Radiation Environment and Medicine 2017 Vol.6, No.2 94–103

REM
Radiat Environ Med

Report

The Medical Treatment of Radiation Exposure and Contamination in Radiation Accidents

Takakiyo Tsujiguchi[1, 2], Hitoshi Yamamura[2, 3] and Ikuo Kashiwakura[1, 2]*

[1]*Graduate School of Health Sciences, Hirosaki University, 66-1 Hon-cho, Hirosaki 036-8564*
[2]*Hirosaki University Center for Radiation Support and Safety, 66-1 Hon-cho, Hirosaki 036-8564*
[3]*Advance Emergency and Critical Care Center, Hirosaki University Hospital, 5 Zaifu-cho Hirosaki 036-8562*

Received 31 March 2017; revised 26 June 2017; accepted 24 July 2017

Various types of radiation accidents can occur, including rare events such as nuclear disasters, and mistakes in handling radiation sources. Although such accidents are less common in comparison to other disasters, a rapid and long-term medical response is necessary, especially in cases in which individuals are seriously injured by radiation exposure or contamination. In order to facilitate prompt medical treatment at the time of an emergency, it is necessary to understand the radiation dose to which the patient was exposed, to determine whether contamination occurred, and to select an appropriate treatment. In addition, we also need to have some basic knowledge of radiation to understand the associated dangers. In this article, we summarize the historical radiation accidents and report the details of treatment for patients who were exposed to radiation.

Key words: radiation accidents, nuclear disaster, radiation emergency medicine

1. Introduction

The various types of radiation accident include events involving the radiation generators that are used for medical and industrial purposes, errors in the handling of radiation sources, and critical accidents at nuclear power plants. People may also be exposed to radiation by a terrorist attack if nuclear weapons are used. Although radiation accidents occur less frequently in comparison to other disasters, the victims of radiation exposure and contamination experience very serious symptoms and a long-term medical response is necessary[1, 2].

Japan's relationship with radiation disasters and radiation exposure medicine began in 1945, with the bombing of Hiroshima and Nagasaki at the end of World War II. This marked the first time in history when large numbers of people were exposed to high doses of radiation[3]. The International Atomic Energy Agency (IAEA) classifies the International Nuclear and Radiological Event Stage (INES) of radiation-related accidents and disasters based on three perspectives: "people and the environment", "radiological barriers and control", and "defense-in-depth"[4]. Table 1 shows the events corresponding to the INES and each of the above-noted items. In Japan, the Tokai-mura nuclear accident was classified as a Level 4 event and ultimately led to the establishment of the "Act on Special Measures Concerning Nuclear Emergency Preparedness"[5]. The Fukushima Daiichi nuclear power plant accident in 2011 was classified as Level 7 nuclear accident (Table 1). Regarding Fukushima Daiichi Nuclear Power Plant accident, it was temporarily classified as Level 7 by the Japanese government in April 2011 one month after the accident occurred[6]. This accident suggested the

*Ikuo Kashiwakura: Graduate School of Health Sciences, Hirosaki University, 66-1 Hon-cho, Hirosaki 036-8564
E-mail: ikashi@hirosaki-u.ac.jp

Table 1. Major radiation accidents worldwide and INES classification[4)].

INES Level	*People and Environment*	*Radiological Barriers and Control*	*Defence-in-Depth*	*Associated with Acident*
Major Accident ***Level 7***	• Major release of radioactive -material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.			Chernobyl, 1986 Fukushima, 2011[a]
Serious Accident ***Level 6***	• Significant release of radioactive material likely to require implementation of planned countermeasures.			Kyshtym, Russia, 1957
Accident with Consequences ***Level 5***	• Limited release of radioactive material likely to require implementation of some planned countermeasures. • Several deaths from radiation.	• Severe damage to reactor core. • Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.		Windscale Plle, UK, 1957 Goiânia, Brazill, 1987
Accident with Local Consequences ***Level 4***	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. • At least one death from radiation.	• Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. • Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.		Tokaimura, Japan, 1999 Fleurus, Belgium, 2006
Serious Incident ***Level 3***	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.	• Near accident at a nuclear power plant with no safety provisions remaining. • Lost or stolen highly radioactive sealed source. • Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.	Sellafield, UK, 2005 Vandellos, Spain, 1989 Yanango, Peru, 1999
Incident ***Level 2***	• Exposure of a member of the public in excess of 10 mSv. • Exposure of a worker in excess of the statutory annual limits.	• Radiation levels in an operating area of more than 50 mSv/h. • Significant contamination within the facility into an area not expected by design.	• Significant failures in safety provisions but with no actual consequences. • Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. • Inadequate packaging of a highly radioactive sealed source.	Atucha, Argentina, 2005 Cadarache, France, 1993 Forsmark, Sweden, 2006
Anomaly ***Level 1***			• Overexposure of a member of the public in excess of statutory annual limits. • Minor problems with safety components with significant defence-in-depth remaining. • Low activity lost or stolen radioactive source, device or transport package.	Breach of operating limits at a nuclear facility.

[a] The classification of Fukushima No,1 nuclear power plant follows the 'Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations -'.

Table 2. Decorporation therapy recommendations in the USA for radionuclides of concern (excerpt of NCRP Report161, 2010).

Radionuclides	*Treatment*	*Preferred Rx*
Barium (Ba)	Ba, Ca Therapy	See NCRP 161
Cesium (Cs)	Prussian blue	Prussian blue
Iodine (I)	Potassium iodine (KI), propylshiouracil, methamizole	KI
Strontium (Sr)	Ra, Sr therapy	-

Table 3a. Major radiation accidents worldwide (1944 - Feb 2012): Classification by device

Radiation Devices			***324***
	Sealed Sources	214	
	X-ray Devices	84	
	Accelarators	25	
	Radar Generators	1	
Radioisotopes			***101***
	Diagnosis and Therapy	44	
	Transuranics	28	
	Fission Products	11	
	Tritium	2	
	Radium Spills	1	
	Other	15	
Criticalities			***20***
	Critical Assenmblies	8	
	Reactors	6	
	Chemical Operations	6	
		total	***445***

need for new guidelines for nuclear emergency disaster countermeasures in Japan, and August 2015 marked a major turning point in relation to radiation disaster countermeasures in Japan. The emergency medical care that is required at the time of radiation accidents and nuclear disasters is sometimes considered special, but it should be regarded as similar to other infectious diseases. Basic knowledge on radiation needs to be widely understood not only by medical squirrels but also by related organizations, and the establishment of systems from around the everyday will be indispensable for the promotion of radiation medicine exposure and improvement of system between institutions is indispensable for promotion of radiation medicine.

In large-scale radiation-related disaster scenarios, the medical personnel who treat patients for exposure would be expected to provide medical care to large numbers of patients. When dealing with incidents involving radiation exposure or radiation, similarly to standard emergency medical care, the priority is to save lives. Decontamination treatment and radiation care are the next priorities. Various decontamination measures exist for specific nuclides; for example, inoculation with a stable iodine agent and Prussian Blue is performed to promote the excretion of radioactive cesium and prevent the adsorption of radioactive iodine in the body (thyroid gland) (Table 2)[7, 8]. On the other hand, when the decontamination of radiation substances and wounds adhering to the body surface is performed, it is necessary to apply appropriate methods of contamination, such as washing with water or wiping. This necessitates other precautions and differs from cases involving contamination with other chemical substances, because radioactive substances cannot be neutralized. Thus, the proper management of radioactive waste such as gauze and the water used for decontamination work is essential. As mentioned earlier, the healthcare professionals who are involved in radiation exposure medicine should be aware of the treatments that have been applied in historical cases involving radiation exposure medicine and their knowledge and skills should be preserved.

In this article, we introduce the history of radiation disasters around the world that have led to changes in radiation-related medical care, and provide examples of actual cases in which patients were treated for radiation exposure, and summarize the future prospects for medicine in this field.

2. The history of radiation accidents around the world

2.1. An investigation of the major radiation accidents

Historically, the highest levels of radiation to which humans were exposed in a single event occurred in Japan with the bombing of Hiroshima and Nagasaki. Dr. Maekawa, who treated patients at the time of Tokai-mura nuclear accident in Tokai-mura, Japan in 1999, said that the origin of the radiation medical field started could be traced to this time[9]. The Radiation Emergency Assistance Center/Training Site (REAC/TS) reports the major radiation accidents and disasters that occur throughout the world[10]. Table 3ab shows the number of reports that were issued until 2012. It is clear that the radiation accidents involving radiation generators, such as sealed source and X-ray generators, are involved in the vast majority of radiation accidents (Table 3a). Critical accidents at nuclear power plants, etc., represent the most serious type of accident, followed by accidents involving medical and industrial isotopes. Even though nuclear power plant accidents have significant human and social impacts, they are rare. In contrast, accidents at industrial and medical facilities are relatively common. Thus, it is deemed important for medical staff to deepen their knowledge on a daily basis and to improve the medical system during normal times. In addition, IAEA and Los Alamos National Laboratory (LANL) also publish various materials on the causes and places of accidents at major nuclear facilities in the world[11, 12]. We herein summarize the details of the accidents that have occurred since the

Table 3b. Major radiation accidents worldwide (1944 - Feb 2012): Classification by country

United States		*Others*			
		Country	Number	Country	Number
New Mexico	3	Algeria	2	Japan	2
Ohio	10	Argentina	1	Marshall Isl	1
Oklahoma	1	Belarus	1	Mexico	5
Pennsylvania	1	Brazil	4	Morocco	8
Rhode Island	1	Bulgaria	1	Norway	1
Texas	9	China (PR)	6	Panama	5
Wisconsin	1	Costa Rica	7	Russia	5
		Egypt	2	Spain	10
		El Salvador	1	Thailand	3
		Estonia	1	USSR	29
		Israel	1	UK	3
		Italy	1	Yugoslavia	1
total	***26***			***total***	***102***

World War II bombing of Hiroshima and Nagasaki, which ultimately became major turning points in radiation-related medical care.

2.2. The Los Alamos criticality accident (1945 - 1946)

Accidents involving nuclear weapons occurred during development experiments at the LANL (New Mexico, USA). Various reports on the LANL accident, including the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have been summarized[9, 13]. In this laboratory, two critical events occurred in 1945 and 1946, when a beryllium neutron reflector was dropped onto plutonium aggregate. Nine people were exposed to high doses of radiation in the first accident, while eight people were exposed to high doses of radiation in the second accident. Later in 1952, Louis *et al.* compiled the symptoms of individual patients and issued a report[14]. According to the accident report of 1946, it was said that the closest experimenter from the critical point was exposed about 21 Sv, and it was stated that it had been vomiting several times when it was transported to the hospital. The numbness of hands and blisters became severer, white blood cell count drastically decreased 5 days after exposure and died 9 days after exposure without transfusion effect. This was the first case involving a patient being exposed to a high-dose of radiation due to an artificial accident. This event led to the formation of the concept of acute radioactive syndrome (ARS), which is still relevant today.

2.3 The ^{241}Am accident at the Hanford site (1974)

In 1974, a patient was exposed to massive ^{241}Am body surface contamination and internal exposure in Hanford (a US nuclear facility). A resin ion exchange column exploded during an experiment and one worker was exposed to a large amount of ^{241}Am[15, 16]. It was reported that the worker was internally exposed to 37 MBq of radiation source. This came to be recognized as the most severe internal exposure accident in history[16]. The patient was treated with Am chelators (CaDTPA, ZnDTPA) for approximately 18 months. Following this accident, there were marked advances in the diagnosis of internal exposure and in treatment practices. Later, the United States Radiation Protection Council's report 65, discussed internal contamination[9, 16].

2.4 The Chernobyl nuclear power plant accident (1986)

The nuclear power plant accident in Chernobyl in 1986 still represents the world's largest nuclear accident, in terms of the number of people who were exposed to radiation[17, 18]. The accident was caused by the melting of the reactor core, which led to an uncontrolled reaction during a confirmation experiment involving an emergency power generation system. The loss of external power supply caused a steam explosion, which resulted in the release of radioactive substances. In addition to affecting local residents, this accident had global effects. It is considered to have been a major disaster[17, 18]. According to UNSCEAR and many other reports, the 134 workers who extinguished the nuclear reactor were considered to have suffered ARS. This accident accounted for approximately one-third of the reported cases of ARS (throughout the world)[19]. Twenty-eight of the 134 people died after a short period of time; 95% of the patients who died showed a total body dose of >6.5 Gy[20]. This represented the largest number of people to be exposed to radiation in peacetime. Furthermore, it was the first time that experimental beta ray burn injury treatments were administered.[9, 18, 20, 21]

2.5. The radioactive contamination accident at Goiânia (1987)

This accident occurred in Goiânia after a cesium source was removed from a radiation treatment facility that was no longer in use. During the accident, the hands of ordinary citizens were exposed to powdered ^{137}Cs[22, 23]. This is ranked as the most damaging radiation accidents that did not involve nuclear weapons development or a nuclear power plant accidents[23]. This accident marked the first time that Prussian Blue, a chelating agent for cesium, was administered over the long term to patients who had inhaled ^{137}Cs[22]. This case showed that the administration of Prussian Blue shortened the biological half-life of cesium.

2.6 Tokai-mura nuclear accident (1999)

The Tokai-mura nuclear accident occurred when employees ignored safe practices and mixed a high-concentration uranium solution. Three employees who

Table 4. Prodromal phase of ARS[30].

Signs and symptoms	*Mild (1-2Gy)*	*Moderate (2-4Gy)*	*Severe (4-6 Gy)*	*Very severe (6-8 Gy)*	*Lethal (> 8Gy)*
Vomiting					
Onset	2h after exposure	1-2h after exposure	Earlier than 1h after exposure	Earlier than 30 min after exposure	Earlier than 10 min after exposure
% of incidence	10-50	70-90	100	100	100
Diarrhea	None	None	Mild	Heavy	Heavy
Onset	-	-	3-8 h	1-3 h	Within minutes or 1h
% of incidence	-	-	< 10	> 10	Almost 100
Headache	Slight	Mild	Moderate	Severe	Severe
Onset	-	-	4-24 h	3-4 h	1-2 h
% of incidence	-	-	50	80	80-90
Consciousness	Unaffected	Unaffected	Unaffected	May be alterd	Unconsciousness
Onset	-	-	-	-	Seconds/minutes
% of incidence	-	-	-	-	100 (at > 50Gy)
Body temperature	Normal	Increased	Fever	High fever	High fever
Onset	-	1-3 h	1-2 h	< 1h	< 1h
% of incidence	-	10-80	80-100	100	100

were working were exposed to neutron radiation at close range, two died and one became severely ill[13, 24-27]. All three patients suffered ARS patients with high-dose external exposure; they were also affected by multiple consecutive multisystem disorders and multiple organ dysfunction. Two of three died 83 days and 211 days after the accident due to multiple organ dysfunction and the remaining one has survived with the result of drug therapy such as cytokine treatment. Among the two deceased, patients with higher dose received peripheral blood stem cell transplantation and skin transplantation, the other received hematopoietic stem cell transplantation and skin transplantation[18]. In peripheral blood stem cell transplantation, donor stem cell engraftment was observed at one time, but it is also known that chromosomal abnormalities of donor cells were subsequently discovered. In another patient, an increase in peripheral granulocytes was observed around 10 days after hematopoietic stem cell transplantation, but gradually the decrease in donor cells was confirmed thereafter. Although neither transplantation had obvious complications, it was not able to prevent multiple organ dysfunction that occurred one after another. Thus, it became clear that a team approach rather than specialized treatment was necessary for treating patients exposed to high doses of radiation[9]. In Japan, this accident led to the enactment of the Law on Special Measures against Nuclear Emergency. This law contains concrete contents such as how to communicate information to residents at the time of a disaster, how to conduct contamination inspection at the time of residents evacuation. In order to reduce ARS patients like Tokai-mura nuclear accident and protect neighboring residents, this law is still enforced while continuing the revision in Japan.

3. Radiation emergency medicine

ME. Berger *et al*. said that triage is important when treating patients for radiation exposure at medical facilities[28]. This includes (1) determining the number of injured/sick people, (2) checking patients for burns, (3) determining the time after exposure, and (4) establishing whether contamination occurred[28]. These 4 points are important when hospitals accept patients who have suffered radiation-related injuries as healthcare providers can respond smoothly after ascertaining the capacity of their facility, the equipment that can be applied in treatment and the personnel. There are various kinds triage methods in disaster medical care such as START / Jump START method and SALT method. For example, at Korea Institute of Radiological and Medicine Sciences (KIRAMS), they add the evaluation of the presence or absence of body surface contamination and the extent of exposure (evaluated by vomiting) after the individual assess (assessment of physiological signs) based on the SALT method[29]. In addition to these points, we will discuss the main biological responses, the findings on dosimetric evaluation, and provide practical examples of treatment in each situation and condition.

3.1. The biological effects of radiation exposure and the methods for evaluating the dose of exposure

Table 4 summarizes the doses the doses absorbed by human patients with ARS as well as the initial medical symptoms and signs[30]. Table 4 was published by the IAEA in 1998 and is the most widely used index for estimating a patient's dose of exposure. Vomiting, in particular, is useful for making a simple estimation of the dose. Anno *et al*. reported that 80-100% of people show vomiting after receiving a dose of ≥3.5 Gy throughout

Table 5. Uneven exposure accident of cobalt gamma ray (China, 1963)[36].

Patient	*E* *Male*	*F* *Male*	*A* *Female (44)*	*B* *Male (20)*	*C* *Female (13)*	*D* *Male (39)*
exposure dose (Gy)	80	40	8	6	4	2
Minimum WBC[a] count /µl	100	55	55	297	213	6,000
Days after exposure	10	10	25	17	28	
Bleeding tendency appearance	10	8	8	15	8	-
High fever	8	8	8	20	26	-
Major obstructive organs	Small intestine Bone marrow	Small intestine Bone marrow	Bone marrow	Bone marrow	Bone marrow	Bone marrow
BMT	+	+	+	+	-	-
Consequence	death	death	amenorrhea	Permanent infertility	normal	Primary sperm count decreases

[a]WBC: White blood cell

the body[31]. Patients who are exposed to >15 Gy develop central nervous system disorder, and the possibility of death within a few hours after exposure is very high. In such cases, countermeasure therapy is provided. To determine the appropriate treatment for patients who receive doses of up to 5-6 Gy, it is important to quickly judge the degree of bone marrow damage[32]. In addition, various researchers continue to search for markers of radiation-related organ damage. For example, the PCC-FISH method has been used to estimate the dose of skin exposure[33], while another study attempted to evaluate the dose in the gastrointestinal tract using the plasma citrulline value[34]. Methods of evaluating radiation doses are continuously being studied.

3.2. The treatment of patients after internal/external exposure

When we treat a patient with exposure/contamination, it is necessary not only to grasp the physiological signs of the patient and the presence or absence of the wound by emergency/disaster medicine but to ascertain the contamination, pollutant nuclides, and exposure dose.

If it is found that contamination is present on the body surface with a survey meter, wipe with gauze or water and decontaminate. At this time, since the gauze and water used contain radioactive substances, it is necessary to pay attention to the curing and waste management to prevent secondary exposure and damage on facilities. Then, when it is found that the contamination exists inside the smear method, it is necessary to administer a chelating agent according to the radionuclide and to follow the patient's exposure dose over a long term by using a whole body counter. It is equally conceivable to administer a hematopoietic factor such as various cytokines in the sense of recovering damage of the hematopoietic system in a patient exposed to high dose exposure.

High-dose exposure to a large part of the body may cause bone marrow damage and gastrointestinal obstruction. Exposure to a relatively small dose of radiation can lead to failure of bone marrow, while gastrointestinal disturbances can develop as the dose increases. Patients who are exposed to doses of >15 Gy are very difficult to treat because they may suffer from central nervous system disorder and multiple organ failure. However, there are cases in which bone marrow transplantation (BMT) was performed to treat patients exposed to semi-lethal doses of 3-5 Gy. The following is a practical example of response to high-dose patients including treatment for hematopoietic disorders, gastrointestinal disturbance and skin disorders.

In the following cases, bone marrow transplantation was used to treat patients with radiation-related injuries: (1) the former Yugoslav Republic Vinka Research Reactor Accident, (2) a ^{60}Co incident that occurred in China in 1963, (3) the Pittsburgh accident in the United States in 1967, (4) the Chernobyl nuclear accident in 1986, and (5) the Tokai-mura nuclear accident in 1999[35-38]. In the Vinca accident, a total of 6 people were exposed due to an out of control furnace, in 4 of the 6 cases, the exposure was >4 Gy; the patients in the other two cases were estimated to have been exposed to 2-3 Gy. It is reported that the beam quality was mainly γ ray, and 1/3 to 1/4 of it was a neutron beam. The patients with the highest dose (4.4 Gy) developed high fever on the 4th day after exposure; it was suspected that organ disorder developed in the 4 preceding days. Bone marrow transplantation (BMT) was applied to the patients who were exposed to ≥4 Gy. Ohkita summarized the changes following BMT[39], investigated the cases that were exposed to 2 Gy, and noted the numbers of neutrophils and platelets over time. The report stated that at the time, homogeneous BMT was performed with a matching phenotype to the extent that was possible, and that there was a significant increase in the number of neutrophils, platelets, and erythrocytes after transplantation and an improvement in the accompanying symptoms. However, intestinal perforation and bleeding were seen in fatal cases, with

Table 6a. The clinical course and medical interventions for the patient[42)]

Day	*Symptons and Data*	*Intervention*
0	transient loss of consciousness	
	vomiting, diarrhea,	fluid Oxygen[a)]
	fever (38.5°C)	
	feel of exhaustion, hypoxemia erythema, skin swelling WBC[b)] count 25,900/mm^3	
1		SDD[c)]
2	lymphocyte count 0/mm^3	
6, 7	dyspnea with hypoxemia and diffuse patchy shadow in chest x-ray[e)]	mask ventilation (BIPAP)[d)]
	WBC count 0/mm^3	PBSCT[f)]
8	massive gastric discharge	
10	restlessness	intubation and ventilation
26	massive diarrhea	
31	massive exudate from skin	
47	melena	transfusion
50	upper GI bleeding[g)]	
58	cardiopulmonary arrest	resuscitation
	anuria	CHDF[h)]
64	hemophagocytic syndrome	plasma exchange
	GVHD was not obserbed	
82	death	

a) Oxygen: a nasal tube and a Venturi-mask were used. b) WBC: white blood cell. c) SDD: selective digestive decontamination. SDD was continued until his death. d) BIPAP: biphasic airway pressure ventilation. e) It was unclear whether the cause of patchy shadow was radiation pneumonitis or congestive heart failure. f) PBSCT: peripheral blood cell transplantation. g) GI bleeding : gastro-intestinal bleeding. h) CHDF: continuous hemo-dialo filtration. The accident occurred on Day 0 (30 th Sep. 1999).

death occurring at 5 days after BMT.

In 1963, China made a ^{60}Co source available for agriculture and five families experienced continuous gamma ray exposure; BMT was performed in 4 cases (Table 5)[37)]. Cases E and F were exposed to estimated doses of 80 Gy and ≥40 Gy. These patients, whose symptoms included intestinal necrosis, did not respond to BMT. In the case of two patients who survived after BMT, although no graft-versus-host disease (GVHD) was observed, there was no evidence of permanent engraftment.

In the Pittsburgh accident in the United States, extremely low bone marrow formation was seen in patients who were exposed to an estimated dose of 6 Gy. BMT was performed at 8 days after exposure. The patients' blood findings improved at 3 weeks after transplantation. One patient was reported to have been exposed to 59 Gy in both hands and 27 Gy in both feet, and limb amputation was eventually recommended due to bubble formation, refractory ulcer formation, infection and necrosis.

Regarding the Chernobyl accident, BMT was initially considered in 25 cases based on the estimated dose of exposure. The transfusion of hematopoietic cells obtained from a fetal liver was performed for 6 patients with severe burn injuries; however, all of these patients died. Thirteen patients underwent BMT; 6 of these patients died by the 11th day after BMT. The remaining seven patients survived for 19 days or more; 5 of these patients died within 2.5 months, while two survived for ≥ 3 years. Although BMT was not performed in the six remaining cases, they recovered[40)].

In the Tokai-mura nuclear accident in 1999, the Maekawa group, who were in charge of patient treatment, summarized the treatment details of the patients who survived until 83 days after the accident[41)]. These patients were estimated to have been exposed to 16-20 Sv of gamma rays and neutron rays. Although it was very difficult for these patients to recover, the information gained from these cases is considered to be valuable to modern radiation medicine. The disease courses over 83 days are summarized in Table 6ab. Transplantation was performed using hematopoietic stem cells provided by real siblings at 7 and 8 days after the radiation exposure. Ishii *et al.*[41)] noted that hematopoietic factors, including granulocyte-colony-stimulating factor (GCSF), granulocyte/macrophage-colony-stimulating factor (GM-CSF), thrombopoietin (TPO) and erythropoietin (EPO) were administered following BMT, in addition to peripheral blood. A bone marrow biopsy performed 10 days after transplantation showed the proliferation of heterochromatic stem cells; no GVHD response was

Table 6b. Smmary of the treatment given for various symptoms[42].

Disorder	Treatments
gastrointestinal syndrome	glutamin, protonpump inhibitor H2-blockade intravenous hyperalimentation
hematopoietic syndrome	PBSCT transfusion (RBC, platelet, fresh frozen plasma) G-CSF, TPO, EPO anti-GVHD therapy (tacrolimus, steroids)
respiratory symptoms	pentoxyphilline, vitamin E kinetic bed artificial ventilation
skin disorder	epidermal growth factor (EGF) cultured-cell-skin grafts vitamin C
Infection	SDD, real time PCR diagnosis frequent specimen culture anti-bacterial, fungal, viral agents

seen. In the initial stage of treatment selective digestive decontamination (SDD) was performed. Thereafter, hematopoietic stem cell transplantation was performed and various cytokines were administered. Thus, despite the patients' state of extreme immunodeficiency, their condition was not complicated by infection. In addition, it is also noted in the report that extreme skin disorders and gastrointestinal disturbance were observed in this patient. Loss of skin stem cells due to radiation caused severe depletion of body fluids, so a large volume of infusion administration including erythrocytes and platelets continued. In addition, transplantation treatment of cultured skin was also conducted, but it has been reported that beneficial results were not obtained. Similarly in order to alleviate gastrointestinal problems, intravenous administration of the intestinal mucosa proliferative agent, L-glutamine, was initiated early in the course of the treatment. However, a large amount of diarrhea and gastrointestinal bleeding persisted until death, eventually leading to gastrointestinal damage and kidney failure due to high dose exposure and died on day 83 after exposure.

4. Issues to be addressed on radiation emergency medicine

In 1998, the IAEA reported early medical treatment methods for external radiation-injured patient and internal pollution-injured patient at the time of radiation accidents and this report is a large manual concerning the current radiation emergency medicine. This report summarized concretely the symptoms and decontamination method according to the dose of external exposure / internal pollution patients that can occur[30]. In addition, they summarized not only medical cares but also general remarks such as what kinds of radiation accidents / disasters can be considered. Although information on chelating agents and the like corresponding to the nuclides of internal pollution is not described, REAC / TS reports a chelating agent list based on various findings[8].

Radiation disasters range from mistakes in handling simple radiation sources to large-scale nuclear power plant accidents and other things. For that reason, it is relatively easy for medical institutions to accept if a few injured or sick people have occurred. On the other hand, in the case of multiple disasters occurring in a large number of general injured people, such as Fukushima Daiichi Nuclear Accident due to the Earthquake, construction of a system that enables prompt response is required. In particular, it is considered that triage of patients with high dose exposure and contamination is very important. Therefore, it is essential to promptly evaluate the dose at the stage of transportation and initial diagnosis.

5. Summary

In this paper, we summarized actual examples of medical treatment that were applied in radiation accidents and the administration of bone marrow transplants and the use of chelating agents, which represent turning points in radiation medical care.

The emergency medical care that is required at the time of radiation accidents and nuclear disasters is similar to that which is required in cases involving infectious disease. For example, a fundamental understanding of radiation, such as the treatment of patients who have experienced external radiation exposure, has no effect on the surgeon, and precautions only need to be taken when treating contaminated patients. In addition, to establish procedures for decontamination and methods of assessing the radiation dose, it is very important to work with health-related physics experts, especially when treating contaminated patients. Meanwhile, for patients who are exposed to radiation and suffer trauma that requires life-saving treatment, it is natural that life-saving measures be given priority, and it is important to remember to perform decontamination treatments after the stabilization of the patient's vital signs.

Most people do not require medical treatment after nuclear disasters and radiation accidents. However, it is important to maintain the radiation-related medical system, and for hospitals, local governments and radiation specialists to maintain their basic knowledge on radiation and to be aware of specialized history such as transplantation. This author is of the opinion that that medical exposure medicine will progress further through learning about actual historical cases and through the preparation of municipal medical care systems.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 16H02667.

Conflict of Interest Disclosure

The authors declare that they have no conflict of interest.

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