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Response to nuclear and radiological emergencies - Brazil and the world

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Abstract: Some nuclear and radiological accidents happened on last decades, providing to specialized personnel a huge change in terms of protocols and safety measures. In Brazil, the experience during the response to the radiologic accident in Goiânia/GO in 1987 showed the need for a rapid and intense mobilization of human resources to act in several areas of knowledge (radiological monitoring of personnel and areas, dosimetry, waste management, logistical support, social communications, among others). At that time, most of the people involved did not have the opportunity to have previously received even necessary training to act in an event of that nature and magnitude. Taking into account the global scenario, the International Atomic Energy Agency (IAEA) has issued a series of documents that aim to guide its Member States, to achieve an adequate level of preparedness to respond to emergency situations of nuclear or radiological origin. The paper brings an introduction, the methodology applied, a contextualization about nuclear accidents; emphasis on ocurrences in Peru; the accident in Goiânia. Finally, the preparation and response to accidents; the Nuclear and Radiological Emergency Response System (SAER), and a conclusion.

Keywords: Emergency response, Nuclear accidents, SAER, Goiânia.

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Respuesta a emergencias nucleares y radiológicas - Brasil y el mundo

Resumen: En las últimas décadas ocurrieron algunos accidentes nucleares y radiológicos que supusieron para el personal especializado un gran cambio en cuanto a protocolos y medidas de seguridad. En Brasil, la experiencia durante la respuesta al accidente radiológico de Goiânia/GO en 1987 mostró la necesidad de una rápida e intensa movilización de recursos humanos para actuar en diversas áreas del conocimiento (monitoreo radiológico de personal y áreas, dosimetría, gestión de residuos, apoyo logístico, comunicaciones sociales, entre otros). En ese momento, la mayoría de las personas involucradas no tuvieron la oportunidad de haber recibido previamente ni siquiera la capacitación necesaria para actuar en un evento de esa naturaleza y magnitud. Teniendo en cuenta el escenario global, el Organismo Internacional de Energía Atómica (OIEA) ha emitido una serie de documentos que pretenden orientar a sus Estados miembros, para alcanzar un nivel adecuado de preparación para responder a situaciones de emergencia de origen nuclear o radiológico. El artículo trae una introducción, la metodología aplicada, una contextualización sobre los accidentes nucleares; énfasis en sucesos en Perú; el accidente en Goiânia. Finalmente, la preparación y respuesta ante accidentes; el Servicio Brasileño de Respuesta a Emergencias Radiológicas y Nucleares (SAER) y una conclusión.

Palabras clave: Respuesta a emergencia, Accidentes nucleares, SAER, Goiânia.

1. INTRODUCTION

Nuclear power reactors are mainly used to obtain electrical energy. There are several types of nuclear power reactors, which can be classified according to the fuel and other components. Brazil has a developing nuclear program, where mechanisms for licensing, operation and control are tasks performed by the regulatory body and operators, that bring consequences in their actions to several other organizations at the federal and regional levels. In this context, the response to nuclear or radiological emergencies and nuclear physical safety events require the joint participation of professionals from different areas of knowledge, belonging to public (municipal, state and federal) and private organizations. One of these documents, entitled Preparedness for and Response to a Nuclear Accident or Radiological Emergency, General Safety Requirements - GSR Part 7, published in 2015 [1], presents a detailed description of the requirements necessary for this purpose.

2. METHODOLOGY

A bibliographic research was conducted, focusing on specialized literature on emergency response, using existing material from the International Atomic Energy Agency (IAEA). In this repository, there are compendiums on the main nuclear and radiological occurrences around the world, which steer to clarification of various aspects regarding accidents and incidents, such as situational alert, mobilization, team support, deployment, medical needs, remediation, damage mitigation and lessons learned. About the lessons, safety standards were developed and improved, serving as a basis for Member States of the international organization [2].

Still in this exploratory research, Brazilian legislation and standards from National Nuclear Energy Commission (CNEN) were consulted, dealing with the topic "emergency response"; notably from the perspective of notification of occurrences [3] and assistance between States [4]. Thus, Internal Guidance ("Orientação Interna" - OI) on the subject [5], was essential, combined with an administrative process conducted at the institution [6], detailing the need for a training program for its professionals. Such actions were the methodological support for the research that aimed to map the preparation of teams for such essential services.

3. NUCLEAR ACCIDENTS

Despite the high degree of safety of nuclear technology, some radiological accidents and emergencies events that have occurred in the past have also brought links; and those ones have been used to increase the reliability of this technology. The accident in unit 2 of the Three Mile Island (TMI) nuclear plant, in Pennsylvania, USA, occurred due to the failure of the water pump supplying the steam generator, and an operational error. The accident began at 4:00 AM on March 28th, 1979, with failures in the secondary system, followed by failure in the primary system relief valve that had been left open, allowing large quantities of escaping coolant. Mechanical failures were created by the reactor operators' initial foul in recognizing the situation, such as a loss of coolant accident, due to inadequate training. Errors observed in drawings, as well, were detected, related to the presence of ambiguous indicators in the control room. Heating and partial melting of the reactor core caused leakings, specially I-131, to the external environment, which led to the evacuation of more than 140,000 residents within a radius of up to 16 km from the plant [7].

The Chernobyl nuclear accident (April 26th, 1986) was the worst ever to happen in history, reaching level 7 on the INIS scale, the largest on this scale [8]. It was the nuclear accident that caused the greatest number of casualties, huge environmental impact and large economic and financial losses. This accident caused great global rejection of the nuclear industry. The Chernobyl nuclear power plant was a complex for producing electricity, located in the region of Pripyat, in Ukraine, about 80 km from Kiev and consisted of four RBMK-1000 reactors, each capable of to produce 1,000 electrical megawatts (MW) (3,200 thermal MW). The four together produced around 10% of the electricity needed to supply Ukraine at that time [8]. The accident happened on the night of April 25th to 26th, 1986 due to a succession of errors. Before the accident, a rapid cooling test of the reactor was scheduled, precisely to prepare teams to act safely when necessary to shut down controlled reactor, in the event of an imminent accident. The RBMK-1000 reactors did not have a structure like the containment building, as is the case of PWR type reactors, such as those in Brazil. In this way, the explosions and the consequent fire caused a radioactive plume that spread across an extensive area in Ukraine, Belarus and Scandinavian countries, including regions in western Europe.

At Fukushima, Japan (March 11th, 2011), the accident began due to the effects of an 8.9 magnitude earthquake that occurred near the northwestern Japanese coast. Reactors 1, 2 and 3 were automatically shut down at the time of the earthquake, while the nuclear plant's three remaining reactors were already shut down for maintenance [9]. As a result of the earthquake, a 14 m high tsunami occurred in the Pacific Ocean, exceeding the existing containment for events of this nature and flooded the six units located on the seafront, damaging the electrical network and emergency generators, preventing the operation of emergency systems. After the earthquake, the reactors at the Fukushima-Daiichi plant that were still operating were turned off automatically. To cool the reactors, in this type of nuclear power plant, it is necessary to power the systems by electrical energy, generally from the external grid; due the earthquake the external power supply had been compromised. The accident aerial view is shown on figure 1 [10].

Figure 1: Fukushima nuclear power plant - aerial view of the site the day after the accident.

Source: LAVELLE (2011)

4. RADIOLOGICAL ACCIDENTS IN PERU - HISTORY REPEATS ITSELF

One of the most frequent radiologic accidents in the world involves the industrial gammagraphy area. In February 20, 1999, during an industrial radiography service at a hydroelectric powerplant in the city of Yanango, about 300 km from Lima, a radiologic accident occurred with a radioactive source of Ir-192. The operation involved the piping repair team performing industrial x-ray essays [11].

In Chilca, Peru, 2012, x-rays were being taken on pipe welding by one operator and two assistants. The work lasted around 2h30 and, at the end, the operators were unable to collect the source from its shielding [12]. Three workers were exposed to radiation emitted by the Ir-192 source with 3.65 TBq of activity. In Ventanilla, the radiologic accident occurred in the early hours of February 14, 2014 at a chemical plant. One company was performing radiography on pipe joints using radiography with a radioactive source of Ir-192. The radioactive source had an activity of about 1.2 TBq (33 Ci) on the day of the accident [13].

Describing the events occurred in Peru, their classifications and consequences, lessons can be identified: even in situations where protection devices are effective, licensing and control by national nuclear authorities should be constantly enhanced. Accidents are likely to occur with similar characteristics in relatively short periods, which imposes the need for constant performance in supervision, control tools and assessment.

5. GOIÂNIA ACCIDENT, 1987 - A NEW PARADIGM

In 1987, Three Mile Island and Chernobyl occurrences had already happened; both of them comprising different levels and circumstances of lessons learned. On September 13th, 1987, a source of cesium-137 was removed from its casing in a teletherapy device. The source, of North American origin, was left inside the equipment. The machine had been left, abandoned, in the old facilities of the Instituto Goiano de Radioterapia, in Goiânia. Five days later, the source was ripped from its protective shield and sold to a junkyard. Four days passed, and on September 21st, 1987, the capsule, previously damaged, was open. Fragments of the source were distributed to people in other areas of the city. Individuals were irradiated directly from the source and were externally and internally contaminated by cesium-137 [14]. Several people became ill and sought medical attention. Finally, on September 28th, 1987, the characteristic symptoms of overexposure to radiation were recognized. National Nuclear Energy Commission employees evacuated affected areas and began identifying people who had been exposed. CNEN immediately sent teams to Goiânia for the action plan.

5.1. Goiânia in numbers

The world's largest radiologic accident left four fatalities. Twenty-eight, severely contaminated. In total, 112,800 people were monitored, of which 249 were identified as contaminated internally or externally [14]. Some suffered very high internal and external contamination due to the way they handled cesium chloride powder, such as painting their skin and eating with hands. More than 110 blood samples from affected people by the accident were analyzed using cytogenetics methods. More than 67 square kilometers of urban areas in Goiânia were monitored. Seven known main foci were confirmed.

A complementary monitoring system covering large areas, although limited to roads, was put into practice. The system used detectors mounted on cars in 80% of the road network. Over 2.000 km were covered in this way. Contamination was removed from 45 different spots, including sidewalks, shops and snack bars. Contamination was also found in vehicles: around 50 in total. There were 3,500 cubic meters removed of material characterized as waste.

5.2. Mobilization

Until 1987, the IAEA registered 17 nuclear and radiologic accidents worldwide, with 59 fatalities. The Agency quotes Goiânia as the most significant radiological occurrence so far, surpassing those occurred in Mexico (1962 and 1983), Algeria (1978) and Morocco (1983). In order to face the emergency in Goiânia, the Brazilian state required a rapid and gigantic mobilization of personnel, especially from CNEN, with the participation of members from bodies of the State of Goiás, the Armed Forces, nuclear sector operators, universities and private organizations, which constituted the teams for operational, support, communication and logistics issues [14], totaling 723 people working only in the period of just three months, with more than 130 thousand hours worked. More than seven hundred people involved were public and private professionals, the vast majority of whom were from CNEN itself; from its headquarters, from the Institute of Radioprotection and Dosimetry (IRD), the Institute for Energy and Nuclear Research (IPEN) and the Nuclear Technology Development Center (CDTN).

Goiania experiente has come up showing interesting evidences. In a retraining, permanent cycle, with monthly frequency as considered appropriate, exercises simulating radiologic accidents can, or should be foreseen; at the same time, it must be planned a schedule on, for instance, a trained employee can participate in data collection activities, as nuclear sources. The perspective of continued training permeates the concept of technical development. Therefore, the Personnel Development Division, from CNEN, must be steered to the process.

Lato sensu, training and occurrence response activities, from a perspective to the emergency scenario, are considered from the approach of technological research and development. The professionals of Science & Technology career that integrate CNEN's headquarters and institutes must participate in such context, which is part of CNEN's legal responsibilities.

5.3. Lessons learned

The Goiânia radiological accident brought countless lessons to Brazil and the world [15]. The Brazilian community and the nuclear and radiologic emergency response team as well, had believed that the worst accident that could jeopardize the country, in this field, would be the one involving the Nuclear Powerplant Almirante Alvaro Alberto (CNAAA), in Angra dos Reis, RJ. However, for this specific context, in the 1980s, it was considered that all items necessary to respond to a nuclear accident or emergency situation in the radiological area were adequately identified, equated and their solutions were clearly established, namely:

1. The site would be well established and its environment studied in detail;
2. The postulated accidents were well described;
3. The logistical and human resources infrastructure present.

Furthermore, regarding to radioactive installations, the planning for response to emergencies considered that 92% of these – public and private ones – were located in the Southeast, South and Northeast of Brazil, where the infrastructure for an eventual response could be easily mobilized. The accident demonstrated how wrong the previous considerations and parameterization were described.

The IAEA (The Radiological Accident in Goiânia, 1988) [14] provides parameters collected during the incident:

> (a) Emergency equipment must be capable of operating in adverse ambient conditions;
>
> (b) There will almost certainly be a need to engage workers without previous experience of radiolocal work, and even professional staff may not have had relevant operational experience. Provision for training should therefore be made within emergency plans. (IAEA, 1988a, p. 90)

The IAEA highlights, in another document (Radiation sources: Lessons from Goiânia. IAEA Bulletin 4/1988) [15]:

> Their contacts with the individuals affected in the accident in Goiânia proved very important: people would gauge the seriousness of contamination by the reactions of the workers. The people most affected by the accident would judge whether their houses were really free of contamination by whether the CNEN personnel accepted water or coffee from them.
>
> An adequate system of social and psychological support should be provided following a radiological accident causing serious contamination. The psychological support should be provided to those individuals directly and indirectly affected and the personnel working in response to the emergency. (IAEA, 1988b, p. 17)

In this particular, experiences in responding to disasters, in Brazil and around the world, reveal that professional rescuers, volunteers and non-fatal victims are subject to post-traumatic stress. Several studies indicate that adequate professional training, as well as an effective publicity system of information act to mitigate consequences.

What could be learned from discussions with CNEN employees — most of whom retired — who participated of the work in 1987, in Goiânia, two issues are notable: 1) greater quantity and quality of the personnel involved would brutally reduce the workload of those who were there deployed; and 2) the lack of knowledge among lay people (and also non-professional employees) about radiation care led to the situation of "Psychoradiophobia", in which the dissemination of untrue or inexact conditions worsened control of the scenario.

Due to the mobilization that was necessary to respond in record time to the accident, in a region with little coverage by CNEN, due to the gigantic resources required, it is possible to state that the response to the radiologic accident in Goiânia constitutes a paradigm shift in relation to the entire knowledge and experience accumulated at that time in this type of emergency.

Some lessons identified:

- There must be a management system, with its chain of command clearly identified;
- The consequences of a radiological accident are directly proportional to the time elapsed between the start of the accident and its effective identification;
- Knowledge of the physical and chemical properties of the radioactive source are factors extremely important to guide response actions;
- An adequate information system is essential for mitigating rumors and panic;
- Each country must be properly prepared to receive international aid;
- Courses and training in response to radiological emergency situations must be conducted for all responders.

6. PREPARATION AND RESPONSE TO ACCIDENTS OR EMERGENCIES, NUCLEAR OR RADIOLOGICAL ONES

The IAEA publication GSR Part 7, General Safety Requirements, entitled "Preparedness and Response for a Nuclear or Radiological Emergency", from 2015, presents a detailed description of the requirements that must be pursued by its Member States, to achieve an adequate degree of preparedness for response to nuclear and radiological accidents [1].

The document presents the objectives of preparing for and responding to a nuclear emergency or radiological situation and the requirements necessary to achieve these objectives. The following are considered objectives in emergency response:

- Regain control of the situation and mitigate its consequences;

- Save lifes;
- Avoid or minimize severe deterministic effects;
- Provide first aid, medical treatment for critical situations and manage treatment for injuries caused by ionizing radiation;
- Reduce the risk of stochastic effects;
- Keep the population informed and maintain public trust;
- Mitigate, as much as possible, non-radiological consequences;
- Protect, as much as possible, properties and the environment;
- Prepare, as much as possible, for the return of social and economic activities to normality.

The requirements for emergency situations are numbered 1 to 26 and are presented in GSR Part 7 as General, Functional and Infrastructure ones [1].

General Requirements

1. Emergency management system
2. Roles and responsibilities
3. International Organizations
4. Hazard assessment (threats)
5. Protection strategy

Functional Requirements

6. Management of response operations
7. Identification, notification and activation
8. Adoption of mitigating measures

9. Adoption of urgent protective measures and other response measures

10. Transmission of relevant instructions, warnings and information to the public

11. Protection of emergency workers and volunteers

12. Medical response management

13. Communication with the public

14. Adoption of immediate protective measures and other response measures

15. Management of radioactive waste

16. Mitigation of non-radiological consequences

17. Requesting, providing and receiving international assistance

18. End of emergency

19. Analysis of the emergency situation and its response

Infrastructure Requirements

20. Authority

21. Organization and Human Resources

22. Coordination

23. Plans and Procedures

24. Logistics Support and Installations

25. Training, Simulations and Exercises

26. Quality Management Program

It is worth highlighting requirements 11, 21 and 25 here, which concern to the permanent training of professionals from all organizations involved in preparing for and responding to accidents and emergencies, nuclear or radiological ones.

7. STRUCTURE OF THE COUNTRY TO RESPOND TO NUCLEAR AND RADIOLOGICAL EMERGENCIES

Among other links identified by the response to the Goiânia radiologic accident in 1987, it may be said that the country has awakened to the need to better prepare itself to respond to any nuclear accident or radiological emergency, regardless the root cause. Within the scope of CNEN, the Nuclear and Radiological Emergency Response System (SAER) was created to carry out facing of nuclear and radiological emergencies. SAER was restructured by Orientação Interna (Ol) PR-002/2022. [5]

However, in order to implement this content, two questions must be answered to SAER coordination.

- What is the challenge?

Respond promptly to any events of a radiological and/or nuclear nature that affect the country, in a coordinated way, integrated with national and international organizations that play roles in responding to emergency situations. Figures 2 and 3 show aspects of working at Goiânia site.

- Is Brazil prepared?

Considering: (i) the country's continental dimensions; (ii) the lessons identified in the response to Goiânia accident; (iii) the occurrence of other happenings in the world, especially in the Latin America region, its causes and consequences; (iv) CNEN standards; and (v) IAEA recommendations, in particular those contained in the GSR Part 7 document; it can be stated that Brazil has achieved a prominent role in the field of nuclear and radiological emergencies, recognized by IAEA and Latin America region. However, even though the system currently has more than two dozen qualified specific professionals, with personnel protective equipment available, specific measuring and detection devices and functional mobile phones, the paradigm of a greater number of trained and re-trained responders demonstrates the professional seriousness in dealing with such important question. World practices show that the quantity and quality of personnel employed “makes the difference”.

Figures 2 and 3: Decontamination work by CNEN teams - Goiânia, 1987.

Source: IAEA (1988a)

8. CONCLUSION

Occurrences such as those reported herein happen around the world and require the attention of national authorities. Brazil, as a regional leader, with primacy in number of operating facilities in the nuclear sector and holding the largest number of qualified people in the area in Latin America, is permanently achieving an adequate level of preparation for responding to nuclear and radiological accidents, as recommended in the publication GSR Part 7, General Safety Requirements, and in Safety Standards Series nº GS-R-2 [16] as well; both from IAEA.

A continuous training program was implemented by CNEN, reaching out its employees and becoming imperative for the organization; to continue playing a leading role in responding to radiological and nuclear emergencies that may eventually occur in any region of the Brazilian territory. The SAER must be a solid, efficient tool, empowering the strength of nuclear activities under the responsibility of CNEN and the country. CNEN presently carries on a training program, in order to provide a comprehensive response system, gathering operational and administrative servants as well.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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