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REVIEW

Appropriate radiation accident medical management: necessity of extensive preparatory planning

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Abstract Despite the rareness of radiation accidents, their potential consequences can be very serious, and appropriate medical management requires sufficient preparatory planning. To identify necessary factors for sufficient preparatory planning, three different radiation accidents were analyzed, i.e. the accidents in Goiânia, Brazil, 1987; Lilo, Georgia, 1997; and Tokai-mura, Japan, 1999. These radiation accidents have been chosen specifically because they provide a wide spectrum of potential radiation accident scenarios. After a brief description of the accidents and the following medical management, the measures taken are analyzed in terms of diagnosing radiation-induced health damage, determining the cause, dealing with contamination/incorporation, pathophysiological and therapeutic principles, preparatory planning, national and international cooperation and training. Several important factors are identified that should be considered in preparatory planning, i.e. preventing delayed diagnosis and training of medical personnel. Due to limited national resources, an intensified international cooperation to manage medical radiation accidents is of great importance.

Introduction

Fortunately, radiation accidents are quite rare in comparison with other types of emergency situations. Nevertheless, worldwide more than 300 radiation accidents happened between 1944 and 1992 with more than 2,000 persons suffering radiation induced health impairments. Although the number of radiation accidents is decreasing, their severity seems to increase regarding the number of victims involved [1]. Despite the rareness of such accidents, the potential consequences of radiation emergencies can be very serious, including acute and chronic health impairment, psychological reactions and considerable direct and indirect economic damage [2].

Appropriate medical management encompasses a number of significant factors. In addition to the type of accident, the number of people exposed to ionizing radiation and the level of exposure plays a particularly important role. Medical treatment of exposed patients depends on the level of radiation exposure. In the case of low levels of radiation exposure a large number of people may be affected, requiring extensive measures such as initial evacuation, decontamination and perhaps distribution of iodine tablets for iodine prophylaxis. Acute radiation-induced health impairments are not expected, but psychological reactions might necessitate medical attendance. Depending on the radiation doses involved, the risk of developing malignant tumors will be increased. Therefore, all efforts must be made to reduce the individual exposure to ionizing radiation and thus, the absorbed dose. High levels of radiation exposure, on the other hand, result in completely different medical problems, and those exposed require immediate, intensive and interdisciplinary medical treatment. Some cases demand early intensive care treatment and special therapeutic options such as hematopoietic stem cell transplantation. Patients exposed to very high levels of radiation developing an

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acute radiation syndrome, will need considerable medical resources for several weeks [3].

In order to reduce potential secondary damage, fast and appropriate reactions to any radiological or nuclear incident are a prerequisite. Thus, organizational and medical measures that have been thoroughly planned in advance are required. The most significant problems in radiation accident management are (1) diagnosis of radiation-induced health damage; (2) determination of the cause/identification of radiation sources; (3) dealing with contamination/incorporation; (4) treatment of patients who suffer from acute radiation syndrome.

Preparatory planning must take these important aspects into account. It should be based on an analysis of possible radiation accident scenarios with their specific causes and consequences. Such scenarios range from the release of small quantities of radioactive substances to uncontrolled chain reactions of various dimensions [4]. Since the attacks of September 11 in New York and Washington, the use of radioactive substances by terrorists is also a subject of concern [5], and an increasing attention has been paid on the threat posed by radiological dispersal devices (RDDs) like "dirty bombs" [6]. As far as scenarios including RDDs are concerned, some specific factors have to be taken in account for preparatory planning [7, 8].

The aim of the present paper is to analyze three different radiation accidents in terms of preparatory planning and medical treatment of exposed patients, to compare these accidents, and to derive general principles. These accidents have been chosen specifically because they provide a wide spectrum of potential radiation accident scenarios. The first radiation accident considered represents a scenario that is rather small, on an industrial scale. It occurred in 1999 in a nuclear facility in Tokai-mura, Japan, and was caused by an uncontrolled chain reaction. The second accident considered occurred in 1987 in Goiânia, Brazil. This accident represents a scenario including many more casualties, because ^{137}Cs was dispersed as cesium chloride in powder form to many individuals, from an abandoned radiation therapy source. In addition to the radiation exposure from the radiation source itself, the radioactive cesium chloride led to contamination and incorporation. Some aspects of this accident might be used to model potential consequences after dissemination of radioactive substances by terrorists. However, it cannot illustrate the impact of a dirty bomb, since there was no explosion that would cause additional effects such as conventional trauma due to the blast, inhalation of the radionuclide, and initial panic or disruption. The third accident to be considered represents a scenario including vagabond radiation sources. It occurred between 1996 and 1997 in Lilo, Georgia, when Georgian border soldiers were exposed to ionizing radiation from enclosed radiation sources, in their barracks.

The radiation accident in Tokai-mura (Japan)

On 30 September 1999, a radiation accident occurred in a nuclear facility in Tokai-mura, Japan, when the critical mass of highly enriched uranium (18.8% ^{235}U) was exceeded. The resulting uncontrolled chain reaction led to the release of high levels of neutron and gamma radiation [9]. Three employees were severely exposed and received whole-body doses of up to 20 GyEq. Two patients suffered from typical prodromal symptoms of the central nervous system such as nausea, vomiting and clouding of consciousness [10]. The central fire service in Tokai-mura immediately contacted the Japanese National Institute of Radiological Sciences (NIRS) in Chiba (near Tokyo).

From this point on, NIRS coordinated the medical treatment. Patient treatment included precautions against external contamination or incorporation of radionuclides, because radioactivity could be detected on the body surface of the patients. The early identification of ^{24}Na in the blood plasma of the patients suggested exposure to neutron radiation, which in turn was interpreted as an indirect indicator of an uncontrolled chain reaction. These findings led to the conclusion that the patients were not externally contaminated during the accident, and that there was no risk of radioactive material being spread further on. Radioactivity induced by neutron radiation in the patients meant, however, that rescue and care personnel would be exposed to ionizing radiation if they were close to the patients. All necessary preparations were made for hematopoietic stem cell transplantation in the two most severely exposed patients. In addition to the clinical picture, knowledge of the absorbed doses was required, to plan further treatment and determine a prognosis. For this reason, teams form the NIRS also performed various physical and biological measurements, to estimate the absorbed doses involved [11, 12].

In the end two patients died as a result of radiation-induced multi organ failure, after 82 and 210 days of intensive treatment. Keeping in mind that after exposure to an $LD_{50/60}$ dose of 3.6 Gy [13], 50% of those exposed are expected to die within 60 days, if no medical treatment is provided, the survival periods achieved confirm the effectiveness of the treatment measures.

NIRS is responsible to treat exposed patients in case of a radiation accident in Japan. For this purpose, it provides personnel and equipment, including radiation measurement devices and decontamination systems. Of particular significance is a network organized by NIRS, for the medical treatment of severely exposed patients (Network Council for Radiation Emergency Medicine, http://www.nirs.go.jp), which had been established just before the radiation accident occurred.

The radiation accident in Goiânia (Brazil)

In September 1987, a major radiation accident occurred in Goiânia, Brazil. A teletherapy unit with a ^{137}Cs source had been abandoned when a clinic for radiation therapy moved to new premises. The ^{137}Cs radiation source contained 93 g of cesium chloride, with an activity of 50.9 TBq or 1,375 Ci resulting in a dose rate of 4.56 Gy h^{-1} at a distance of 1 m. The unit was found by two men who dismantled it for scrap parts. A rotation mechanism made of stainless steel and lead was removed from a lead canister and, together with the ^{137}Cs source, taken to the house of one of the two men. The mechanism was later further dismantled. On this occasion, the encasement of the ^{137}Cs source was damaged and cesium chloride (which was present in powder form) was released. The material was sold to a scrap dealer who noticed a bluish glow in the dark and thus took the cesium chloride capsule home. During the next few days, the capsule was shown to neighbors and friends. Three days later, some of the cesium chloride was removed from the source and given to other people.

During the first day, two people who came into contact with the radiation source already showed first symptoms of acute radiation sickness. Both suffered from vomiting, and later one of them suffered from diarrhoea and skin symptoms (erythema and edematous swelling). As time went by, additional people reported on symptoms of acute radiation sickness, but these symptoms were interpreted as allergic reactions or infectious diseases. Most of the patients were then admitted to a clinic for tropical diseases. Finally, someone suspected a connection between the symptoms and the radiation source and informed a local health authority (vigilância sanitátia). It was only then, i.e. 15 days after the radiation source had been opened, that a medical physicist identified the radiation source, and measures for radiation accident medical management, adequate patient treatment and contamination monitoring could be introduced. A total of 112,000 people were examined for contamination, and 249 were diagnosed as being contaminated. Twenty of the victims were given inpatient treatment; almost all (19 patients) developed radiation-induced skin damage. For the first time, a decorporation therapy with Prussian blue (Radiogardase®) was successfully performed on such a large scale (46 patients) [14]. Within 4 weeks following hospitalization, four patients succumbed to their acute radiation syndrome [15].

In Brazil, the National Nuclear Energy Commission (NNEC) is responsible for dealing with radioactive material. Subordinate to it are three research institutes: the Institute for Nuclear and Energy Research, the Institute of Radiation Protection and Dosimetry, and the Nuclear Engineering Institute. In the case of a radiation accident, the NNEC introduces an Executive Group for Emergency Control that serves as a coordinating body. Prior to the Goiânia radiation accident, emergency plans existed for the nuclear power plant in Angra and for radiological accidents [14].

The radiation accident in Lilo (Georgia)

In 1997 it became known that a total of 11 soldiers had been exposed to ionizing radiation at a training facility for border troops in Lilo, Georgia [16]. Between May 1996 and August 1997, these soldiers had developed uncharacteristic symptoms such as nausea, vomiting, headache, lack of appetite and weakness, combined with skin abnormalities. In retrospect, these symptoms all were clearly radiation-induced. A tentative diagnosis of radiation syndrome was made for the first time in September 1997 (i.e. 15 months after clinical symptoms first appeared in the patients) by Russian physicians from the Institute of Biophysics in Moscow. This institute is a collaboration centre of the World Health Organization (WHO) for radiation accident medical management within the Radiological Emergency Medical Preparedness and Assistance Network (REMPAN). The cause of exposure was then identified in September 1997 as several concealed radiation sources. A total of 12 ^{137}Cs, 1 ^{60}Co and 200 ^{226}Ra radiation sources were discovered on the premises of the training facility [16].

In Georgia, the State Sanitary Supervision and Hygiene Standardization (SSSHS), which is directly subordinate to the Ministry of Health, is responsible for supervising radiation protection measures. After the radiation accident was announced, the Georgian Minister of Health informed the International Atomic Energy Agency (IAEA) about the appearance of radiation-induced skin damage in nine soldiers. He also asked for assistance in investigating the cause of the accident and in treating the exposed patients. In October 1997, a team of experts from the IAEA met in Lilo and examined the radiation sources that had already been identified and recovered. The IAEA immediately informed the WHO about the accident. The Georgian Minister of Health asked for WHO assistance on the basis of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The collaboration centres in the REMPAN network were then alerted immediately. The WHO established contact between the Georgian Minister of Health and REMPAN centres that were able to provide medical support. In the end, two patients were treated at the Curie Institute in Paris, two at the Percy Hospital of the French Armed Forces, also located in Paris. Seven patients were treated at the WHO REMPAN Centre/University Clinic of Ulm (Department of Dermatology of the Bundeswehr Hospital, Ulm) [16, 17].

In 2003, IAEA received a second request from Georgia for medical support for 2 of the 11 patients still suffering from radiation-induced health impairment. These patients were then treated at the Bundeswehr Hospital Ulm in cooperation with the Bundeswehr Institute of Radiobiology and the REMPAN Centre at the University of Ulm.

Discussion

Diagnosis of radiation-induced health damage

In Tokai-mura, it was clear from the outset that the accident had involved exposure to ionizing radiation. It was therefore possible to immediately arrange all necessary diagnostic and therapeutic measures. Special diagnostic procedures, such as the identification of ^{24}Na in blood plasma, were used to quickly acquire information that was decisive for the treatment of the patients.

In the Goiânia accident, 15 days elapsed from the appearance of the first symptoms until the diagnosis of a radiation-induced health impairment. A particularly tragic feature of this accident was that most of the other patients were contaminated with the released ^{137}Cs or incorporated it at a later stage. All patients exposed to high levels of radiation developed an acute radiation syndrome with typical symptoms.

In Georgia, patients developed mostly unspecific symptoms and skin lesions. There were no additional indications of exposure to ionizing radiation. The spectrum of diagnoses ranged from serum disease to toxic dermatitis. In the end, the symptoms were correctly interpreted by employees of the Institute for Biophysics in Moscow who had experience with radiation-exposed patients. The long period (more than 1 year) between the appearance of the first symptoms and the diagnosis meant that treatment was unnecessarily delayed, and that the affected soldiers continued to be exposed to ionizing radiation.

The radiation accidents presented here illustrate the problems involved in the early diagnosis of radiation-induced health impairment, particularly when there are no additional indications of exposure to ionizing radiation. Of particular importance is the fact that therapeutic measures can only be initiated at an early stage if radiation-induced health impairment is diagnosed as early as possible. Furthermore, setting the correct diagnosis is a prerequisite for identifying the source of ionizing radiation, and thus for preventing other potential victims from exposure.

The initial symptoms of acute radiation syndrome occur during what is known as the prodromal phase. They can, if the possibility of a radiation exposure is not taken into account, be misinterpreted as unspecific symptoms of gastrointestinal or other infectious diseases. Prodromal symptoms include lack of appetite, nausea, vomiting, diarrhoea and in the case of high radiation doses, clouding of consciousness or even coma. For this reason, the possibility of a radiation-induced health impairment should always be considered, if unspecific symptoms cannot be properly explained.

Determination of the cause/identification of radiation sources

Since the Tokai-mura accident occurred in a nuclear facility, trained rescue forces were aware of the possibility of radiation exposure. A detailed reconstruction of the accident allowed reconstruction of the patients' exposure to ionizing radiation.

The cause of the Goiânia radiation accident was not known until the radiation source had been given to a local health authority. Only after the radiation source had been identified, the accident was associated with ionizing radiation and appropriate measurements could be initiated, in the contaminated areas. Most importantly, however, the measures that were then introduced prevented the contamination from being further spread.

In Lilo, the radiation sources were only identified and recovered after it had become known that the patients were suffering from radiation-induced health impairment. The individual reconstruction of the radiation exposure was based on a combination of hematological and dermatological findings. Special mobile equipment (e.g. a gamma spectrometer) as well as qualified personnel was needed to locate and identify the radiation sources. After the concealed radiation sources had been identified, it became possible to match these sources with the exposure patterns of the patients.

A comparison of the three radiation accidents in terms of determining the cause and identifying radiation sources also reveals the importance of recognizing radiation-induced health impairment. As in the Goiânia and Lilo accidents, the appearance of radiation-induced health impairment may therefore be the first and only indicator of any radiation exposure. On the other hand, identification of a radiation source can shift the focus to radiation-induced health impairment and necessary specific diagnostic measures. If a certain radionuclide was released from a source leading to external contamination or incorporation, then its identification is of great importance for taking appropriate measures and separating victims from people suspected of being victims.

Dealing with contamination/incorporation

In Tokai-mura, radiation was detected on the body-surface of the patients. Based on the suspicion that the patients were contaminated with radioactive material, precautions were taken to prevent contamination of the surroundings. For this reason, corridors, floors and equipment in the clinic were covered with plastic foil. Due to special diagnostic measures, external contamination was ruled out, which had important consequences for patient treatment. It was, for example, no longer necessary to apply decontamination measures, which would have meant unnecessary stress for the patients. Radioactivity induced in the patients themselves by neutron radiation led to dose rates up to 1.5 μSv h^{-1}, which meant that medical personnel was exposed to ionizing radiation [18].

Identifying or ruling out external contamination with radioactive substances is an important task. In the case of external contamination, patients must be decontaminated as soon as possible and special precautions must be taken to protect medical personnel, facilities and equipment from contamination. If patients have incorporated radionuclides, a specific decorporation therapy must be carried out. The Goiânia radiation accident exemplarily illustrates the potential consequences of the dissemination of radioactive materials by terrorists.

Pathophysiological and therapeutic principles

In Japan, the type, severity and onset of initial symptoms in combination with hematological findings (initial granulocytosis, early formation of lymphopenia) quickly indicated that two of the patients were likely suffering from an irreversible impairment of the hematopoietic system. The transplantation of hematopoietic stem cells was therefore included into the therapeutic strategy at an early stage. The treatment of skin injuries was of particular significance. A limiting factor was the gastrointestinal syndrome with an almost complete aplasia of the mucosa. Intensive care was thus required to compensate for the loss of blood and fluid [18]. In the end, the two patients developed a multiorgan failure as a result of their exposure to ionizing radiation. This supports a new concept considering multiorgan involvement and failure as a common denominator of the radiation reaction. The pathophysiological mechanisms behind this development are still poorly understood. For this reason, it is essential to carry out further interdisciplinary research in this area [19].

In the Goiânia radiation accident, the treatment of acute radiation syndrome played an essential role, but decorporation therapy was also important. A decorporation therapy with Prussian blue (Radiogardase©) was carried out on a total of 46 patients, representing the first successful use of this compound in a radiation accident [15]. It is important to note that any decorporation therapy has to be specific for the incorporated radionuclide. For example, the administration of Prussian blue is specific in the case of a cesium-incorporation. Therefore, the incorporated radionuclide must be identified as soon as possible. It is only after knowledge of the incorporated radionuclide that the adequate decorporation agent can be applied. Whether a decorporation therapy should be performed in an individual case depends on several aspects, such as the level of internal dose, the number of patients involved, and the availability of the decorporation agent. Internal dose assessment could also be problematic as a basis for the decision [20].

The Goiânia radiation accident also indicates the importance of psychological reactions of involved and not involved persons, which can be of great relevance for the medical personnel. For example, such reactions can hinder medical personnel performing necessary measures [21].

Due to the 15 months that had elapsed before radiation-induced health impairment was diagnosed in the Georgian patients, changes in the peripheral blood count were no longer visible when the patients were admitted to the Ulm and Paris hospitals. For this reason, emphasis was placed on treating radiation-induced skin damage. Despite a normal peripheral blood count, however, some pathological features were still noticeable by examining bone marrow smears [16].

Although the therapeutic measures taken in each radiation accident had a different focus, some common conclusions to be drawn. For example, medical care for the exposed patients must be provided by specialists from various fields including radiation medicine. Since dose estimates are usually not available in the beginning, clinical signs and symptoms of the patient are of utmost importance as the basis for the initial planning of diagnostic and therapeutic measures [22]. If an unrecoverable damage to the hematopoietic stem cell pool is noticed, an early decision about the necessity of the transplantation of hematopoietic stem cells has to be made. Medical treatment of exposed patients always necessitates and ties up considerable resources. This should be taken into account for preparatory planning.

Preparatory planning

In Japan, the organizational structures set up by the NIRS proved to be well prepared for the treatment of radiation-exposed patients. Potential treatment facilities and applicable medical personnel had been clearly defined in advance. The institutions had sufficient personnel and equipment at their disposal.

In Brazil, the national institutions were able to use existing emergency plans to take necessary steps and prevent further contamination. The available personnel had adequate measuring devices at their disposal.

Prior to the Lilo radiation accident, Georgia was insufficiently prepared to respond to such an accident and to treat exposed patients. Medical treatment for the exposed patients was organized by the WHO REMPAN network and provided at the national REMPAN centres in Germany and France.

At the time of the accidents, Japan and Brazil had well-established organizational structures with qualified personnel, equipment and sufficient resources for diagnosing and treating exposed patients. In addition, international experts lent their support to the medical treatment provided. In particular, however, the Lilo radiation accident underscores the need for international radiation accident medical management networks.

National and international cooperation

In Japan, national institutions were well prepared to deal with the Tokai-mura accident, since there was an established network for the medical management of severe radiation exposures. Coordinated by the NIRS, sufficient resources were available for treating the two most severe exposed patients. In addition to Japanese experts, international specialists were consulted through the REMPAN network.

In Brazil, national institutions were also able to use existing emergency plans. Here as well, national expertise was complemented by participation of IAEA and international experts. For example, the decorporation therapy, was carried out with the assistance of the German GSF Research Center for Environment and Health [14].

In Georgia, adequate medical management would have been very difficult without international assistance and cooperation. The WHO REMPAN network in particular was effective in identifying international experts in radiation accident medical management and suitable medical facilities for providing adequate medical treatment.

International networks can provide specific expertise as well as personnel and material resources of the few world-wide institutions that are actively involved in radiation accident medical management and in the treatment of radiation-exposed patients. In addition, established international networks encourage cooperation and exchange of experience. International networks such as REMPAN also allow countries to compensate for unavailable national resources. Depending on the size of the radiation accident, international support may also be necessary if national resources become exhausted.

Training

After the Tokai-mura radiation accident, the patients were provided with the best possible multidisciplinary medical treatment. This was made possible by the specialized training of medical personnel.

In Brazil, the national institutions involved had appropriately trained personnel to ensure that exposed patients were given effective treatment. Two physicians in the medical response teams initially employed in Goiânia, for example, had received special training in treating patients exposed to radiation. This training had been assisted in part by the IAEA [14].

The radiation accident in Georgia clearly illustrates the importance of providing medical personnel with adequate training. It is very important for physicians to include radiation-induced health impairment in a differential diagnosis, particularly if patients are present with ambiguous skin symptoms.

Thus, all medical personnel who could potentially be involved in the treatment of radiation-exposed patients should receive basic training that enables them to identify radiation-induced health impairment at an early stage, and ensures appropriate diagnosis and therapy. Besides direct training in special disciplines, multidisciplinary cooperation necessitates appropriate training in the use of telemedicine [23].

Conclusion and perspectives

In summary, a comparison of the Tokai-mura, Goiânia and Lilo radiation accidents reveals that extensive preparatory planning is mandatory for an appropriate medical management in radiation emergencies. Although the three radiation accidents presented here differed in terms of type and size, some common principles for the medical management of any radiation accident can be derived.

The main problem is the identification of radiation-induced health impairment. In the Goiânia and Lilo radiation accidents, a delayed diagnosis caused delays in treatment and in identifying the radiation source, and also resulted in continued exposure. The early identification of radiation-induced health impairment is also essential for determining the cause of radiation accidents and for identifying radiation sources. For this reason, medical personnel should have a broad general knowledge on diagnosis and treatment of radiation-induced health impairment. Personnel directly involved in the medical treatment of radiation-exposed patients should also receive further certified training [24, 25].

One of the lessons learned in the Lilo radiation accident is that the existence of radiation sources and contamination with radioactive substances should always be considered as a potential hazard, especially in an unknown environment. In addition, it particularly illustrates the problem of "orphan" radiation sources. These radiation sources are usually outside institutional control and can therefore appear anywhere. In this context the IAEA has developed the "Code of Conduct on the Safety and Security of Radioactive Sources" and the "Guidance on the Import and Export of Radioactive Sources" [26, 27]. Although it is not legally binding, many countries expressed their support for the Code. By following the Guidance and some additional measures, the loss of highly active incapsulated sources could be avoided and the problem of "orphan" radiation sources could hopefully be limited.

The Goiânia radiation accident illustrates the far-reaching consequences of an external contamination with radioactive substances. Planning should thus include sufficient resources for detecting contamination and for decontamination measures. The possibility of an incorporation of radionuclides will lead to special aspects of preparatory planning [28].

Since both internal and external contamination must always be taken into account whenever radioactive substances were released, specific decorporation agents must be stockpiled so that decorporation therapy can be initiated at an early stage. Given the threat posed by RDDs, the above-mentioned aspects are extremely relevant and should therefore be taken into account in preparatory planning [29]. Because of the new threat analysis, the IAEA concentrates on the implementation of security measures to prevent misuse of radiation sources [30].

In addition to the above-mentioned consequences, the release of radioactive substances can also lead to psychological reactions such as mass panic. In this case, people who are not directly affected but who are afraid and uncertain may even hinder measures that need to be taken [21].

In Japan, new therapeutic paths were taken in the Tokai-mura radiation accident which allowed one of the patients to reach a survival time of 210 days. This illustrates the need for internationally recognized guidelines for the treatment of severely radiation-exposed patients. Further research is necessary to determine prognostic parameters for estimating irreversible damage to vital organ systems, and to study the pathophysiology of radiation-induced multiorgan failure [31].

Collecting clinical data on exposed patients in special databases like the SEARCH database (System for Evaluation and Archiving of Radiation Accidents based on Case Histories) would also be very important [32].

Especially the Lilo radiation accident underlines the urgent need for international networks in radiation accident medical management. Without international assistance and cooperation, it would have been impossible to provide the patients with appropriate medical treatment. Even in the Tokai-mura and Goiânia radiation accidents, assistance from international institutions and networks also played an important role. Since national resources are generally limited, international networks could also help to make resources from other countries available if needed. This is particularly important when multidisciplinary, resource-intensive treatment is required, for patients severely exposed to ionizing radiation.

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