage the incident in compliance with regulatory requirements (see Section 13).

3. SAFETY ASSESSMENT

GENERAL

3.1. Requirement 13 of GSR Part 3 [9] states that:

> "The regulatory body shall establish and enforce requirements for safety assessment, and the person or organization responsible for a facility or activity that gives rise to radiation risks shall conduct an appropriate safety assessment of this facility or activity."

Requirements for safety assessment are established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [16].

3.2. Many of the radiation sources used in well logging can produce high dose rates and hence should be subject to a comprehensive safety assessment. For sources and well logging tools of an identical type, it might be acceptable to conduct a generic safety assessment.

3.3. The initial safety assessment, sometimes called a 'prior radiological evaluation', is the primary tool for determining which control measures should be taken, and for confirming that all factors that have a bearing on protection and safety are considered. In accordance with Requirement 13 of GSR Part 3 [9], the safety assessment is required to be documented and, where appropriate, independently reviewed within the operating organization's management system.

3.4. Prospective users of well logging sources should submit a safety assessment to the regulatory body when applying for an authorization; therefore, the safety assessment should be prepared and documented before any radiation sources are received by the operating organization. Suppliers of well logging sources should seek an appropriate authorization before selling or delivering such sources in a State, in accordance with the regulatory requirements of the State.

3.5. The operating organization should plan ahead to ensure that there is sufficient time for the required control measures for protection and safety to be established and applied. A new safety assessment might not be necessary when a radiation source used in well logging is to be replaced with a source of an identical type unless there are changes in the working arrangements.

3.6. The safety assessment is required to be independently verified before being submitted to the regulatory body as part of the authorization process: see Requirement 21 of GSR Part 4 (Rev. 1) [16].

3.7. In the event of well logging work being carried out for which no safety assessment has been made, the operating organization should carry out and document a retrospective safety assessment. On the basis of the retrospective safety assessment it should either be confirmed that all the necessary control measures are in place, or else additional control measures should be identified and implemented.

METHODOLOGY FOR THE SAFETY ASSESSMENT

3.8. The radiation risks arising from the use of each radiation source, together with the probability and magnitude of potential exposures due to incidents, should be taken into account in the safety assessment. The safety assessment should include a consideration of:

(a) The dose rates from shielded and unshielded radioactive sources and from neutron generators, as appropriate;

(b) The exposure of well logging engineers, other workers and the public, from normal well logging operations, and potential exposures from reasonably foreseeable incidents (including exposures due to loss of shielding, due to contamination from a damaged radioactive source, and from other scenarios including very low probability events);

(c) Limits and technical conditions for operation of the well logging source;

(d) Ways in which structures, systems and components, as well as procedures relating to protection and safety, might fail or might otherwise lead to potential exposures, and the consequences of such failures;

(e) Ways in which external factors could affect protection and safety;

(f) Ways in which operating errors and human factors could affect protection and safety;

(g) Evaluation of the implications of any proposed modifications for protection and safety;

(h) Any uncertainties or assumptions, and their implications for protection and safety.

The elements of a safety assessment for well logging are described in Annex II.

OUTCOMES OF THE SAFETY ASSESSMENT

3.9. The safety assessment should be used by the operating organization to provide a basis for decision making in relation to the following:

(a) The engineered control measures that are necessary for safety.

(b) The administrative controls that are necessary for safety, for example the development of safe working procedures (local rules) to be implemented for storage, operation, maintenance of a source inventory, servicing and maintenance, and management of disused sources.

(c) Procedures for designating controlled areas and supervised areas (see Sections 4 and 11).

(d) Any measures necessary for the protection of the public.

(e) The assessment of occupational exposure (gamma and neutron radiation, as appropriate): (see Section 6).

(f) The training programme for well logging engineers and other workers (see Section 5).

(g) An effective emergency preparedness and response programme to manage reasonably foreseeable events (including very low probability events). This should include information on: reasonably foreseeable incidents; the measures necessary to minimize the likelihood of occurrence of such incidents; the necessary emergency arrangements (including emergency plans and procedures, and emergency equipment: see Section 13.

(h) The security of radiation sources used in well logging with the objective of deterring, delaying, detecting and responding to the theft of sources: see Section 9.

REVIEWS OF THE SAFETY ASSESSMENT

3.10. The safety assessment should be reviewed annually and whenever any of the following factors apply:

(a) When safety might be compromised or affected as a result of modifications to facilities or activities;

(b) When the acquisition of a new radiation source or a source with different characteristics is planned;

(c) When operating experience or the investigation of incidents, failures or errors indicates that current safety measures are invalid or are not fully effective;

(d) When significant changes to relevant standards, regulations or guidance have been made or are envisaged.

The operating organization should ensure that the safety assessment reflects current working practices and that no changes have been overlooked.

RECORD OF THE SAFETY ASSESSMENT

3.11. The safety assessment should be documented and independently reviewed within the operating organization's management system. Revisions and modifications of the safety assessment should be subject to audit by the regulatory body.

OPTIMIZATION OF PROTECTION AND SAFETY

3.12. The safety assessment should take into account that the magnitude of the individual doses, the number of people exposed, and the likelihood of incurring potential exposures , are all to be kept as low as reasonably achievable, economic and societal factors being taken into account. Any interaction between these various factors should be taken into account. If the next step of reducing the detriment can be achieved only with a deployment of resources that is disproportionate to the consequent reduction in detriment, it might not be appropriate to take that step, provided that individuals have been adequately protected. Protection and safety can then be said to be optimized and the exposures to be as low as reasonably achievable, economic and societal factors having been taken into account. Such a procedure should also be applied when an existing practice is being reviewed [17].

3.13. When protection and safety are optimized, the occupational exposures and public exposures arising from well logging are expected to be low, owing to a combination of engineered controls (e.g. the shielding incorporated in the containers for well logging tools) and administrative controls (e.g. training, designation of areas, source handling procedures and monitoring).

4. RADIATION PROTECTION PROGRAMME

OBJECTIVES AND SCOPE

4.1. Requirement 24 of GSR Part 3 [9] states that:

> "Employers, registrants and licensees shall establish and maintain organizational, procedural and technical arrangements for the designation of controlled areas and supervised areas, for local rules and for monitoring of the workplace, in a radiation protection programme for occupational exposure."

4.2. Paragraph 3.93 of GSR Part 3 [9] states that:

> "Employers, registrants and licensees shall minimize the need to rely on administrative controls and personal protective equipment for protection and safety by providing well engineered controls and satisfactory working conditions, in accordance with the following hierarchy of control measures:
>
> (1) Engineered controls;
>
> (2) Administrative controls;
>
> (3) Personal protective equipment."

4.3. The radiation protection programme is a key factor in relation to the development and maintenance of safety culture within an organization [18]. The radiation protection programme should cover the operating organization's management structure, policies, responsibilities, procedures and organizational arrangements. All of these should be put in place by the operating organization to control radiation hazards and to optimize protection and safety. Detailed recommendations on establishing and maintaining a radiation protection programme for the protection of workers are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [19].

4.4. The radiation protection programme should be customized and scaled to meet the needs of the operating organization. The programme should reflect the complexities and hazards associated with the well logging facilities and activities involving radiation sources. The programme should be based on the operating organization's safety assessment (see Section 3), and it should address both planned exposure situations and, as appropriate, emergency exposure situations (see Section 13).

4.5. The operating organization should take into account any additional industrial safety measures necessary to address other workplace hazards, which might include:

(a) Chemical hazards;

(b) Fire and explosion;

(c) Noise and vibration;

(d) Mechanical hazards (e.g. lifting equipment and overhead cranes);

(e) Pressure vessels;

(f) Other radiation sources (e.g. on nuclear facility sites, or sources used in industrial radiography).

STRUCTURE AND CONTENT

4.6. The radiation protection programme should cover the main elements contributing to protection and safety. The structure and contents of the radiation protection programme should be documented to an appropriate level of detail. The radiation protection programme should address the following essential elements:

(a) The management structure and policies relevant to protection and safety;

(b) The assignment of individual responsibilities for protection and safety;

(c) An education and training programme on the nature of the radiation hazards associated with well logging, and on the measures required for protection and safety;

(d) Local rules and the arrangements for supervision of work;

(e) The designation of controlled areas and supervised areas, as appropriate;

(f) Safety and security of radioactive sources including management of disused sources;

(g) Emergency preparedness and response;

(h) The arrangements for assessing occupational exposure and for monitoring the workplace, including the acquisition, testing and maintenance of workplace monitoring instruments;

(i) The programme for health surveillance of workers;

(j) A system for recording and reporting information relating to the control of exposures, the decisions regarding measures for occupational radiation protection and safety, and the results of individual monitoring and workplace monitoring;

(k) Methods for periodically reviewing and auditing the performance of the radiation protection programme;

(l) Requirements for quality assurance and procedures for process improvement.

4.7. These elements of a radiation protection programme, which are more fully described in the following sections, can be incorporated into a single document or a series of documents, depending on the scale and complexity of operations. The radiation protection programme, or a summary of it, should be made accessible to workers.

MANAGEMENT STRUCTURE AND POLICIES

4.8. The radiation protection programme should include a description of the management structure as it relates to protection and safety. This structure could be represented in the form of an organizational chart. This chart should clearly show the lines of reporting – from workers to the senior managers with overall responsibility – and should state the names and contact details of the persons with specific responsibilities for protection and safety (e.g. the radiation protection officer: see Section 2). If the operating organization has more than one location of operations, the management structure should clearly specify the lines of responsibility and responsible persons at each location.

4.9. The radiation protection programme should include the company policies on radiation safety, and should include a commitment by the management to keeping radiation doses as low as reasonably achievable and to fostering a positive safety culture.

PROGRAMME OF EDUCATION AND TRAINING

4.10. The radiation protection programme should describe the scope of the training programme in protection and safety for all workers directly involved in well logging activities and associated emergency response actions. It should also include a ‘radiation awareness’ programme for other staff, where appropriate. Such staff might include managers, trainees, workers not directly involved with well logging (such as cleaners and maintenance staff), and contractors. The radiation protection programme should also specify the minimum educational

and professional qualifications for relevant staff, especially the radiation protection officer and well logging personnel, in accordance with regulatory requirements. Section 5 provides more details on training and qualification of personnel.

4.11. The operating organization should keep suitable training records, which should be consistent with regulatory requirements. The record keeping arrangements should be specified in the radiation protection programme.

LOCAL RULES AND SUPERVISION

4.12. Paragraph 3.94 of GSR Part 3 [9] states that:

> "Employers, registrants and licensees, in consultation with workers or through their representatives where appropriate:
>
> (a) Shall establish in writing local rules and procedures that are necessary for protection and safety for workers and other persons;
>
> (b) Shall include in the local rules and procedures any relevant investigation level or authorized level, and the procedures to be followed in the event that any such level is exceeded;
>
> (c) Shall make the local rules and procedures and the measures for protection and safety known to those workers to whom they apply and to other persons who may be affected by them;
>
> (d) Shall ensure that any work in which workers are or could be subject to occupational exposure is adequately supervised and shall take all reasonable steps to ensure that the rules, procedures, and measures for protection and safety are observed;
>
> (e) Shall designate, as appropriate, a radiation protection officer in accordance with criteria established by the regulatory body."

4.13. Local rules that describe the procedures for carrying out well logging work should be written in a language that is understood by the workers who are expected to follow the rules. These local rules should cover all procedures associated with well logging work where there is the potential for radiation exposure, such as routine operations, source loading and unloading, transport of radioactive sources and emergency response (see Sections 10–13). The local rules are an important tool in the restriction of radiation exposures. They should include sufficient

information to allow well logging personnel and other workers to carry out their duties safely and in compliance with regulatory requirements.

4.14. A copy of the local rules should be provided to workers involved in well logging and to other relevant persons; additional copies should be displayed in the work area, as appropriate. Managers should ensure that all relevant persons have read and understood the local rules.

4.15. In organizations with a limited range of well logging sources, it might be appropriate to have one set of local rules covering all procedures. In larger organizations, it might be appropriate to have several sets of specific local rules. Such sets might comprise procedures for logging tool assembly and calibrations, for carrying out well logging work on a site, and for loading and unloading well logging sources. Some clients might also require specific local rules to be drawn up to cover well logging work on their premises.

4.16. The operating organization is required to designate a radiation protection officer (see paras 2.40–2.43), and may appoint more than one employee as radiation protection officer to oversee the day to day implementation of the local rules and to carry out other duties as required by the programme.

4.17. A suggested structure for local rules for well logging is provided in Annex V.

RADIATION SAFETY COMMITTEE

4.18. In larger well logging companies, (of around 100 employees or more) with a significant number of well logging tools and well logging applications, a radiation safety committee should be established for the purpose of regularly reviewing the implementation of the radiation protection programme. This committee might be dedicated to radiation safety or it might have other (conventional) safety related responsibilities. The radiation safety committee should include the radiation protection officer, the drilling manager, the health safety and environment officer and well logging engineers, as appropriate. The committee might also include a security officer, as emergencies can arise due to loss or theft of a source. The committee should include the senior manager(s) responsible for radiation safety, and representatives of the workforce.

4.19. The major task of the radiation safety committee is to review and evaluate the application and effectiveness of the radiation safety programme. The responsibilities of the radiation safety committee should include, but not be limited to, the following:

(a) Regular reviews of the radiation protection programme;

(b) Reviews of occupational radiation doses, workplace monitoring programme results, and any incident reports prepared by the radiation protection officer;

(c) Reviews of results of audits on the performance of the radiation protection programme;

(d) Making recommendations to senior management for improvements in the radiation protection programme;

(e) Provision of guidance and direction on the performance of the radiation protection officer's duties;

(f) Monitoring the investigation of any incident with the potential for unplanned exposure to radiation;

(g) Preparation of reports about relevant radiation safety issues for dissemination to managers and workers, as appropriate.

DESIGNATION OF CONTROLLED AREAS AND SUPERVISED AREAS

4.20. Paragraph 3.88 of GSR Part 3 [9] states that:

"Registrants and licensees shall designate as a controlled area any area in which specific measures for protection and safety are or could be required for:

(a) Controlling exposures or preventing the spread of contamination in normal operation;

(b) Preventing or limiting the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions."

4.21. Paragraph 3.89 of GSR Part 3 [9] states that:

"In defining the boundaries of any controlled area, registrants and licensees shall take account of the magnitudes of the exposures expected in normal operation, the likelihood and magnitude of exposures in anticipated operational occurrences, and the type and extent of the procedures required for protection and safety."

4.22. Paragraph 3.90 of GSR Part 3 [9] states that:

"Registrants and licensees:

(a) Shall delineate controlled areas by physical means or, where this is not reasonably practicable, by some other suitable means.

(b) Shall, where a source is only intermittently brought into operation or energized, or is moved from place to place, delineate an appropriate controlled area by means that are appropriate under the prevailing circumstances and shall specify exposure times.

(c) Shall display the symbol recommended by the International Organization for Standardization [see Ref. 20]] and shall display instructions at access points to and at appropriate locations within controlled areas.

(d) Shall establish measures for protection and safety, including, as appropriate, physical measures to control the exposure to radiation and spread of contamination and local rules and procedures for controlled areas.

(e) Shall restrict access to controlled areas by means of administrative procedures such as the use of work permits, and by physical barriers, which could include locks or interlocks, the degree of restriction being commensurate with the likelihood and magnitude of exposures.

…….

(h) Shall periodically review conditions to assess whether there is any need to modify the measures for protection and safety or the boundaries of controlled areas.

(i) Shall provide appropriate information, instruction and training for persons working in controlled areas."

4.23. As stated in para. 3.91 of GSR Part 3 [9]:

"Registrants and licensees shall designate as a supervised area any area not already designated as a controlled area but for which occupational exposure conditions need to be kept under review, even though specific measures for protection and safety are not normally needed."

4.24. The radiation protection programme should describe how controlled areas and supervised areas are to be designated. It should also describe the arrangements for delineating and restricting access to designated areas, the use of warning signs and the radiation monitoring programme for designated areas.

4.25. Controlled areas should be used to restrict exposures in well logging work, particularly when radioactive sources are unshielded, for example during the transfer of well logging tools

to and from the borehole, during loading and unloading of radioactive sources in logging tools, and during tool calibrations.

4.26. The designation of controlled areas and supervised areas should be based on the safety assessment (see Section 3) and the measured dose rates in the workplace. Dose rates can be high inside an operational area during well logging work, and the area should be designated as a controlled area, normally on a temporary basis (i.e. for the duration of the work). The precise approach adopted will depend on national or local regulations and requirements. Further recommendations on the designation of a controlled area during well logging on a site are provided in Section 11.

4.27. The well logging work should be arranged in such a way that there is no need to designate a controlled area outside the operational area. Depending on the dose rate outside the operational area, the surrounding area might be designated as a supervised area.

PROGRAMME OF WORKPLACE MONITORING

4.28. The radiation protection programme should describe the arrangements put in place by the operating organization for the selection, calibration, maintenance, testing and use of workplace monitoring equipment to measure the dose rates during well logging activities. The radiation protection programme should specify the locations where dose rate measurements should be made around fixed facilities (e.g. source storage facilities), during calibrations and when carrying out site work. The radiation protection programme should also specify the frequency of such measurements.

4.29. The radiation protection programme should describe the arrangements for recording monitoring results and the length of time that the records should be retained. Further details on the records retention periods are recommended in GSG-7 [19]. The radiation protection programme should specify the number and type of suitable workplace monitoring instruments that need to be available to the workers.

4.30. The radiation protection programme should include dose rate investigation levels, as recommended in GSG-7, [19]. These investigation levels should represent the maximum dose rates that are acceptable during the performance of specific activities and/or at specific locations such as at controlled area barriers during site work and at the operator’s position. Such dose rate investigation levels should be consistent with regulatory requirements and guidance.

ARRANGEMENTS FOR INDIVIDUAL MONITORING

4.31. The radiation protection programme should specify the individual dosimeter(s) to be used for recording the doses received by well logging workers from neutron and gamma sources, as appropriate. The programme should also specify when the dosimeters are to be worn, the period of wear, and the arrangements for proper storage when not in use, the assessment of dosimeters and for keeping of dose records. The radiation protection programme should also specify that the dosimetry service provider should be appropriately approved or accredited. The radiation protection programme should also provide guidance to the radiation protection officer on reviewing the dose records periodically to identify doses that are higher than usual and determining whether doses are as low as reasonably achievable.

HEALTH SURVEILLANCE PROGRAMME

4.32. The radiation protection programme should include details of the procedure for periodic health surveillance of well logging workers, in accordance with Requirement 25 of GSR Part 3 [9] and with regulatory requirements. The objective of a health surveillance programme is to assess the initial and continuing fitness of workers for their intended tasks. A qualified expert and/or an appropriately qualified occupational physician (see GSG-7 [19]) should be consulted regarding the establishment of the programme for health surveillance, which should be consistent with regulatory requirements.

4.33. Medical examinations of occupationally exposed workers should follow the general principles of occupational medicine and should be conducted by an occupational physician. Each worker covered by the health surveillance programme should be subject to a medical examination before commencing work with radiation, and thereafter at specified intervals, in accordance with regulatory requirements.

4.34. The initial medical examination should assess the health of workers and their fitness for the intended tasks, and should also identify those workers who have a condition that might necessitate particular precautions during work.

4.35. Periodic medical examinations should focus on confirming that no clinical condition that could prejudice the health of the worker has developed during work in areas involving occupational health hazards, including hazards due to radiation [19]. The nature and frequency of a periodic medical examination should depend on the type of work that is undertaken and the age and health status, and possibly the habits (e.g. smoking), of the worker and other

considerations that may be specified in the regulations. The frequency of periodic medical examinations should depend on the state of health of the worker and the type of work, but would typically be once a year.

4.36. Medical records associated with the health surveillance programme should be kept confidential, and should be preserved in a manner approved by the regulatory body. Medical records should be retained for at least the lifetimes of the workers concerned.

4.37. Health surveillance can also provide a baseline of information that can be used in the event of accidental exposure to a particular hazardous agent or in the event of occupational disease, and to provide workers with access to counselling with respect to any radiation risks to which they are or might be subjected.

PERIODIC REVIEWS AND AUDITS OF THE PERFORMANCE OF THE RADIATION PROTECTION PROGRAMME

4.38. As an integral part of the operating organization's management system, the radiation protection programme and its implementation should be reviewed on an annual basis. This periodic review should be carried out to identify any performance problems and to make recommendations to improve the effectiveness of the radiation protection programme.

4.39. A key part of this periodic review process is a series of workplace audits. The operating organization should specify the designation and qualifications of the persons who will conduct these audits, the frequency of audits, the expectations of the audit team, and the procedures for the reporting of results and their follow-up.

MANAGEMENT SYSTEM AND PROCESS IMPROVEMENT

4.40. Well logging work and its associated activities should be carried out in accordance with the established management system. The management system should include a quality assurance programme to ensure that all equipment and safety systems are regularly checked and tested, and that any faults or deficiencies are promptly brought to the attention of management and quickly remedied.

4.41. Management should ensure that the correct operating procedures are followed, and that the management system specifies the relevant checks and audits to be made and the records to be kept. The relevant regulatory requirements should be taken into account and reflected in the management system.

4.42. The management system should include a mechanism for the collection and feedback of lessons from incidents (including those reported within the organization and by other organizations), and how these lessons can be used to enhance safety.

4.43. The management system should itself be reviewed and updated as necessary on the basis of pre-identified performance indicators.

5. TRAINING AND QUALIFICATION

GENERAL

5.1. The operating organization is responsible for ensuring that well logging work with radiation sources is carried out safely and in compliance with all relevant regulations and safety standards. The operating organization should, therefore, ensure that such work is only carried out by well logging engineers and other workers who are qualified and/or certified, and who are trained and competent in well logging technology as well as in protection and safety.

5.2. The programmes for the training and qualification of well logging personnel will vary from company to company. If the training programme includes only a limited amount of training in radiation safety, appropriate additional training in protection and safety, and in meeting regulatory requirements, should be arranged by the operating organization. Such additional training may be provided by specialized training organizations rather than by the operating organization. Training courses in protection and safety may be delivered by a range of training providers, including colleges, universities, radiation protection institutions and training consultants [21].

DESIGN OF A TRAINING PROGRAMME

5.3. Well logging personnel should be classified into different levels of competence on the basis of their training and experience. Two levels of personnel can be identified for the purposes of training, as follows:

– Level 1: personnel working in supervised areas;

– Level 2: personnel handling radiation sources (including personnel involved in the transport, calibration and assembly of logging equipment containing sources) and/or working in controlled areas.

5.4. Training programmes should be established for the different levels of competence and should correspond to the responsibilities of the worker. The training programme should establish the criteria for passing written and practical examinations, as well as the procedures to be followed if an applicant fails an examination. The details of the training programme should be incorporated into the radiation protection programme.

STRUCTURE AND CONTENT OF TRAINING COURSES

5.5. Each training course should be structured around specific aims and objectives and should be customized to the needs of the target audience [21].

5.6. A summary of the essential aspects of basic training in radiation safety for Level 2 well logging personnel is provided in Table 1.

TABLE 1. SUMMARY OF THE ESSENTIAL ASPECTS OF BASIC TRAINING IN RADIATION SAFETY FOR LEVEL 2 WELL LOGGING PERSONNEL

Fundamental concepts and measurements	• Basic concepts of ionizing radiation; • Radiation quantities and units; • Instruments for detection of ionizing radiation; • Biological effects of ionizing radiation.
Principles of radiation protection	• The system of radiation protection: o Justification of practices; o Optimization of protection and safety o Dose limitation.
Practical radiation protection	• Regulatory requirements; • The designation of controlled areas and supervised areas; • Dose investigation levels for workers and dose rate investigation levels at specified locations; • Evaluation and control of hazards; • Outputs from radioactive sources; • The effects of time, distance and shielding; • Workplace monitoring; • Individual monitoring and health surveillance; • Working practices to limit doses and maintain them as low as reasonably achievable; • Storage of radioactive sources; • The correct operation and maintenance of well logging equipment; • The radiation protection programme; • Local rules;

- The management of radiation protection;
- Transport of radioactive sources;
- Decommissioning of facilities and disposal of radioactive sources;
- End-of-life considerations for sources following decay;
- Accidents and other incidents involving well logging sources, their consequences and lessons identified;
- Security of radioactive material;
- Emergency preparedness and response.

5.7. The training should include practical exercises, including procedures for retrieving a stuck or detached tool containing a radioactive source. Actual radioactive sources should not be used in such training: devices are available for training purposes that simulate radioactive sources and the associated workplace monitoring equipment. An alternative is to use unloaded (i.e. empty) well logging tools and/or 'dummy' sources that are not radioactive.

5.8. Section 13 provides recommendations on training and exercises in emergency preparedness.

5.9. The training on security aspects of radioactive sources used in well logging operations should be an integral part of training.

REFRESHER TRAINING

5.10. The operating organization should arrange for a programme of refresher training for well logging personnel to ensure that their knowledge and skills are kept up to date. Such training should include a review of the fundamentals of protection and safety, and information on changes to safety standards, equipment, policies and procedures, and any changes in regulatory requirements.

5.11. The frequency of refresher training should be consistent with regulatory requirements. Refresher training relating to protection and safety could be combined with other refresher training on well logging techniques. A typical frequency for refresher training is every three to five years; however, changes in regulations or the occurrence of safety issues should be disseminated as written instructions as soon as practicable, and then followed up by inclusion in the next scheduled refresher training.

TRAINING ASSESMENTS AND CERTIFICATION

5.12. Written examinations and practical training sessions on the handling of radiation sources in well logging should be conducted for level 2 well logging personnel. An internal certification of competence by the well logging company is sufficient for level 1 personnel.

6. INDIVIDUAL MONITORING OF WORKERS

GENERAL

6.1. Paragraph 3.99 of GSR Part 3 [9] states that:

> "Employers, as well as self-employed persons, and registrants and licensees shall be responsible for making arrangements for assessment of the occupational exposure of workers, on the basis of individual monitoring where appropriate, and shall ensure that arrangements are made with authorized or approved dosimetry service providers that operate under a quality management system."

6.2. Paragraph 3.100 of GSR Part 3 [9] states that:

> "For any worker who usually works in a controlled area, or who occasionally works in a controlled area and may receive a significant dose from occupational exposure, individual monitoring shall be undertaken where appropriate, adequate and feasible. In cases where individual monitoring of the worker is inappropriate, inadequate or not feasible, the occupational exposure shall be assessed on the basis of the results of workplace monitoring and information on the locations and durations of exposure of the worker."

6.3. The results of workplace monitoring can be used to indirectly estimate the radiation dose to workers, and this will often be appropriate for those workers that are not directly involved in well logging work with radiation sources. For work involving the assembly, calibration and use of well logging tools containing radiation sources, it will normally be appropriate for workers to wear personal dosimeters to directly assess their individual dose due to occupational exposure.

DOSE LIMITS FOR OCCUPATIONAL RADIATION PROTECTION

6.4. Paragraph 3.26 of GSR Part 3 [9] states that:

> "The government or the regulatory body shall establish and the regulatory body should enforce compliance with the dose limits specified in Schedule III [of GSR Part 3] for occupational exposures and public exposures in planned exposure situations."

6.5. Paragraph 3.27 of GSR Part 3 [9] states that:

"The government or the regulatory body shall determine which additional restrictions, if any, are required to be complied with by registrants and licensees to ensure that the dose limits specified in Schedule III [of GSR Part 3] are not exceeded owing to possible combinations of doses from exposures due to different authorized practices."

6.6. Paragraph 3.28 of GSR Part 3 [9] states that:

"Registrants and licensees shall ensure that the exposures of individuals due to the practices for which the registrants and licensees are authorized are restricted, so that neither the effective dose nor the equivalent dose to tissues or organs exceeds any relevant dose limit specified in Schedule III [of GSR Part 3]."

6.7. Paragraph III.1 of GSR Part 3 [9] states that:

"For occupational exposure of workers over the age of 18 years, the dose limits are:

(a) An effective dose of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years), and of 50 mSv in any single year;

(b) An equivalent dose to the lens of the eye of 20 mSv per year averaged over 5 consecutive years (100 mSv in 5 years) and of 50 mSv in any single year;

(c) An equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

Additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breast-feeding."

The start of the averaging period shall be coincident with the first day of the relevant annual period after the date of entry into force of [GSR Part 3] with no retrospective averaging.

6.8. Paragraph III.2 of GSR Part 3 [9] states that:

"For occupational exposure of apprentices of 16 to 18 years of age who are being trained for employment involving radiation and for exposure of students of age 16 to 18 who use sources in the course of their studies, the dose limits are:

(a) An effective dose of 6 mSv in a year;

(b) An equivalent dose to the lens of the eye of 20 mSv in a year;

(c) An equivalent dose to the extremities (hands and feet) or the skin of 150 mSv in a year."

6.9. Short-term contract workers are subject to the same dose limits as permanently employed workers.

INDIVIDUAL DOSE ASSESSMENT USING PASSIVE DOSIMETERS

6.10. The operating organization should ensure that radiation doses to well logging personnel who work with radiation sources are routinely assessed to ensure that doses are kept as low as reasonably achievable and are below the dose limits. An assessment of the doses can also highlight good or bad working practices, faulty equipment, or the degradation of shielding or other safety systems.

6.11. The operating organization should make arrangements with a dosimetry service for the provision of suitable dosimeters, which should be assigned to workers by name for the purpose of formal dose record keeping. Dosimeters should be worn by all well logging personnel and any other workers who are required to regularly enter controlled areas (and also supervised areas, where this is required by national regulations).

6.12. There are various types of passive dosimeter available for measuring individual doses from gamma well logging sources. These include thermoluminescent dosimeters, optically stimulated luminescent dosimeters and film dosimeters. Some of these dosimeters also offer a neutron dose measurement capability. Alternatively, separate neutron dosimeters (for example, track etch detectors) may be worn. All these types of dosimeter incorporate one or more passive elements to record radiation exposure. The dosimeters are supplied by, and returned to an accredited agency providing a specialized dosimetry service that then processes the dosimeters to assess the dose.

6.13. The choice of type of dosimeter to be used by well logging personnel should be evaluated by the radiation protection officer, possibly in conjunction with a qualified expert in radiation dosimetry. In addition to the need to fulfil various technical requirements, the choice of dosimeter might also be influenced by considerations of availability, cost and robustness, as well as regulatory requirements.

6.14. To ensure that the dosimeter provides an accurate assessment of the effective dose to the worker, the following guidelines should be followed:

(a) Dosimeters should be worn by well logging workers at all times when carrying out work with radiation sources;

(b) Dosimeters should be worn in accordance with the recommendations of the dosimetry service provider;

(c) The measuring element should be correctly positioned in the dosimeter holder;

(d) The dosimeter should be worn only by the person to whom it is issued;

(e) Care should be taken to avoid damaging the measuring element of the dosimeter (dosimeters can be damaged by water, high temperature, high pressure or physical impact);

(f) Dosimeters should not be exposed to radiation when not being worn by the worker (i.e. the dosimeter should be kept away from sources of radiation when not in use);

(g) Dosimeters should be promptly returned to the dosimetry service for processing at the end of the period of wear. Dosimeters that have been returned early due to a suspicion of abnormal exposure should be processed urgently;

(h) The dosimetry service should be informed if the operating organization suspects that the dosimeter has been damaged or has been exposed to radiation while the worker to whom it was assigned was not wearing it, in order that the correct dose to be assigned to the worker can be determined;

(i) Neutron dosimeters with a suitable neutron energy response should be worn by personnel performing operations involving radioactive neutron sources or neutron radiation generators.

ACTIVE PERSONAL DOSIMETERS

6.15. Active personal dosimeters are small electronic radiation detectors that emit a warning signal when a pre-set dose rate or dose alarm level is exceeded. Most of these devices also provide a digital display of the cumulative personal dose equivalent. The warning signal is normally an audible alarm, although this can be supplemented by a vibration or a visual signal (which is useful if the ambient noise level is high and/or if ear protectors are being worn).

6.16. Active personal dosimeters are a useful tool to warn of high dose rates or to prevent over exposures. They can also help to immediately alert workers to problems, hence preventing incidents or mitigating their consequences. The operating organization should provide active personal dosimeters to well logging personnel who regularly undertake well logging work with radiation sources.

6.17. Important considerations in relation to the use of personal alarm monitors include the following:

(a) Active personal dosimeters should not replace passive dosimeters unless they have been specially approved (for example by the regulatory body) for this purpose. In most cases, active personal dosimeters will supplement the passive dosimeters worn by well logging personnel.

(b) Active personal dosimeters should not be used as a replacement for workplace monitoring instruments (e.g. dose rate meters).

(c) Active personal dosimeters should be tested periodically in accordance with national recommendations and/or guidance from the manufacturer.

(d) Active personal dosimeters should be calibrated in terms of the radiation fields likely to be encountered in the workplace.

(e) The alarm settings of the active personal dosimeters should reflect an appropriate level of either dose or dose rate and the alarm level should be visible during operation of the device.

(f) Changes to active personal dosimeters should not be allowed, except by persons with appropriate roles and responsibilities.

RECORD KEEPING

6.18. Paragraph 3.103 of GSR Part 3 [9] states that:

> "Employers, registrants and licensees shall maintain records of occupational exposure for every worker for whom assessment of occupational exposure is required…"

6.19. The operating organization should keep records of doses received by well logging personnel and any other persons who regularly enter controlled areas (and also supervised areas, where this is required by national regulations). These records should contain details of the doses recorded by the dosimeters worn by workers. If possible, the records should clearly identify any

doses received as a result of incidents or while following emergency procedures, as distinct from doses received during routine work.

6.20. The records should reflect the doses recorded by the worker's primary individual dosimeter(s) issued by the dosimetry service, rather than the doses measured by additional devices such as active personal dosimeters.

6.21. Paragraph 3.106 of GSR Part 3 [9] states that:

"Employers, registrants and licensees:

(a) Shall provide workers with access to records of their own occupational exposure;

(b) Shall provide the supervisor of the programme for workers' health surveillance, the regulatory body and the relevant employer with access to workers' records of occupational exposure;

(c) Shall facilitate the provision of copies of workers' exposure records to new employers when workers change employment;

(d) Shall make arrangements for the retention of exposure records for former workers by the employer, registrant or licensee, as appropriate;

(e) Shall, in complying with (a)–(d) above, give due care and attention to maintaining the confidentiality of records."

6.22. Paragraph 3.104 of GSR Part 3 [9] states that:

"Records of occupational exposure for each worker shall be maintained during and after the worker's life, at least until the former worker attains or would have attained the age of 75 years, and for not less than 30 years after cessation of the work in which the worker was subject to occupational exposure."

6.23. Paragraph 3.107 of GSR Part 3 [9] states that:

"If employers, registrants and licensees cease to conduct activities in which workers are subject to occupational exposure, they shall make arrangements for the retention of workers' records of occupational exposure by the regulatory body or a State registry, or by a relevant employer, registrant or licensee, as appropriate."

INVESTIGATION OF DOSES EXCEEDING DOSE LIMITS

6.24. The operating organization is required to conduct an investigation if a dose to a well logging worker, other worker or member of the public exceeds any dose limit or an investigation level specified by the regulatory body or operating organization (Requirement 16 of GSR Part 3 [9]). The investigation should focus on the causes that resulted in the exposure, and on any failures in procedures or safety systems. The investigation report should identify any improvements to facilities, equipment or procedures to optimize protection and safety, to reduce the likelihood of a similar event occurring and/or to mitigate the consequences.

6.25. Recommendations on the notification and reporting of incidents are provided in Section 13.

TESTING AND CALIBRATION OF DOSIMETRY EQUIPMENT

6.26. Dosimeters should be of an approved type and should be subjected to periodic quality assurance tests. Personal dosimetry systems should be calibrated periodically (typically every one or two years), with more frequent checks being carried out on the performance of the system. National regulations may require different frequencies of calibration. Recommendations on the testing and calibration of dosimeters and dosimetry equipment are provided in GSG-7 [19].

7. WORKPLACE MONITORING

MONITORING PROGRAMME

7.1. Paragraph 3.96 of GSR Part 3 [9] states that:

> "Registrants and licensees … shall establish, maintain and keep under review a programme for workplace monitoring under the supervision of a radiation protection officer or qualified expert."

7.2. The programme for workplace monitoring should be designed to assess the adequacy of the arrangements for protection and safety in well logging work with radiation sources. The programme should include measurements of dose rate at the following positions:

(a) Around source storage facilities at the main base of the well logging company and, as appropriate, at the well logging site, to ensure that an adequate level of shielding is provided;

(b) Around the barriers during well logging operations, to confirm that dose rates remain below any values specified in national regulations or guidance and/or by the operating organization;

(c) At the operator's position during loading and unloading of a logging tool or termination of operation of a neutron generator, to confirm that radiation levels are acceptable;

(d) On the site on completion of the well logging work, to confirm that no radioactive sources have been left on the site;

(e) Around the transport package prior to transporting radioactive sources to and from the site, to confirm the presence of the source, and also to demonstrate compliance with SSR-6 (Rev. 1) (see Section 12);

(f) Around vehicles transporting radioactive sources prior to departure to and from the site, including at the driver's seat.

7.3. It might be necessary to perform periodic checks for radioactive contamination on accessible surfaces of the logging tool or radioactive source at time intervals specified by the regulatory body. Monitoring for radioactive contamination within the well logging operational area, on the surface of the transport package, or on well logging workers is not normally necessary.

7.4. The operating organization should consider the need to monitor logging tools for radioactive contamination due to naturally occurring radioactive material. If contamination due to naturally occurring radioactive material is detected, the operating organization should ensure that the tool is decontaminated and the resulting waste is disposed of. Practical guidance on the radiation safety and waste management aspects of naturally occurring radioactive material is provided in Ref. [22]. If it is known that naturally occurring radioactive material is present in areas where well logging operations are to be performed, the operating organization should cooperate closely with the client to agree on suitable arrangements to prevent the spread of radioactive contamination, and to dispose of any waste arising.

7.5. The workplace monitoring programme should describe the locations to be monitored, the frequency of monitoring and the records to be kept. This information should be included in

the local rules and should also be described in the radiation protection programme. Dose rate investigation levels (see para. 4.30) for each measurement location should be prescribed, and the actions to be taken if these values are exceeded should be specified. Records of the workplace monitoring programme are required to be made available to appropriate persons, including workers and the regulatory body (see paras 2.45 and 3.98 of GSR Part 3[9]).

SELECTION, MAINTENANCE AND CALIBRATION OF WORKPLACE MONITORING INSTRUMENTS

7.6. The operating organization should ensure that a sufficient number of suitable dose rate monitors are made available. While there are many types of monitor for measuring gamma radiation levels, some might not be suitable for accurately measuring low energy photons (e.g. from Am-241), which could result in an underestimation of the dose rate. Monitors should be calibrated in terms of the radiation fields likely to be encountered in the workplace. Specialized monitoring instruments are necessary for the measurement of neutron radiation. Information and guidance on the suitability of monitors should be obtained from manufacturers and from qualified experts.

7.7. The operating organization should arrange for workplace monitoring instruments to be formally tested or calibrated at periodic intervals by a specialized testing laboratory. A number of operating characteristics of the monitoring instrument should be assessed in these tests or calibrations. These operating characteristics include the response to known dose rates at specific energies, the linearity of the response including the behaviour of the monitor at low dose rates and at very high dose rates. The frequency and the method of test or calibration, together with the associated record keeping, should comply with regulatory requirements, or else as recommended in appropriate international guidelines. The operating organization should also follow the recommendations of the manufacturer of the workplace monitoring instruments.

7.8. The operating organization should prepare a procedure for undertaking routine operational checks of workplace monitoring instruments. These checks might include physical checks of whether the instrument is damaged, battery checks and, if required, zeroing of the scale. The response of the monitor to radiation should also be checked. This can be done, for example, by using a low activity test source, or by placing the instrument close to the surface of a transport package containing a radioactive source. The regulatory body may require that such checks are performed in accordance with formal procedures and that the results are recorded.

7.9. Account should be taken of the conditions in which workplace monitoring instruments are to be used. Some instruments are unsuitable for use in very humid or very hot locations, and some are not robust enough for use at a well logging site. On some sites where well logging work is carried out, special types of workplace monitoring instrument might have to be used. For example, in many oil and gas facilities, only monitoring instruments that are designed to minimize the likelihood of accidental ignition of flammable fumes or vapours (‘intrinsically safe monitoring instruments’) are allowed to be used.

7.10. Some workplace monitoring instruments are affected by radiofrequency transmissions. If well logging is to be carried out close to equipment that generates high levels of radiofrequency radiation, then consideration should be given to the use of specially designed instruments that are shielded from radiofrequency interference.

7.11. Account should also be taken of noise levels in the workplace. Audible warning signals from workplace monitoring instruments should be loud enough to be heard and they should be supplemented by vibration or visual signals, as appropriate.

8. CONTROL OF RADIOACTIVE SOURCES

8.1. The Code of Conduct on the Safety and Security of Radioactive Sources [15] applies to all radioactive sources that might pose a significant risk to individuals, society and the environment, and serves as guidance to States on the safety and security of Category 1, 2 and 3 sources.

8.2. Radioactive sources used in well logging are generally considered to be Category 3, as defined in RS-G-1.9 [3]: however, as shown in Annex I, depending on the activity of the well logging sources used they can also be assigned to Category 2 or Category 4.

8.3. The operating organization is required to ensure that sources are kept under proper control: see para. 3.55 of GSR Part 3 [9]. This should apply from the time they are first acquired until they are finally returned to their original supplier or are otherwise safely dealt with at the end of their lifetime.

8.4. The operating organization should ensure that it only obtains radioactive sources from authorized suppliers and that disused sources are returned to the original supplier or transferred to another authorized body in accordance with regulatory requirements. The import and export of radioactive sources should be consistent with the recommendations in the Code of Conduct on the Safety and Security of Radioactive Sources [15] and the supplementary guidance on import and export controls [23].

8.5. Paragraph 3.53 of GSR Part 3 [9] states that:

> "Registrants and licensees shall maintain an inventory that includes records of:
>
> (a) The location and description of each radiation generator and radioactive source for which they are responsible;
>
> (b) The activity and form of each radioactive source for which they are responsible."

8.6. As well as maintaining the inventory records described in para. 8.5, the operating organization should conduct periodic accountancy checks of its sources, to confirm that they are in their assigned locations and are secure.

8.7. Radiation sources should only be removed from a source store or moved to another location by trained workers authorized by the operating organization. The workers should log their name, the date and time, and the new location of the source(s). These records should be audited by the radiation protection officer at least once per month, to ensure that all radiation

sources are in the correct location. Well logging tools that incorporate neutron generators should be included in such accountancy procedures.

8.8. Each container for a radioactive source should have a lock (or outer locked container or enclosure) designed to prevent unauthorized or accidental removal of the source. Storage facilities are required to be kept locked when containing radioactive sources except when under the direct surveillance of operating personnel: see para. 3.59 of GSR Part 3 [9].

8.9. Well logging sources for which there is no further identified use should be considered to be disused sources and arrangements should be made for the disposal of such sources by transfer to an authorized facility in accordance with regulatory requirements. Until such transfer is effected, the disused source should be included in the source inventory of the facility and subject to accountancy checks as specified in para. 8.6.

8.10. Any suspected loss of control over a radioactive source or neutron generator should be promptly investigated by the operating organization: the regulatory body (and any other relevant authority) should be notified as specified in regulatory requirements and the relevant emergency plans and procedures.

9. NUCLEAR SECURITY CONSIDERATIONS

9.1. The aim of security measures for radioactive sources is to deter, detect, delay and respond to unauthorized access to radioactive sources. Radioactive sources used for well logging have been involved in incidents (see Annex VI), and it should be assumed that there could be a significant radiological impact if such sources were to be used for malicious purposes.

9.2. The following paragraphs are intended to raise awareness about the security issues that need to be addressed and which are covered in detail in the IAEA Nuclear Security Series publications. In particular, IAEA Nuclear Security Series No. 14 [24] provides recommendations to States and competent authorities on how to develop or enhance, to implement, and to maintain a nuclear security regime for radioactive material, associated facilities, and associated activities. IAEA Nuclear Security Series No. 11 [25] contains more specific guidance to assist States in the development of regulatory requirements for the security of radioactive sources. IAEA Nuclear Security Series No. 9 [26] provides guidance on security in the transport of radioactive material.

THE INTERFACES BETWEEN SAFETY AND NUCLEAR SECURITY

9.3. Safety measures and security measures have in common the aim of protecting human life and health, society and the environment. Safety measures and security measures should be designed and applied in an integrated manner, and as far as possible in a complementary manner, so that security measures do not compromise safety and safety measures do not compromise security.

9.4. To ensure that safety measures and security measures are applied in a complementary manner, the government may designate a body responsible for managing the interfaces between safety and security in relation to radioactive sources. Alternatively, a single regulatory body may be assigned responsibility for both the safety and the security of radioactive sources under the national regulatory infrastructure.

9.5. In the use of radioactive sources for well logging, there might be an interface between security and safety measures with regard to access to information. For safety purposes, information on the locations and characteristics of radioactive sources and the safety measures in place might need to be readily accessible. However, this information might also be of

potential value to an adversary and therefore security considerations may necessitate that the confidentiality of some sensitive information be protected. Guidance on the protection and confidentiality of sensitive information in nuclear security is provided in IAEA Nuclear Security Series No. 23-G [27]. An appropriate balance needs to be maintained between the availability of information for safety reasons and the need to protect sensitive information for security reasons.

SECURITY MEASURES

9.6. The accidental loss of well logging sources, which might have security as well as safety implications, is addressed through the control measures described in Section 8. The primary security concerns are the possibility of theft and sabotage of radioactive sources. Effective security measures will address these concerns and also provide some inherent benefit towards preventing accidental loss of control.

9.7. Safety measures aimed at preventing the loss of radioactive sources or for general radiation protection purposes can also provide some benefit against the theft of sources. However, the element of intent involved in theft means that additional considerations apply, especially for higher activity sources, and additional and/or different security measures might be needed to protect against theft.

9.8. The IAEA Nuclear Security Series provides guidance on how to define the requirements for the security of radioactive sources using a graded approach, based on considerations of threat, the nature of the sources, and the relative attractiveness of the material for use in a malicious act. IAEA Nuclear Security Series No. 11 [25] suggests using the categorization system set out in RS-G-1.9 [3] in order to assign a particular security level to sources and to help define the necessary security measures. Well logging sources are typically assigned to security level C, and not higher than security level B. The security measures required for each security function (deterrence, detection, delay, response and security management) for security levels B and C are described in detail in IAEA Nuclear Security Series No. 11 [25].

9.9. Owing to their small size, portability and the fact they are most often used far from a secure facility, well logging devices might need additional security measures or procedures to ensure that they remain adequately protected and under control during use, during transport and when they are not in use (i.e. in storage). The specific details of such additional measures will depend on the threat assessment. IAEA Nuclear Security Series No. 11 [25] also contains

illustrative security measures including those for mobile operations where measures applicable to a fixed installation are not practicable.

10. SAFE HANDLING OF RADIOACTIVE SOURCES AND RADIATION GENERATORS

GENERAL

10.1. Information on the various types of radioactive source and neutron radiation generator used in well logging is provided in Annex I.

10.2. A range of radioactive sources, neutron generators and ancillary equipment are commercially available for carrying out well logging work. Radiation sources and other equipment used for well logging should be obtained from an authorized manufacturer with an established quality management system such as ISO 9001 [28] or the system described in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [29] or an equivalent national standard, to ensure that the design safety features are reproduced consistently.

10.3. Equipment used for well logging typically consists of several subcomponents that make up a well logging tool string. The design and operation of these various components are interrelated. Safety should not be compromised by using components that do not meet the original design specifications.

10.4. Manufacturers and suppliers of radioactive sources and radiation generators are required to ensure that information on the safe use of the equipment is made available to operating organizations. This information is required to be made available in an appropriate language that is understandable to users (Paragraph 3.49(c) of GSR Part 3[9]).

10.5. The operating organization should ensure that equipment used for well logging purposes is not modified without a prior assessment of the implications of the modification for protection and safety. The safety assessment should be reviewed by a qualified expert or by the supplier, and it should be verified that the equipment meets the requirements of the regulatory body. It should also be determined whether additional authorization or approval by the regulatory body is required.

RADIOACTIVE SEALED SOURCES FOR WELL LOGGING

10.6. Well logging equipment utilizes radioactive sealed sources that emit gamma radiation or neutron radiation (see Annex I). The sealed radioactive sources are installed into logging

tools using special source handling tools. The radioactive sources (or in some cases, the pre-loaded logging tools), are housed in shielded containers when not in use. The part of the tool containing the radioactive source is attached to the main logging tool string (if required, by using appropriate handling tools) to be transferred to the borehole or well (or else to a calibration facility).

10.7. Sealed radioactive sources (gamma and neutron) used for well logging purposes should be compatible with the tool and any ancillary equipment (such as handling tools) with which they are used. Such sources should also meet international or equivalent national standards, for example:

(a) Sources should comply with the relevant requirements set out in ISO 2919 [30];

(b) Sources should be certified as meeting the requirements for special form radioactive material, as established in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [31];

(c) Sources should be leak tested in accordance with ISO 9978 [32] or an equivalent national standard and there should be a valid leak test certificate that is traceable to each individual source;

(d) Sources should be marked in accordance with ISO 2919 [30] or an equivalent national standard, or, as a minimum, marked with the radiation symbol (trefoil) [20] and the legend ‘RADIOACTIVE’.

10.8. Some manufacturers specify a recommended working life for a radioactive sealed source. The recommended working life is based on a number of factors, including the half-life of the source, the construction of the source encapsulation and the impact of the environment in which the source is to be used. The recommended working life is an indication of the period of time over which the source is expected to retain its integrity.

10.9. Manufacturers usually recommend that a source is replaced when it reaches the end of its recommended working life. At the discretion of the regulatory body, an extension of the use of a source beyond its recommended working life may be granted if the source is subjected to more frequent wipe tests or to more detailed leakage tests as specified in ISO 9978 [32]. Alternatively, a physical assessment of the condition of the source by a suitably qualified body or expert might be carried out to advise about its continued use.

10.10. For well logging sources that are to be transported, the special form certificate should be revised and updated at least every 5 years or as required by national regulations. Records of qualification of special form radioactive material should be available for verification during regulatory inspections [33, 34]. The issue of updated special form certificates is normally undertaken by the source manufacturer; however, it is the responsibility of the operating organization (as consignor) to ensure that there are valid special form certificates for all well logging sources that are to be transported in accordance with SSR-6 (Rev. 1) [31].

MARKING AND LABELLING OF WELL LOGGING EQUIPMENT CONTAINING SEALED RADIOACTIVE SOURCES

10.11. Each logging tool assembly that contains a radioactive source should be permanently and clearly marked with the following details:

(a) The international ionizing radiation symbol (trefoil) [20];

(b) The word ‘RADIOACTIVE’ in letters not less than 10 mm in height, together with a brief warning in a language appropriate to the country or region of use;

(c) The chemical symbol(s) and mass number of the radionuclide(s) for which the tool is suitable (e.g. Cs-137 or Am-241);

(d) The source activity in the tool, quoted for each radionuclide for which the tool is suitable, and the date of source calibration;

(e) The make, model and serial number of the tool;

(f) The date of manufacture of the tool.

10.12. The shielded container for a well logging tool containing a radioactive source should display a durable fireproof label or tag bearing information about the radioactive source that it currently contains, including:

(a) The chemical symbol and mass number of the radionuclide;

(b) The activity on a stated date;

(c) The identification number of the sealed source;

(d) The name of the source manufacturer.

NEUTRON RADIATION GENERATORS FOR WELL LOGGING

10.13. The neutron radiation generator used for well logging applications is a compact linear accelerator of deuterium nuclei, which produces 14 MeV neutrons. Its components include an accelerator tube (neutron tube), a target containing deuterium or tritium, a high voltage power supply and a measurement module. Some information on the radiation safety aspects of neutron generators is given in Annex III.

10.14. The dose rates on the exterior of the neutron generator should be within the limits stipulated by the regulatory body.

10.15. Gamma radiation is emitted both during neutron generation (from inelastic interaction of high energy neutrons), and for some time after the generator is turned off (from capture of thermal neutrons and the subsequent radioactive decay of neutron activation products).

10.16. If the dose rate from the neutron generator immediately after the generator is switched off is acceptable (as determined by the operating organization in the safety case: see Section 3), authorized personnel can be permitted to handle the generator. Otherwise, a holding time is necessary to allow for the decay of activation products created in the neutron generator.

10.17. In some cases, neutron generators can accumulate radioactive contamination on their outer surfaces. In such cases, appropriate personal protective equipment should be worn by workers when handling the generator. Checks for contamination should be conducted periodically (at least once a year), upon receiving and shipping out the neutron generator, and prior to the repair of the neutron generator.

SOURCE CHANGERS AND SHIPPING CONTAINERS FOR RADIOACTIVE SOURCES

10.18. Source changers should be used for the safe exchange of old and new well logging sources between the operator’s tool and the source changer (normally the shipping container) used by the source supplier (which should normally be returned to the supplier after the exchange of a source). Storage containers should allow for the safe storage of sealed sources when not in use, and should prevent unauthorized access.

10.19. Source changers or storage containers should meet all applicable national standards in terms of dose rates and labelling. Such containers should include a lock or should have an outer locked container designed to prevent unauthorized or accidental removal of the sealed source from its shielded position. Storage containers and source changers should be kept locked (with

the key removed at all times) when they contain sealed sources, unless they are under the direct surveillance of an authorized worker. Often source changers are used as transport containers and therefore, the consignor should ensure that source changers are transported in compliance with SSR-6 (Rev. 1) [31].

SAFETY OF NEUTRON RADIATION GENERATORS IN CALIBRATION OPERATIONS

10.20. Shielding materials of low atomic number are normally the most cost-effective and practical approach for reducing dose rates around neutron generators during calibration operations. Information on shielding calculations for neutron radiation is provided in Annex IV. The geometry of the shielding should be designed to restrict the exposure of the workers undertaking the calibrations, with due account taken of scattered neutron radiation.

10.21. The neutron flux can be measured by the neutron detectors integrated into the generators. Account should be taken of the fact that the pulsed emission of neutrons can significantly influence the readings of such detectors and therefore, necessary corrections should be applied to the readings.

10.22. If radioactive sources are used in the calibration of radiation generators, the sources should be used in accordance with the regulations established for sealed sources, with the application of a graded approach to safety for calibration sources of low activity.

CESSATION OF USE AND REMOVAL OF RADIOACTIVE SOURCES

10.23. As stated in para. 3.60 of GSR Part 3 [9], the operating organization:

> ”shall ensure that arrangements are made promptly for the safe management of and control over radiation generators and radioactive sources, including appropriate financial provision, once it has been decided to take them out of use.”

10.24. When a well logging facility or radiation sources are no longer used, and there are no plans to use them again in the foreseeable future, the facility should be formally decommissioned and the sources disposed of. All disused radiation sources should be managed in a manner that is consistent with the national regulatory framework and, if necessary, is subject to approval by the regulatory body. This should include the following:

(a) Gamma and neutron radioactive sources (including calibration sources, as applicable) and neutron generators should, subject to approval by the regulatory body, be transferred to

another authorized organization. If possible, the operating organization should return the source or generator to the original supplier; alternatively, the operating organization may take another action as authorized by the regulatory body. Comprehensive records should be kept by the operating organization of all authorizations for the receipt, storage, transfer or disposal of radioactive sources (including any certificates provided by recipients or by disposal facilities for radioactive waste). The relevant records should be maintained as specified by the regulatory body.

(b) The operating organization should return disused neutron generators to the original supplier. Otherwise, the generator should be made inoperable and, subject to approval by the regulatory body, be transferred to an authorized organization for safe disposal (i.e. of the tritium source).

(c) In cases where all radiation sources are to be removed from the facility, all radiation symbols (trefoils) and other relevant notices should be removed from the facility and a workplace monitoring survey (see Section 7) should be conducted by the radiation protection officer or a qualified expert to provide additional confirmation that the sources have been removed from the site. A final decommissioning plan should be prepared in advance, which includes the final radiation survey and details of the storage, transfer or disposal of sources of radiation. The final decommissioning plan is required to be submitted to the regulatory body for review and approval: see Requirement 11 of IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [35]. Further recommendations are provided in IAEA Safety Standards Series No. SSG-49, Decommissioning of Medical, Industrial and Research Facilities [36]. Decommissioning and disposal of old well logging sources in cases where the manufacturer or original supplier is no longer in business, should be arranged according to the requirements specified by the regulatory body. Further recommendations for managing orphan sources are provided in IAEA Safety Standards Series No. SSG-19, National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources [14].

(d) The operating organization should inform the relevant authorities when all sources of radiation have been removed from the site.

(e) Radioactive waste should be managed in accordance with recommendations provided in IAEA Safety Standards Series No. SSG-45, Predisposal Management of Waste from the

Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education [37], or corresponding national standard, and in accordance with regulatory requirements.

(f) An option for disposal of sealed sources used in well logging devices is borehole disposal. Recommendations on borehole disposal facilities are provided in IAEA Safety Standards Series No. SSG-1, Borehole Disposal Facilities for Radioactive Waste [38]: a technical manual on borehole disposal of disused sealed sources is provided in Ref. [39].

11. SITE OPERATION

GENERAL

11.1. The operating organization carrying out site well logging work should ensure that one or more suitably trained workers are present when operations involving well logging sources are being carried out. If neither of these workers is a radiation protection officer (see paras 2.40–2.43), they should be able to obtain the support at any time from a radiation protection officer who is able to travel to the site of operation at short notice, for example to supervise the recovery of a source.

PREPARATION FOR OPERATION

11.2. As well logging work is generally carried out on the premises of a client rather than on the premises of the operating organization, the client should be consulted on the preparation and planning. This should include agreeing the location and time for the well logging work to be carried out. The classification of areas and the use of notices, warning signals and alarms during the well logging work should be discussed between the parties, to avoid possible confusion on the site, while remaining consistent with regulatory requirements. It is often useful to prepare a written agreement between the operating organization and the client clearly specifying the outcomes of the planning and preparation, and the associated roles and responsibilities of each party.

11.3. The well logging personnel should be made aware of any hazards on the site in the locations where the work is planned. Any permit to work systems or other site safety procedures of the client should be followed. The client should be provided with a copy of the operating organization’s local rules and emergency plans and procedures.

11.4. The operating organization and the client should agree on the planned timescale of the work and the duration of the period over which well logging work will be performed. The client should allow the well logging personnel sufficient time for the well logging work to be performed safely.

11.5. The operating organization should inform the client about the radiation source(s) that it is planning to use on the site and the associated hazard. It should ensure that proper storage facilities are available for any radioactive sources that are intended to be stored on the site overnight (this might require separate authorization by the regulatory body).

11.6. Site well logging work should be carried out in an area designated as a controlled area. No other work should be permitted in this area until the well logging work has been completed and the controlled area has been de-designated.

11.7. The boundary of the controlled area should be set to ensure that the radiation exposures received by persons outside the controlled area are below any relevant dose constraints. The regulatory body may specify the maximum permitted dose rate at the boundary of a controlled area during site well logging work. Typical values for this maximum dose rate are in the range 2.5–20 μSv/h. It is often practicable to achieve a dose rate of less than 1 μSv/h at the boundary.

11.8. To limit the extent of the controlled area, additional shielding should be used, where practicable.

11.9. Transient dose rates outside the controlled area boundary during source loading and unloading will be much higher than the dose rates during the actual well logging operation when the source is in the borehole. Additional care should be taken during these operations, to ensure that loading and unloading is carried out efficiently, and that there is no significant risk to persons standing at the boundary of the controlled area.

11.10. The boundary of the controlled area should be demarcated. When reasonably practicable, this should be done by physical means. This should include using existing structures such as walls, using temporary barriers or cordoning off the area with tape. Care should be taken to ensure that unauthorized access to the controlled area is prevented.

Warning notices

11.11. Notices should be displayed at suitable positions on the boundary of the controlled area. The notices should bear the radiation symbol [20], warnings and appropriate instructions in a language understood by persons working on the site. In some cases, it may be appropriate to post additional notices at the entrance to the site, to inform persons entering the site that well logging work is due to take place.

Supervising and monitoring the boundary of the controlled area

11.12. Before the start of well logging work, the controlled area should be cleared of all persons except for the well logging personnel who will be performing the work. Prior to conducting the

well logging work, the well logging personnel should confirm that there are no unauthorized persons within the controlled area and that access to the area is prevented.

11.13. The boundary of the controlled area should be clearly visible, well lit and constantly supervised during well logging work to ensure that no unauthorized persons enter the area. More than one person should supervise the boundary if the area is large or if it cannot be effectively supervised by a single person.

11.14. The dose rates should be measured around the boundary of the controlled area during a test of the source (or during first use of the source, depending on the circumstances) to confirm that the barriers are correctly positioned. The boundary and the demarcation of the controlled area should be adjusted, if necessary.

USE OF NEUTRON RADIATION GENERATORS ON A SITE

11.15. Precautions for the use of neutron generators on a site include the following:

(a) Off-shore well logging may involve two or more neutron generators. Additional precautions (including double authentication to control access) should be implemented in such cases;

(b) Neutron generators containing tritium should be transported in accordance with SSR-6 (Rev. 1) [31];

(c) Safe operating procedures should be observed for handling the well logging tool: see para. 11.17.

11.16. The neutron generator should be kept switched off until the well logging tool is underground: in typical industry practice, the generator remains switched off until the well logging tool is at a depth of 20–50 metres. Safety systems and operating procedures should be implemented to prevent battery-powered neutron generators turning on prematurely. When raising a generator from a well, the generator should be switched off and left downhole, at a depth of 20–50 metres, for an amount of time as specified by the manufacturer to allow for the decay of short-lived activation products.

DOSE RATE MONITORING

11.17. For well logging operations, there should be at least one suitable workplace monitoring instrument available on the site for each type of well logging source. Prior to the

commencement of well logging work, each instrument should be subject to the operational checks described in para. 7.8.

11.18. The dose rate around any packages used to transport radioactive material should be measured to confirm the presence of the source(s) and to check compliance with SSR-6 (Rev. 1) [31].

11.19. During well logging work, one of the main objectives of monitoring is to determine that a well logging source is properly shielded, or that radiation emission from a radiation generator has ceased, after each operation. Well logging tools should always be approached with the workplace monitoring instrument switched on to check the presence of the source in the tool string and/or to confirm safe radiation levels.

INDIVIDUAL MONITORING OF WORKERS

11.20. Passive personal dosimeters and active personal dosimeters (see Section 6) should be worn by well logging personnel at all times when they are performing site work with radiation sources. Active personal dosimeters should be periodically checked by the workers to review the doses received during the work.

WELL LOGGING EQUIPMENT

11.21. Only equipment that is specifically manufactured for well logging should be used for well logging operations. Workers should be familiar with the equipment and trained to understand its mode(s) of operation, correct use and potential problems. Workers should also have an understanding of the source assembly, its appearance and the manner in which it is operated, and the risks associated with inappropriate handling.

11.22. Whenever practicable, radioactive sources with lower activity should be used, provided the activity is sufficient to achieve acceptable well logging results. Using lower activity sources can have several benefits, such as:

(a) Smaller controlled areas that are easier to manage;

(b) Lower dose rates at the barriers and at the operator’s position;

(c) A lower radiation hazard in the event of an incident, for example, if the logging tool becomes stuck.

11.23. Well logging work should be performed only when the tool and all the necessary items of equipment are available and in good working order. These items should include:

(a) Workplace monitoring instrument(s) (including spare batteries) and personal dosimeters;

(b) Source handling tools and local shielding, if required;

(c) Temporary barriers, tapes, warning notices and warning signals, as appropriate, for demarcating the controlled area;

(d) Emergency equipment, including remote source handling tools and a spare shielded container for emergency use.

11.24. The properties of containers for radioactive sources (i.e. physical properties, labelling, shielding and features for the manipulation of the container and the source and for the safe loading and unloading of the logging tool) should be in accordance with regulatory requirements.

SAFETY CHECKS

11.25. The following checks should be made before using well logging equipment, and should be described in the operating procedures:

(a) Measuring the dose rate to confirm that the radioactive source is shielded.

(b) Checking warning labels and plaques or tags containing source details for legibility.

(c) Checking the source handling tools for functionality. To avoid exposure to personnel during these checks, a dummy source can be used (the diameter of dummy source should fit the tool).

(d) Checking that all the securing and retaining features of the well logging tool are functional.

(e) Checking that the source transport container is in good condition and good working order and securing any shielding plugs to reduce the likelihood of loss.

11.26. If any faults are found, the equipment should not be used until a replacement is provided or a repair is made.

TEMPORARY STORAGE OF RADIOACTIVE SOURCES ON A SITE

11.27. If there is a need to store radioactive sources on a site overnight or between operations, they should be kept in tamper-proof sealed containers in an appropriate storage facility. The need for such storage should be identified in the planning phase, and arrangements should be made with the client for the provision of suitable storage facilities that comply with regulatory requirements.

11.28. On-site storage facilities should consist of a lockable room, or a purpose-built store or storage pit to which access is controlled. On-site storage facilities should provide the same level of protection and safety, and security as storage facilities at the operating organization's main base. A suitable storage facility should protect well logging equipment from the prevailing environmental conditions and should also provide an adequate level of safety. The store should be weatherproof and resistant to fire. The store should be located at a remote distance from any corrosive and explosive materials.

11.29. The store should be built of materials that provide sufficient shielding to reduce dose rates outside the store to levels specified by the regulatory body. The inside of the store should be designated as a controlled area or supervised area, as appropriate.

11.30. The door to the storage facility should be kept locked and the keys should be held only by authorized personnel. Keys should be of specific design that cannot be easily reproduced. A warning notice incorporating the radiation symbol [20] and emergency contact number should be displayed on the door. It is good practice to have two separate locks with different keys on the door to the storage facility, with the two keys being kept by different persons.

COMPLETION OF WORK AND REMOVAL OF SOURCES FROM SITE

11.31. On completion of the well logging work, workers should use a workplace monitoring instrument to confirm that each source has been placed into a shielded container and that no source has become detached. The results of this check should be recorded.

11.32. Before leaving the site, the workers should carry out a visual examination to ensure that equipment has not been damaged. Well logging tools housing radioactive sources should be made ready for transport by locking and securing the appropriate containers and transport packages. The transport package should be securely stowed in the vehicle to avoid damage during transport.

12. TRANSPORT OF RADIOACTIVE SOURCES

12.1. Radioactive sources used in well logging will need to be transported:

(a) From the supplier of the source to the operating organization's facility;

(b) From the operating organization's facility to the site of operation;

(c) From the operating organization's facility to the supplier or other suitably authorized facility at the end of the useful life of the source, if it has become disused for some other reason, or following an accident involving the source.

Radioactive sources used in well logging will also need to be moved within the operating organization's facility, for example from the storage room to the calibration room.

12.2. The transport of radioactive sources (including neutron radiation generators containing tritium) used in well logging should conform to national regulations and the requirements of SSR-6 (Rev. 1) [31]. 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 [40] of the International Civil Aviation Organization (ICAO), and the International Maritime Dangerous Goods (IMDG) Code [41] of the International Maritime Organization (IMO). Regional agreements such as the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [42] the Agreement of Partial Reach to Facilitate the Transport of Dangerous Goods, signed by the Governments of Argentina, Brazil, Paraguay and Uruguay (MERCOSUR/MERCOSUL) [43] and the European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) [44] may also apply.

MOVEMENT WITHIN THE WORKSITE

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

12.4. Radioactive sources should be moved only in suitably shielded containers, and these should be locked and the keys should be removed and held only by authorized personnel. Such containers should be kept under surveillance for the duration of the movement on the worksite.

TRANSPORT TO ANOTHER SITE

12.5. When well logging sources are to be transported to another site, they should be kept in the storage facility until they are ready to be moved to the new site. The sources should be transported only in shielded containers, and these should be locked and the keys should be removed.

12.6. SSR-6 (Rev. 1) [31] assigns responsibilities for the transport of radioactive material to the following:

(a) The consignor (the person or organization that prepares a consignment for transport);

(b) The carrier (the person or organization that undertakes transport of radioactive material);

(c) The consignee (the person or organization that receives a consignment).

In many cases, for site well logging work, the operating organization performs all three functions. As such, the operating organization is required to ensure that the transport of radioactive sources used in well logging complies with the requirements of SSR-6 [31] or equivalent national regulations, including the requirements for the design and labelling of transport packages, requirements for vehicles and for controls during transport.

12.7. The transport of radioactive material is a complex activity, and a comprehensive overview of the requirements of SSR-6 [31] is outside the scope of this Safety Guide. Guidance on how to meet these requirements is provided in IAEA Safety Standards Series No. SSG-26, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) [45].

12.8. Comprehensive guidance on nuclear security in the transport of radioactive material is provided in IAEA Nuclear Security Series No. 9 [26].

13. EMERGENCY PREPAREDNESS AND RESPONSE

GENERAL

13.1. The requirements for an adequate level of preparedness and response for a nuclear or radiological emergency are established in IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [46]. An emergency is:

> "A non-routine situation that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human life, health, property or the environment.
>
> This includes nuclear and radiation emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes.
>
> This includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard." [8]

13.2. A nuclear or radiological emergency is:

> "An emergency in which there is, or is perceived to be, a hazard due to:
>
> (a) The energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction;
>
> (b) Radiation exposure." [8]

13.3. Incidents involving radiation sources in well logging have occurred mainly as a result of operator error or equipment failure; some examples are provided in Annex VI. Incidents involving well logging sources have included the following:

- Mechanical damage to well logging equipment;
- Loss of shielding resulting in higher dose rates than expected;
- Missing (or lost) radioactive sources;
- Dropped or detached sources;
- Sources stuck in a well or borehole;
- Leaking sources due to mechanical impact, corrosion or fire;

– Natural disasters (e.g. a hurricane);

– Malevolent actions such as theft of sources.

13.4. In many cases, incidents involving well logging sources can be prevented or their consequences can be mitigated if the following precautions are taken:

(a) Well logging equipment should meet current regulatory standards;

(b) Workers:

  – Should be properly trained and qualified, and they should be competent;

  – Should follow the local rules and other relevant procedures;

  – Should use calibrated workplace monitoring instruments and wear suitable personal dosimeters before, during and after every source use;

  – Should make regular and appropriate inspections of well logging equipment prior to use;

  – Should make proper use of emergency equipment;

  – Should conduct a final survey of the work area before leaving the site.

DEVELOPMENT OF EMERGENCY PLANS AND PROCEDURES

13.5. Although the prevention of incidents and accidents is the first priority, events could still occur that would necessitate protective actions or other response actions. The operating organizations is required to have an emergency plan and procedures prepared in advance, for the goals of emergency response to be achieved and for the emergency response to be effective: see Requirement 23 of GSR Part 7 [46]. When well logging work is to be carried out on a client’s premises, the emergency plans and procedures should be discussed with the client.

13.6. The hazards associated with radiation sources used in well logging and the potential consequences of an emergency need to be assessed to provide a basis for establishing arrangements for emergency preparedness and response, in accordance with Requirement 4 of

GSR Part 7 [46]. Potential emergencies that could affect workers, members of the public or the environment should be identified in the operating organization's hazard assessment.

13.7. Emergency preparedness category IV — as described in Table 1 of GSR Part 7 [46] — generally applies to well logging involving radioactive sources. Appropriate, emergency arrangements (including plans, procedures, equipment, training, drills, exercises and a quality management programme) that correspond to this category are required to be established. Further recommendations are provided in IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [47] and IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [48].

13.8. The emergency plan for a well logging facility should address scenarios such as a missing or lost source, the theft of a source, and damage to well logging equipment leading to contamination and/or increased dose rates. Emergency procedures should include:

- A clear statement of roles and responsibilities;
- A concept of operations;
- Communication and coordination arrangements;
- Protocols for notification of an emergency;
- Instructions to site personnel;
- Delineation of the affected area and access control;
- Measures to protect emergency workers, as appropriate.

A qualified expert should be consulted, where possible, when drawing up emergency plans and procedures.

13.9. Recommendations on developing adequate emergency arrangements at the organizational, local and national levels on a step by step basis, including templates for emergency plans, are provided in GS-G-2.1 [47]. Further practical guidance regarding generic procedures for assessment and response during a radiological emergency is provided in Ref. [49]. Action guides for dealing with radiological emergencies are provided in Ref. [50].

13.10. Emergency arrangements can be regarded as comprising several tasks, each of which should be addressed by the operating organization and relevant response organizations, in accordance with the recommendations provided in GS-G-2.1 [47] for facilities and activities in emergency preparedness category IV.

13.11. Implementation of the on-site emergency plan and procedures may require off-site support (e.g. off-site response organization, emergency services, radiation protection specialists), as addressed in GSR Part 7 [46] and GS-G-2.1 [47]. The on-site emergency plan should provide details of any off-site support, and it should be ensured that responders are fully aware of and accept their responsibilities. In particular, the on-site emergency plan should specify the arrangements for immediate and efficient communication between all the parties involved.

13.12. The operating organization is required to submit its on-site emergency plan to the regulatory body for approval, when applying for an authorization (para. 6.19 of GSR Part 7 [46]. The operating organization should also make the emergency plan and associated procedures available to the appropriate off-site authorities.

EMERGENCY EQUIPMENT

13.13. The operating organization is required to ensure that all necessary tools, instruments, supplies, equipment, communication systems, facilities and documentation for responding to emergencies are made available and are under the control of a quality management programme that includes inventory control, testing and calibration: see para. 6.34 of GSR Part 7 [46].

13.14. If it is suspected that a sealed source capsule might have been damaged, extra care should be taken, as radioactive material could leak out of the source and there could be a risk of contaminating people and objects in the vicinity. The detection and measurement of radioactive contamination from the leaking source needs specialized monitoring equipment and expertise. If it is known or suspected that a source capsule has ruptured, the operating organization should promptly seek advice from a qualified expert if it lacks the necessary capabilities to respond to such an event. Adequate consideration should be given to the decontamination of persons and equipment, as appropriate, in such instances.

13.15. For emergencies involving well logging sources, consideration should be given to the need for the following equipment, as appropriate:

(a) Appropriate workplace monitoring instruments to measure both high and low dose rates;

(b) Active personal alarm dosimeters;

(c) Additional personal dosimeters;

(d) Barrier materials and warning notices for the temporary designation of a controlled area;

(e) Local shielding, such as bags of lead shot or lead sheets;

(f) Suitable tool kits and source recovery equipment (long handled tongs, pliers, screwdrivers, bolt cutters, adjustable spanner);

(g) A spare shielded container;

(h) Wipe test kit for leak testing sources and for other surface contamination checks;

(i) Communication equipment (e.g. mobile phones, radio transmitters and receivers);

(j) Spare batteries and torches.

EXAMPLE RESPONSE PROCEDURES FOR INCIDENTS INVOLVING RADIATION SOURCES IN WELL LOGGING

13.16. Paragraphs 13.17–13.20 provide practical guidance on the immediate actions to be taken by workers and by the radiation protection officer in an emergency. Although the actions are listed in the sequence in which they can be expected to be performed, it might be necessary to implement the actions in another sequence depending on the actual circumstances. The operating organization should develop its emergency procedures and instructions taking account of the recommendations provided in this section and the postulated accident scenarios based on the hazard assessment. As with any radiological emergency, the first priority of the emergency response should be the protection of persons.

Actions to be taken for events involving gamma and neutron radioactive sources

13.17. Workers should undertake the following actions:

(a) Quickly recognize an abnormal situation that might constitute an emergency and implement the appropriate emergency procedures;

(b) Remain calm and move away from the radioactive source, and ensure that any other workers in the vicinity are evacuated and informed that there might be an emergency;

(c) Inform the radiation protection officer of the operating organization;

(d) Measure the neutron and/or gamma radiation dose rates and record any doses measured by active personal dosimeters;

(e) Confirm, establish or re-establish controlled area barriers on the basis of dose rate reference levels, consistent with regulatory requirements and the emergency plan and procedures;

(f) Prevent access to the controlled area;

(g) Use necessary personnel protective equipment;

(h) Maintain surveillance of the controlled area;

(i) Inform the relevant authorities (and the client, if the emergency occurs at the client's site) and seek assistance as prescribed in the emergency plan and procedures.

13.18. The radiation protection officer should undertake the following actions:

(a) Plan and implement a specific course of action on the basis of previously established emergency plans and procedures, taking care to minimize doses that might be received as a result of this course of action.

(b) Move to a location away from the controlled area and rehearse the planned course of action before entering the controlled area to implement the emergency plan.

(c) Implement the planned course of action to the extent that training, equipment, the actual situation and authorizations allow; under no circumstances should the source come into contact with the hands or other parts of the body.

(d) If the course of action taken is unsuccessful, leave the controlled area and consider the next course of action while maintaining surveillance of the controlled area.

(e) Call for technical assistance, if necessary, from a qualified expert or from the manufacturer of the source and/or well logging equipment, as appropriate. Such assistance may form part

of the emergency plan and procedures, in which case it should be planned and agreed upon between the various parties in advance.

(f) When the situation has been brought under control and the source is safe, investigate the emergency, and estimate the doses received.

(g) Return personal dosimeters to the dosimetry service for rapid assessment.

(h) Arrange for any damaged or malfunctioning equipment to be repaired by the manufacturer or arrange for a qualified expert to undertake a detailed examination and repair prior to any reuse.

(i) Prepare an accident report and notify the regulatory body, in accordance with regulatory requirements.

Actions to be taken for events involving neutron generators

13.19. Workers should undertake the following actions:

(a) Quickly recognize an abnormal situation that might constitute an emergency and implement the appropriate emergency procedures;

(b) Turn off the electrical power to the neutron generator;

(c) Inform the radiation protection officer of what has happened;

(d) Perform a radiation survey to confirm whether there is any residual radiation hazard;

(e) Not move the well logging equipment until details such as its position, beam direction and exposure settings (tube voltage, current and time) have been recorded;

(f) Not use the neutron generator until it has been examined and repaired by the manufacturer or by a qualified expert;

(g) Use necessary personnel protective equipment.

13.20. The radiation protection officer should undertake the following actions:

(a) Estimate the doses that could have been received;

(b) Return personal dosimeters to the dosimetry service for rapid assessment;

(c) Prepare an accident report and notify the regulatory body, in accordance with regulatory requirements.

TRAINING AND EXERCISES

13.21. In accordance with para. 5.44 of GSR Part 7 [46], all personnel who will participate in implementing the emergency plans are required to be adequately qualified and trained for the effective fulfilment of their roles. This should include familiarization with and understanding of the emergency plan, together with specific training on the application of emergency procedures and on the use of emergency equipment. This is also required to include guidance and training on the approximate radius of any inner cordoned off area in which urgent protective actions would initially be taken and on the adjustment of this area on the basis of observed or assessed conditions on the site.

13.22. Individual workers should implement only those parts of the emergency plan for which they have been authorized and trained and for which they have the appropriate equipment. Provisions for training should be reviewed periodically to ensure the continued proficiency of workers.

13.23. Emergency exercises should be held to test critical components of the emergency plan, at intervals that are commensurate with the potential hazard. Frequent small scale exercises should be organized to ensure that the contact details of all persons and organizations with responsibilities in the emergency response are up to date.

13.24. Any lessons identified from exercises are required to be fed back into reviews and, as necessary, revisions of the emergency plan and procedures: see para. 6.36 of GSR Part 7 [46].

PERIODIC REVIEWS OF THE EMERGENCY PLAN

13.25. Formal reviews of the emergency plan should be undertaken periodically. Such periodic reviews should include provisions to update the emergency plan in response to lessons from exercises or from emergencies.

REPORTING

13.26. The primary objective of emergency preparedness and response is to mitigate the consequences of an emergency. To achieve this, incidents that have occurred should be critically reviewed, so that the lessons identified can be used to provide feedback for improving equipment, maintenance procedures, operating procedures and emergency response arrangements. A comprehensive report that includes an analysis of the emergency and the emergency response should be prepared.

13.27. The report of an incident involving radiation sources used in well logging should be prepared by the radiation protection officer with the assistance of qualified experts, if necessary. Such reports should be submitted to senior management, the regulatory body and other relevant authorities at local, regional or national level. If the incident could have been caused by an equipment malfunction, the supplier and the regulatory body should be notified so that the equipment can be evaluated and appropriate action taken.

13.28. The report of an emergency should include the following:

(a) A description of the emergency, with as much detail as possible of the equipment involved. The details should include model numbers and serial numbers, wherever possible.

(b) Environmental conditions at the time of the emergency, with particular reference to whether or not these conditions played any significant part in causing the emergency or affecting the outcome.

(c) The specific cause(s) of the emergency.

(d) Details of actions taken to regain control of the situation and to restore conditions to normal, with special reference to any actions that were notably beneficial or detrimental.

(e) The personnel involved and their duties, tasks and qualifications.

(f) An assessment and summary of the doses received by all affected individuals.

(g) Corrective actions recommended with the aim of preventing similar emergencies in the future.

(h) Lessons learned from managing the emergency.

COMMUNICATION WITH THE PUBLIC

13.29. Communication with the public on emergencies involving well logging sources (for example, in the event of a source being stolen) should be carried out by the operating organization in discussion with the regulatory body and other relevant authorities, as specified in the emergency plan and procedures. Requirements 10 and 13 of GSR Part 7 [46] address arrangements for communication with the public, and further recommendations on keeping the public informed are provided in GS-G-2.1 [47]

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ANNEX I: OVERVIEW OF RADIOACTIVE SOURCES USED IN WELL LOGGING

I-1. Radioactive sources are widely used in various well logging techniques. Table I-1 provides examples of radioactive sources typically used in well logging applications in the petroleum industry [I-1], including the categorization of these sources in accordance with IAEA Safety Standards Series No. RS-G-1.9, Categorization of Radioactive Sources [I-2].

TABLE I-1. SELECTED SOURCES USED IN APPLICATIONS IN THE PETROLEUM INDUSTRY[II-1]

Application	Radioisotope	Half-life, years	Typical activity (TBq)	D Value (TBq)	A/D Ratio	Category (A/D-based)	Recommended Category
Well logging: neutron porosity or capture lithography	^{241}Am-Be	433	0.02–0.8	0.06	0.33–13	2, 3 or 4	3
Well logging: density	^{137}Cs	30.2	0.037–0.074	0.1	0.37 – 0.74	4	3
Well logging: neutron porosity	^{252}Cf	2.65	0.001 – 0.004	0.02	0.05–0.02	4	3
Well logging with deuterium-tritium (DT) neutron generator	^{3}H	12.33	0.11–1.1	2000	05–5x10^{-4}	5	5

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ANNEX II: CONSIDERATIONS FOR A SAFETY ASSESSMENT FOR WELL LOGGING

II-1. To prepare a safety assessment for normal operating conditions and foreseeable incident scenarios the associated hazards and control measures need to be considered and documented. Some of the important elements of a safety assessment for well logging are described below.

NORMAL OPERATING CONDITIONS

II-2. Normal operating conditions include:

- Storage of the well logging sources;
- Calibration and operation of the well logging tools;
- Transport of the sources;
- Work at the site with the well logging tools;
- Maintenance of the tools;
- Disposal of disused sources.

II-3. For each of the above conditions, the hazards involved and the necessary control measures should be identified.

REASONABLY FORESEEABLE INCIDENTS

II-4. A list of reasonably foreseeable incidents involving radiation sources used in well logging is given below. This list is by no means exhaustive.

(a) A source becoming detached from the logging tool (down the well or otherwise);

(b) A source stuck in the tool or container;

(c) A tool stuck down the well or borehole;

(d) A neutron generator failing to de-energize;

(e) High dose rates present in an area that is not designated as a controlled area;

(f) Suspected or actual overexposure of individuals to gamma and/or neutron radiation;

(g) A missing, lost or stolen source;

(h) A damaged or leaking source, for example due to mechanical damage, fire or explosion in a work area or storage area;

(i) Events involving rupture of well logging source including rupture during recovery attempts of a well logging source that has logged down hole;

(j) An accident during the transport of radioactive sources.

II-5. The elements to be considered in the safety assessment for each of these scenarios are discussed below.

HAZARDS

External radiation hazards

II-6. The following external radiation hazards are to be taken into account in the safety assessment:

(a) Radioactive sources: gamma and, as appropriate, neutron dose rates from well logging sources during storage, use (shielded and unshielded), transport and in accident scenarios.

(b) Neutron generators: neutron and gamma dose rates from neutron generators in normal use and during accident scenarios.

(c) Gamma radiation emitted by any neutron activation products.

Internal radiation hazards

II-7. The following aspects are to be taken into account in the safety assessment:

(a) Potential for contamination of the logging tool with naturally occurring radioactive material (this is out of scope of this document).

(b) Potential for internal exposure if a sealed radioactive source were damaged.

Who would be exposed to the hazards?

II-8. Consideration is to be given to the following persons, as appropriate:

(a) Workers: well logging personnel and other workers present on the site (e.g. crane operators);

(b) Members of the public, including visitors to the site.

CONTROL MEASURES

Engineering controls

II-9. Considerations are to be given to the following engineered controls:

(a) Shielding of storage facilities, logging tool containers, transport packages and overpacks (for gamma emitting and neutron emitting radionuclides, as appropriate);

(b) Design of transport packages;

(c) The use of appropriate handling tools (i.e. to maintain distance from the source);

(d) The design of logging tools, for example to minimize the likelihood of a detached source;

(e) Temporary source containers to be used following an accident.

Administrative controls

II-10. Considerations are to be given to the following administrative controls:

(a) Safe working procedures, including local rules;

(b) Transport package labelling and documentation;

(c) Designation of controlled areas and delineation with barriers and warning signs;

(d) Staff training and appointment of a radiation protection officer;

(e) Advice from a qualified expert;

(f) Workplace monitoring and individual monitoring (gamma and neutron radiation), and health surveillance;

(g) A preventative maintenance programme and periodic checks on the condition of well logging equipment;

(h) Periodic safety audits of operations;

(i) Leak testing of sealed radioactive sources;

(j) Records of source accountancy and source movements.

ANNEX III: INFORMATION ON RADIATION SAFETY OF NEUTRON GENERATORS USED IN WELL LOGGING

III-1. The type of neutron generator used in well logging is a compact accelerator of deuterium nuclei. Its components include an accelerator tube (neutron tube), a target containing deuterium or tritium, a high voltage power supply and a measurement module.

III-2. The following characteristics are important for radiation safety in the use of neutron generators:

— The ambient dose rate equivalent (neutron and gamma radiation) at 1.0 m from the neutron generator while being operated at nominal power;
— The ambient dose rate equivalent (gamma radiation) at 0.1 m from the target of neutron tube of a neutron generator for up to 1 hour after operation at nominal power;
— The tritium activity in the target.

III-3. The dose rate at 0.1 m from the tube target should normally be below 1 μSv/h, or else below a value established by the regulatory body, before personnel can be permitted to directly handle the generator. Otherwise, a holding time to allow the decay of activation products in the tube is necessary. The major issue from neutron activation is gamma radiation emitted by ^{56}Mn (half-life 2.6 hours) created from ^{57}Fe and ^{55}Mn present in the cover of the neutron generator: the relevant reactions are ^{56}Fe(n,p)^{56}Mn (for 14 MeV fast neutrons) and ^{55}Mn(n,γ)^{56}Mn (for thermal neutrons). As described in para. 11.17, when raising a generator from a well, the generator is switched off and left downhole, at a depth of 20–50 metres, to allow the decay of short-lived activation products.

ANNEX IV: CALCULATION OF RADIATION SHIELDING

IV-1. In this annex some simple examples of shielding calculations for gamma sources and neutron sources used in well logging industry are provided.

SHIELDING FOR GAMMA RADIATION SOURCES

IV-2. As gamma rays pass through a medium they are absorbed. This absorption is characterized by the linear attenuation coefficient of the medium for the gamma ray of the specified energy. Linear attenuation coefficients vary with the density of the absorber, even for the same absorber material. The attenuation law is written as:

$$I = I_0 \cdot e^{-\mu t}$$

where:

I = Intensity of photons transmitted across an absorber

I_o= Initial intensity of photons

μ = Linear attenuation coefficient, cm^{-1}

t = Thickness of the absorber material, cm.

IV-3. For gamma radiation it is useful to consider the half-value thickness (HVT) of a given absorbing material for the gamma ray energies of interest. The HVT is that thickness of the shielding material that will transmit half of the radiation incident on it. The half-value thickness is determined from the linear attenuation coefficient, as follows:

$$1 \text{ HVT} = 0.693/\mu$$

Similarly, the TVT is that thickness of the shielding material that will transmit one-tenth of the radiation incident on it. 1 TVT is approximately equal to 3.3 HVTs.

IV-4. Half values thicknesses for ^{137}Cs are:

- Steel: 1.6 cm
- Lead: 0.7 cm

IV-5. As an example, the dose rate at 50 cm from the centre of a lead container of thickness 3.2 cm housing 1 GBq of ^{137}Cs can be calculated as follows:

(1) The dose rate at 1 m from an unshielded ^{137}Cs source of activity 1 GBq is 80 µGy/h.

(2) The dose rate at 50 cm from the unshielded source = 320 µGy/h

(3) The thickness of shielding = 32 mm = 1 TVL + 2 HVT

(4) The dose rate at the place of interest = 8 µGy/h

SHIELDING FOR NEUTRON RADIATION SOURCES

^{241}Am-Be sources

IV-6. Neutron shielding calculations are best done by digital computation. However, approximate calculations can be done using the concept of removal cross section, using the following formula:

$$D(t) = D(0)\, e^{-\Sigma t}$$

where:

D(t) is the dose rate with shield;

D(0) is the dose rate without shield;

t is the shield thickness (in cm);

Σ is the neutron removal cross section (in cm^{-1}). For example, the removal cross section of water is 0.103 cm^{-1}.

Using the value of the removal cross section and the thickness of the shielding it is possible to calculate the dose rate outside a shielded container.

Neutron generators

IV-7. The necessary shielding thickness, *d*, for neutron radiation from an operating generator (for out-of-well operations) can be obtained as follows [IV-1]:

$$d = \lambda \cdot \ln\left(\frac{C \cdot Q \cdot h}{4 \cdot \pi \cdot R^2 \cdot \dot{H}_{np}}\right) \text{ cm}$$

where:

λ is the relaxation length of the neutron flux (in cm);

C is a dimensionless correction factor;

Q is the average flux of neutrons generated (in s^{-1});

h is the dose factor (in μSv cm^2);

R is the distance from the generator tube to the outer surface of the shielding or fence restricting access to a generator operated outside the well (in cm);

$\dot{H}_{np}$ is the target dose rate (in μSv/h).

IV-8. Values of λ, C and h are provided in Table IV-1 for 14 MeV neutrons and various shielding materials.

TABLE IV-1. VALUES OF λ, C AND h FOR 14 MeV NEUTRONS

Shielding material	λ, cm	C	h, μSv cm^2
Concrete	19.7	1.2	$4.96x10^{-4}$
Paraffin	17.5	1.3	$4.96x10^{-4}$
Water	16.9	1.3	$4.96x10^{-4}$

REFERENCES FOR ANNEX IV

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ANNEX V: SUGGESTED STRUCTURE OF WELL LOGGING LOCAL RULES

V-1. Local rules should be developed by the operating facility and should specifically describe the actions to be implemented to ensure protection and safety and the persons responsible for these actions. A suggested structure of the local rules for well logging is provided in Table V-1.

TABLE V-1. LOCAL RULES FOR WELL LOGGING OPERATIONS: SUGGESTED STRUCTURE

Section	Contents
Introduction	• Who do the local rules apply to? • Which well logging tools or sites do they cover? • Which regulations apply?
Procedures for transportation of well logging tools containing radioactive sources (if applicable)	• Preparation to consign a radioactive source • Transport package requirements • Marking, labelling and other operational control measures • Transport documentation requirements including emergency preparedness and response arrangements • Transport management system • Arrangements for receipt of a radioactive source
Procedures for storage and source accountancy	• Description of storage facilities for radioactive sources • Security aspects, e.g. key control • Designation of storage areas and warning signs • Periodic physical inventory checks of sources • Record keeping for source accountancy • Record keeping for source movements
Procedures for control of exposure	• Description of controlled areas and supervised areas • Workplace monitoring programme • Arrangements for individual dosimetry • Dose investigation level • Arrangements for health surveillance
Calibrations, testing and maintenance	• Annual testing of workplace monitoring instruments • Preventative maintenance programme on well logging tools • Leak testing of radioactive sources
Roles and responsibilities, and contact details	• Relevant managers • Workers operating the well logging tools • Radiation protection officer • Qualified expert • Regulatory body • Occupational physician • well logging tools supplier and maintenance organizations • Security officer
Emergency procedures	• Roles and responsibilities

- Immediate actions to be taken
- Emergency contact details

ANNEX VI: EXAMPLES OF INCIDENTS INVOLVING RADIATION SOURCES IN WELL LOGGING

EXAMPLE 1: WELL LOGGING SOURCE DAMAGED [VI-1]

VI-1. The US Nuclear Regulatory Commission received the following information from the State of California via e-mail:

> "At about 9:45 am October 6, 2006, [Deleted] from Schlumberger's Houston office contacted the RHB South ICE RM office to notify RHB that a well logging tool with two sources (63 GBq ^{137}Cs and 592 GBq ^{241}Am-Be) had become stuck the day before yesterday near the bottom of the hole. They worked over the last two days, 'fishing' for the sources, and recovered the ^{241}Am-Be source when the tool broke. Neither of the sources has been compromised. They have not yet determined that the remaining source must be abandoned, but expect to make that determination over the weekend, and requested approval to abandon it, if additional retrieval attempts fail. Approval was granted, and Schlumberger was provided an emergency contact number to provide information over the weekend, if any health and safety concerns arise (e.g., if the source is compromised).
>
> "At 9:30 am on October 7, 2006, [Deleted] called again to report that they had reason to believe the Cesium-137 source had ruptured down-hole. Chevron had commenced a cut and thread fishing operation for the stuck well logging tool late Wednesday evening, October 4th. On the first trip into the hole the well logging tool was engaged into the grapple, when the rig started to pull out of the hole the drill pipe was stuck, the drill pipe would not move up or down. The decision was made to gently reverse rotate the pipe in an attempt to free the well logging tool from the grapple. Once the tool was released from the grapple, the drill pipe was pulled out of the hole and the fishing assembly removed and replaced with wash over pipe. During the second trip in the hole with the wash over pipe the tool was engaged and part of the tool came out of the hole. This part of the tool contained the 592 GBq ^{241}Am-Be source. The 63 GBq ^{137}Cs source remained down hole in another tool. Several more trips were made with the wash over pipe in an attempt to recover the remaining tools. It was during an attempt with the wash-over pipe when Schlumberger personnel who were monitoring the mud returns noticed a

substantial increase on their survey meter from 4 µSv/h to 70 µSv/h. Since an increase such as this could indicate a potentially ruptured source all operations and circulation were immediately stopped with all personnel removed from the rig and the immediate area.

"At this time the area around the rig, mud pit and shale shaker were cordoned off. Schlumberger personnel are conducting further surveys of all personnel and the area at this time."

VI-2. The state of California also reported that Schlumberger was sending additional staff to the site to conduct further surveys and determine their future course of action. The state of California had been notified of the event on October 7 2006 at 21:30.

EXAMPLE 2: ABANDONMENT OF A WELL LOGGING SOURCE [VI-2]

VI-3. The US Nuclear Regulatory Commission received the following information relating to an event in Texas:

"Late Friday evening, November 28, 2003, a logging source string became stuck in the customer's well. After several fishing attempts without success, it was decided to abandon the sources downhole. The sources will be cemented in place with the topmost point covered by a minimum of 30 m of red dyed cement. A deflection device will be place above the source string. A plaque has been ordered for installation on the wellhead.

"The source string held three sources: one ^{241}Am-Be source manufactured by NSSI, Model DA-5 with an activity of 166.5 GBq; one ^{137}Cs source manufactured by AEA, Model CDC.CY4, with an activity of 74 GBq; and a second ^{137}Cs source, manufactured by Gammatron, Model GT-GHP, with an activity of 29.6 GBq."

EXAMPLE 3: TEMPORARY LOSS OF A BOREHOLE LOGGING SOURCE [VI-3]

VI-4. A 55 GBq source (Cs-137) fell from its container while being moved on an offshore installation. The source fell to a platform below the level on which it was being carried. An employee picked up the source and replaced it in the container, a process that took about 45 seconds.

VI-5. Dose calculations indicated that the effective dose received by the employee was approximately 0.8 mSv. The radiation advisory committee recommended that a blood

chromosome aberration test be carried on the individual who picked up the source. The results of blood tests for lymphocytes indicated normal levels.

VI-6. Several basic rules were broken during this incident, as follows:

(a) The incident was not reported when it occurred;

(b) No recovery tool was available (none was present on the installation at which the incident occurred);

(c) A retrieval protocol was not in place;

(d) One employee was wearing a personal monitoring device that had not been approved for use in the State.

EXAMPLE 4: LOSS OF CONTROL OF A CAESIUM-137 WELL LOGGING SOURCE RESULTING IN RADIATION EXPOSURE [VI-4]

VI-7. The incident occurred on a drill rig in the state of Montana on May 21st, 2002, and was reported to the United States Nuclear Regulatory Commission (NRC) on May 23rd, 2002. The NRC's initial response to the notification was to send a reactive inspection team to the site to determine the details of the incident. However, a blood test (cytogenetics) performed on one of the workers suggested that the worker had been exposed to a radiation dose of the order of 2 Gy, and consequently the inspection was upgraded to an 'augmented inspection'.

VI-8. The source assembly consisted of a sealed source capsule (Model AEA Technology X2170/2) inside a metal shield, which in turn was contained within a source housing (Model DH604538). The source capsule contained 48 GBq of ^{137}Cs. The shield that surrounded the source capsule provided substantial shielding in all directions except towards the front and to one side of the housing, where the shielding was lighter and from which the radiation was emitted for use in the logging operations. The source housing assembly was about 10 cm long and 3 cm in diameter. One end of the source assembly had a flared (dove-tail) shape, designed to fit within the logging tool, and was also used for picking up the source assembly with a special handling tool. When not in use, the source assembly fitted inside a shielded storage container that was used for safe storage of the source and also to transport the source to the well sites.

VI-9. On May 23rd, 2002, the operating organization's radiation protection officer was notified by the field office of an incident that occurred at a temporary job site, involving the loss of control of a well logging source containing 48 GBq of ^{137}Cs. The NRC's operations center received notification of this event from the radiation protection officer at 16:35 on May 23rd, 2002.

VI-10. The operating organization reported that, following the well logging operations that took place on May 21st, 2002, the logging engineers failed to properly transfer the sealed source from the well logging tool to its shielded transport container. As a result, the source was left unshielded, on the rig floor, until it was discovered missing, and subsequently recovered, two days later. A number of rig workers were believed to have been exposed to this unshielded source. Such rig workers are not exposed to radiation as a normal part of their work, and are expected to receive the same level of protection as for members of the public.

VI-11. The investigation identified that the direct cause of the event was the failure of a logging engineer to properly transfer the ^{137}Cs source to its storage container immediately following removal of the source from the logging tool. This led directly to the loss of control of the source. There were many contributing causes such as failure to perform a radiation survey, a false indication by the Plug Assembly and failure to provide the design specifications of the Plug Assembly. A possible root cause of the event was the failure of the operating organization to adequately investigate earlier events to determine their underlying causes.

EXAMPLE 5: RECOVERY OF A RADIOACTIVE SOURCE STUCK DOWN A WELL

VI-12. While conducting pressure tests in a well, differential sticking of the tool string containing radioactive sealed sources was encountered. The regulatory body was notified of a stuck radioactive source and a decision was made to commence a reverse cut and thread procedure in order to recover the stuck tool string.

VI-13. The operator proceeded to thread a drill pipe onto a cable with an overshot fishing assembly on the end of the string. As the drill pipe and overshot approached the tool string, high tension was seen on the well logging cable, indicating possible cable damage down the hole. A decision was then made to pull the weak point in the cable head and to recover the tool string with the pipe and overshot only. This was the only way forward to recover the sources and tool string. The operator pulled back two stands of drill pipe and prepared to pull the weak point using the rig elevators and a cable clamp; the weak point was successfully pulled. The

drill pipe was run to just above the fish and mud was circulated to ensure a clean connection could be made with the tool string. The drill pipe was successfully latched onto the tool. During the recovery operation an overpull of around 30klb (130 kPa) was seen.

VI-14. The tool string, including the radioactive sources, was recovered. On initial inspection there appeared to be no damage to the sources and minimal damage to the tool string. The sources were shipped back to base to be leak tested for integrity and were quarantined until the test results were returned. It was ultimately confirmed that there was no leakage of radioactive material from the sources.

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