PECULIARITIES OF THE CLINICAL COURSE OF RADIATION SICKNESS AND ORGANIZATIONAL DECISIONS FOR RADIATION ACCIDENTS WITH BETA–GAMMA SOURCES

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Abstract

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The analysis of a number of recent large scale accidents involving beta–gamma sources in the last 40 years, such as those of the Marshall Islands (1954); Windscale, UK (1957); Chernobyl, USSR (1986) and Goiânia, Brazil (1987) demonstrates the predominance and importance of health and social impacts.

1. THE MARSHALL ISLANDS ACCIDENT

This event occurred during a nuclear test in the Marshall Islands in 1954 where moderate radiation damage to the whole body, associated with local radiation injuries, were followed by long term development of thyroid cancer. The social repercussions of such an event were enormous. The understanding of the consequences of beta–gamma exposure in humans is the result of more than 40 years of observation of persons who presented after-effects as a consequence of a nuclear explosion in the Bikini Atoll. For the purposes of the study, the dose ranges in the major cohorts of 1250 inhabitants of the Marshall Islands, 23 Japanese fishermen and 28 American military personnel observed were adjusted by age and ethnic group. The main health effects were the following:

- despite the relatively low accuracy of the estimated doses derived from the external beta–gamma exposure and internal dose assessments for radioiodine isotopes, the dose-dependence on the health effects became clear, both for early reactions (haemopoiesis condition, skin status and signs of thyroid hypofunction) and late consequences (thyroid adenoma and tumours, single cases of kinds of tumours and one case of leukaemia);
- the occurrence of mild signs, including subclinical shifts and clinical manifestations, was very thoroughly analysed from different standpoints and a clear dose-dependence was revealed, as well as an age-dependence of these findings for thyroid effects (revealing that thyroid hypofunction and nodules were regularly increased in the dose range of 15 Gy). Altogether 586 persons had atypical adenomas and the incidence of cancer was found in only 6.2–6.6% of the inhabitants who had received high doses of external radiation (1.72 Gy) and thyroid doses of 3.85–29 Gy. In the control group and in the inhabitants of the atoll with minimum thyroid doses of 0.5–4.5 Gy and whole body doses of 0.14–0.7Gy the cancer incidence was of 1–2% (after 30 years of observation).

Based on the information of the Marshall Islands accident, judgements were made with regard to the peculiarities of thyroid tumour pathogenesis for different dose ranges which proved essential for the analysis of the Chernobyl accident. The ratio between the sexes was similar, both for the control and exposed populations, as well as for the specific ages when different endocrine changes and diseases were revealed.

Information on the fishermen of the "Lucky Dragon" is provided by Kumatori et al. The number of persons exposed reached 23. The length of exposure amounted to five hours (direct fallout exposure) in the course of several days. Patients were admitted to the hospital two weeks after exposure. One fatality was registered six months after exposure. The primary radiation factor was the prolonged external gamma exposure (at a dose rate of 1.2–2.5 Gy/day and an accumulated total dose estimated at 5 Gy) from radioactive aerosol fallout. The principal clinical manifestations during the acute period were typical for the individual dose ranges and included radiation dermatitis, moderate and transient neutropaenia at four to eight weeks after exposure with recovery to baseline standard, moderate anaemia and oligospermia in some cases (between two and eight months) with complete recovery two years after the event.

Specific peculiarities related to the characteristics of irradiation were transient liver hypofunction at week 4, with more steady recovery in all patients but one, who died of hepatic insufficiency at week 20. The aetiology of hepatitis was not purely of radiation origin. Other factors included syphilis and active treatment with hepatotoxic drugs.

Early findings of eye changes were not related to radiation.

Dicentric aberrations of chromosomes were verified in seven persons and other chromosome anomalies were found in all victims. Eighteen patients were followed up for a period of ten years and observations were fragmented. The majority of the victims were in their early thirties at the moment of exposure (one person was 38) and 22 persons had been married at different times (seven persons prior to the accident and the others thereafter). They had had 15 children before the accident and another 29 in the following years. Two couples did not register their children in the first ten years of observation.

The following lessons can be drawn from the Marshall Islands experience:

- the typical ratio of major radiation exposure factors was confirmed;
- the full recovery of the main clinical syndrome of acute radiation sickness matched well with the individual dose ranges and the gamma dose rate;
- the predominant late effects were nodulation and thyroid tumour induction;
- the relatively low exposure to beta irradiation and its limited corporal distribution did not induce significant clinical problems both in the acute and long term periods;
- social and political problems accompanied all stages of the accident and required specific organizational and economic decisions on the part of the United States administration.

2. THE WINDSCALE ACCIDENT

The Windscale accident occurred in October 1957 at the reactor No. 1 of the Windscale complex, located on the northwest coast of England. The reactor was an of an air-cooled graphite moderated type using natural uranium, destined to produce plutonium. Due to a buildup of excess energy undetected by the alarm system, the combustion of graphite occurred on October 8, and continued until October 12, causing the destruction of a substantial portion of the core reactor. The release of radionuclides was evaluated as follows:

20 kCi of ^{131}I, 600 Ci of ^{137}Cs, 80 Ci of ^{89}Sr and 9 Ci of ^{90}Sr[1]. The highest dose rate measured one mile downwind was 4 mR/h[2]. The external gamma dose assessed for a person who remained outdoors one week after the accident was in the range of 30–50 mrem[3]. The maximum thyroid dose in children was estimated to be 16 cGy and the maximum adult dose was assessed to be 9.5 cGy. No death or early morbidity was directly attributed to the accident.

The Windscale accident was the first ever large scale accident with beta–gamma emitters demonstrating the possibility of the involvement of large groups of population in an accident, even though the medical consequences of the accident were of no clinical importance and below the epidemiology detection limit. This accident was the first large scale accident with beta–gamma sources in the atomic industry. Windscale has been the object of study by the national and international scientific community over the past 40 years. The retrospective analysis has confirmed the following conclusions:

- the beta–gamma radiation doses were far below the threshold for mild early health effects;
- the efficiency of sanitary and technical protective measures substantially decreased the exposure derived from radioiodines; this precluded the occurrence of late effects in the thyroid;
- appropriate information to the public prevented unfavourable sociopsychological consequences in the region surrounding the site of the accident.

3. THE ACCIDENT IN GOIANIA

Owing to the dismantling in September 1987 of the shielding of a radiotherapy source in Goiânia (Brazil), some seven large pieces and more than 50 smaller fragments of the source were disassembled or sectioned. The total activity of the source was evaluated to be 50.9 TBq. Contamination of a large area required the evacuation of some 200 persons from 40 houses (with dose rates of ~ 10μSv/h). After decontamination of some of the houses (30 altogether), the residents returned to live in them. The monitoring of the environment was accompanied by a radiological survey of persons suspected of having entered into close contact with the radioactive material (more than 250 individuals). Twenty patients were admitted to hospital, where medical teams detected clinical signs of acute radiation sickness (ARS) and local radiation injuries in 17 of them. Eight patients showed a significant degree of severity of radiation damage (leading to four deaths), three patients presented moderate severity and nine were diagnosed with mild severity. Whole body gamma exposure doses did not exceed 6 Gy according to clinical and laboratory data, a level which did not warrant bone marrow transplantation. Towards the end of the fourth week after the accident, a young child died with expressive radiation aplasia; another three exposed persons died between days 32 and 38. These casualties were caused by severe infection complications. Local radiation injuries were observed in the most exposed patients, affecting 20–25% of the surface of their body; in certain cases, these injuries required specific conservative therapy and surgery [4–10]. The following factors played a key role in the Goiânia accident:

- organizational tasks in the aftermath of the accident became further complicated because of the involvement of a large number of non-prepared members of the public;

[1] 1 Ci = 37 GBq
[2] 1 R = 258 μC/kg
[3] 100 rem = 1 Sv

this had an impact on the early medical assistance and the establishment of a diagnosis for the injured;
- experts encountered significant difficulties in the evaluation of the temporal-spatial dose distribution of external gamma exposure to individuals; this added uncertainty to the establishment of the prognosis and the interpretation of clinical manifestations in the victims;
- external gamma exposure was the primary cause of the radiation effects and led to a combination of whole body exposure with severe local injuries — a mix which caused four fatal casualties;
- the magnitude of the local radiation injuries was determined by the high energy of the gamma exposure from caesium.

The following conclusions can be drawn from the Goiânia accident:

- the frequency and character of radiation injuries were typical;
- the measures taken immediately after the accident — evaluation of contamination, decontamination and hygienic countermeasures — were adequate and effective;
- of the four fatal casualties, three were the result of significant deficiencies in medical management and prophylactic measures (poor aseptic environment, multiple evacuation of patients, inadequate antibacterial therapy, lack of experience of the medical staff);
- the effectiveness of the administration of granulocyte-macrophage colony-stimulating factor beginning in the fourth week of medical therapy could not be demonstrated owing to the spontaneous recovery of haemopoiesis and corresponding influence on the complications of radiation myelodepression;
- international co-operation during the different phases of the response efforts and the information provided was comprehensive;
- a number of significant publications about the accident were published in the United States, the former USSR, France as well as by international bodies (such as the IAEA) on the dynamics of ^{137}Cs in wound scars and the body, the skin condition and general status of acute radiation sickness survivors.

4. THE CHERNOBYL ACCIDENT

The combination of clinical signs varied for the different groups of individuals involved in the accident of April 26, 1986 at the Chernobyl nuclear power plant in the former USSR. These groups are categorized as follows:

Group (A): the direct participants in the accident — personnel working during the shift when the accident took place, during the first shift following the accident and the members of the fire rescue team;

Group (B): the members of the team sent to determine the reasons for the accident and those involved in the first stages of the accident remediation;

Group (C): persons involved in specific accident remediation tasks and those employed for the start-up of Units I, II and III (July 1986–1987), as well as the personnel involved in the control of the damaged core of Unit IV (1987–1995);

Group (D): employees involved in the recovery operations within the 30-km exclusion zone and at the NPP site (1988–1990);

Group (E): population of the 30-km exclusion zone, who were evacuated on 27 April and in May 1986;

Group (F): population living continuously in the zones covered by the five principal administrative regions of Ukraine, Belarus and Russia (between 250 000 and 300 000 individuals);

Group (G): population of the other regions of the former Soviet Union, including the controlled areas of the three republics (nearly 2 million people).

The direct effects of radiation consist primarily of the following:

- One hundred and thirty-four cases of acute radiation disease (ARD) were identified in Group (A). The main radiation factors in this group consisted in external beta–gamma exposure and, in some cases, in radionuclide deposition on skin and through inhalation. The dose range was equal to 0.1–13 Gy. Beta radiation doses were 10–20 times higher, with non-uniform distribution on body surface. The number of people surveyed for thyroid exposure was 237. Thyroid doses were less than 4 Gy for 94% of Group (A) members. Five persons received more than 4 Gy and two individuals received 11–13 Gy in the thyroid. Clinical findings when the disease was manifest were typical of acute radiation syndrome with different degrees of severity, caused by homogeneous gamma exposure.
- Twenty-eight patients died as a result of the combined external beta–gamma exposure.
- Radiation cataracts developed in eight cases (average outbreak period: 38 months for doses higher than 5 Gy).
- Dystrophic changes to the skin were observed in 10 persons.
- Moderate unstable cytopaenia was determined.
- Other consequences (asthenia, neurovegetative dysfunctions) were clearly caused by the long term sociopsychological situation in the aftermath of the accident and by deficiencies in compensation legislation.

Peculiarities in the manifestations in Group (A) during the acute period include:

- the development of a bone marrow syndrome picture compatible with a homogenous exposure;
- the multi-organ character of the disease, which combined damage to bone marrow, skin, intestine and lungs;
- the high level of social and psychological resonance of all events for the victims, related to massive damage and the specific social and psychological situation worldwide at that time;
- increased recovery period before returning to work and incompleteness of social rehabilitation due to deficiencies in compensation legislation; social and psychological orientation of patients themselves; insufficient competence of medical and social authorities responsible for the patients — these three factors often interacting together.

On the basis of the late radiation consequence prognosis, Group (B) needed to be classified as the category with potentially increased risk. This conclusion was further supported by the fact that Group (B) had been exposed to the greatest share of the cumulative collective dose. Moreover, it was also supported by similar findings on the incidence of neoplasm and leukaemia for specific dose range groups (>0.25–0.5 Gy and 1 Gy), obtained through studies of atomic bomb survivors by the Radiation Effects Research Foundation in Japan.

Group (C) was not well categorized, considering all the criteria. We believe that this Group was not properly surveyed. Conventional periodical blood counts can miss a short term decrease of indices, when an extremely inhomogeneous dose distribution over time is present. This leads to a miscorrelation between the relatively high exposure doses assessed biologically (through chromosome aberrations), the physical doses values (obtained on ESR tooth enamel) and the absence of visual clinical signs.

Group (D) can be considered a control group for the radiation factor (dose levels were less than 0.05 Gy for long periods of work related to remediation of the accident consequences). The influence of social and psychological factors on health was most obvious in this Group. A number of recent publications have shed light on this fact, which was highlighted during an international conference held in Kiev in 1995 on the sociopsychological consequences of the Chernobyl accident. The presentations made during this meeting were crucial for the development of rehabilitation measures for 'liquidators'.

Group (E) can be clearly differentiated owing to the evacuation (from Pripyat, Chernobyl and the 30-km zone) and the system of preventive countermeasures adopted. The exposure doses in this Group were less than 0.13 Gy and between 0.3 to 1.0 Gy.

The occurrence of higher thyroid doses was particularly specific to the first subgroup. The maximum traumatic influence of acute stress factors caused by the emergency evacuation and the real difficulties of adaptation to the new environment were obvious. This was also true for the people resettled later out of the 30-km zone (days 7–10 following the event). In the second subgroup, the slightly higher exposure risk can be linked to the development of tumours and pathologies such as adenomas, dysfunctions and cancer in the long term.

According to the 1990 Recommendations of the ICRP, populations of contaminated areas were to be subdivided into relatively small subgroups (272 000 people or so). These populations would possibly receive a slight excess of radiation during their lifetime (accumulated dose above 0.35 Sv), if all their members (close to 2 million people) continued to live in the contaminated territories.

The incomplete implementation of the initial suggestions of the ICRP, intensive migration and the consequent enlargement of areas designated as 'accident regions' render extremely complex the interpretation of health data on the population of some regions and settlements.

Small population samples are very representative for determining living standards and exposure conditions, but they are insufficient to draw conclusions on health deviations. Additionally, these samples are frequently specific to sociodemographic situations. Large regions (oblast, province, economical region) are more representative in terms of demographic data and health status prior to the accident, but are inhomogeneous for the determination of exposure levels and to survey that part of the population which was clearly affected by all the accident factors; in this sense, large regions are difficult to intercompare.

At the present time, only preliminary conclusions on the main health trends are possible. For unusual events (strong increase of thyroid cancer in children, growth of severe forms of chronic diseases or leukaemia), the establishment of an accurate radiation epidemiology survey is necessary. To establish the role of the radiation factor, direct case control and case cohort studies with an accurate selection of comparison groups are essential. Multifactorial analysis of polyaetiological factors can only cause an erroneous appreciation of the importance of radiation in shifts observed in health, as evidenced by the majority of publications on this topic.

We believe that the insufficiently competent attempts of some highly qualified general pathology internists and psychiatrists, who have based their conclusions concerning "the peculiarities of the course of diseases in individuals involved in the Chernobyl accident" on

small in-patient group samples, are very dangerous when they are not supported by control groups or when the control is inadequate to compare data for small samples.

More than a decade after this event, the health status of the people involved in the Chernobyl accident can be summarized as follows:

- because of the extraordinary accident of 26 April 1986, several hundreds of individuals on the site of the nuclear power plant at the time of the accident were acutely and subacutely exposed to external beta–gamma irradiation to the whole body;
- one hundred and thirty-four cases of ARD were identified among these victims, a significant number of whom suffered severe injuries and even death (28 fatal casualties);
- therapeutic results were achieved in the dose range of up to 6 Gy with the aid of modern treatment techniques including supportive and transfusion therapies. Transplantation of allogenic bone marrow did not influence the course of the disease: this can be explained essentially by the compounded character of polyorganic damage in combination with beta radiation injury to the skin;
- residual health effects included skin damage as well as cataracts in some patients; later deaths were not directly related to ARD; the mortality parameters observed were usual for persons of a similar age and sex;
- somatic diseases (chronic processes) existing prior to the accident aggravated the course of ARD.

The Chernobyl accident has been extensively analysed by the international scientific community in the past 10 years. The main conclusions of this analysis are as follows:

- the experience gained in the medical assistance of victims of previous accidents with beta–gamma sources, including accidents which happened in other areas of the world, was important for the care of the Chernobyl victims;
- the data gained on the acute period of a large group of victims (134 patients) and on the victims who died are comprehensive;
- an extraordinary number of people were involved in the event and its aftermath (nuclear professionals, recovery workers and a large number of members of public);
- the accident had an enormous sociopsychological resonance, which widely exceeded the scale of the radiation health effects themselves;
- modern systems of medical diagnosis and treatment were highly effective and a good foundation was at hand for prognosis of the incidence of late effects;
- significant deficiencies were observed in the provision of information to the public and organizational decisions were unduly complicated, a situation which was further aggravated by the specific social situation which prevailed in the country at the time of the accident;
- international co-operation was very important in the evaluation of the consequences of the accident.

5. GENERAL CONCLUSIONS

Accidents with beta–gamma sources are usually of a large scale and involve large groups of population and/or personnel without the knowledge necessary to handle radiation sources.

Of this large number of people (which can include children), only a relatively small part may have received really significant doses: these persons must be quickly sorted out so that they can receive medical and prophylactic attention.

If radiation monitoring is organized properly and timely, evaluation of internal exposure doses will be available. Assessment of external gamma doses, usually obtained by calculation, is more complex, even though they are the primary tool for the development of early deterministic effects. These effects vary from subclinical changes up to rare, but possibly lethal, outcomes.

Provisional readiness of medical facilities and the level of specific qualification of medical staff are determinant for the fate of accident victims receiving doses in the range of average lethality.

Local radiation injuries caused by both the deposition of radionuclides on skin and mucosa, by direct contact with the radiation source, and also by distant beta–gamma exposure are an additionally important clinical problem. Measures for skin protection and adequate decontamination, care and wound management determine the outcome of local radiation injury and combined trauma.

Excepting external and internal exposure from radioiodine, the importance of internal exposure is not significant. Internal exposure did not contribute to the clinical picture of the persons involved in the accident. The inhalation of beta–gamma emitters is of lower importance than the ingestion of radionuclides in drinking water and food. Simple countermeasures for limitation of this intake pathway and the timely administration of stable iodine are of great effectiveness in such cases, and an appropriate administration policy has to be established to this effect.

The following observations can be made concerning beta–gamma exposure:

- external beta–gamma exposure is the primary contributor to clinical effects, moreover, individual dose reconstruction of this component is very difficult;
- internal dose evaluation is possible using major radionuclides of interest (iodine, caesium, ruthenium);
- the specific presence of beta dermatitis a very important component of radiation health effects;
- a significant disproportion exists between the number of people involved in an accident (of the order of 1000 to 10 000 persons), those exposed to doses above the threshold for early effects (of the order of ten to 100 persons) and those with early lethal injuries from radiation exposure (of the order of one to ten persons);
- individual doses can be an accumulation of external beta–gamma doses with multiple types of spatial and temporal distribution which cause peculiarities in early clinical manifestations;
- specific late radiation effects are predominantly in the form of beta dermatitis and damage to the thyroid, with radioiodine exposure to be expected in the case of damage to this organ.

BIBLIOGRAPHY

CONARD, R.A., Late Effects in Marshall Islands Inhabitants to Fallout 28 Years Ago, Radiation Cancerogenesis: Epidemiology and Biological significance, Raven Press, New York (1984) 57–71.

GOODWIN, V.R., Radiological and Medical Consequences of the Windscale Fire in October 1957, Special Report presented at Symp. on "Nuclear Accidents: their Consequences for the Development of Energy in the Future", Paris (1991).

GUSKOVA, A.K., et al., "Medical assistance given to personnel of the Chernobyl nuclear power plant after the 1996 accident", Hematology Review 7 (1995) 27–99.

GUSKOVA, A.K., BAYSOGOLOV, G.D., Radiation Sickness in Man, Meditsina Moscow, English translation, AEC-tr-7401, USAEC, NTIS, Springfield, VA (1973) 1–560.

INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, ICRP, Pergamon, Oxford, New York (1991).

KUMATORI, et al., Report on Medical Survey of Japanese Fishermen Exposed to Fallout Radiation in 1954, National Institute of Radiological Sciences, Chiba (1995).

LITTLEFIELD, L.G., LUSHBAUGH, C.C., "Cytogenetic Dosimetry for Radiation Accidents", Medical Basis for Radiation Accident Preparedness (Ricks, R.C., Fry, S.A., Eds), Elsevier, Amsterdam and New York (1990) 461–478.

OLIVEIRA, A.R., DE SOUZA, P.C., TABAK, D., BRANDAO-MELLO, C.E., VALVERDE, N.J.L., Use of a Hematopoietic Growth Factor (rHu GM-CSF) for Treating Irradiated Persons: The Goiânia Experience, European School of Hematology, Course on Acute and Late Effects of Irradiation on the Hematopoietic System, Paris (June 1989) 30.

OLIVEIRA, C.A., et al., In Vivo Measurements of Cs-137 Long Term Retention in Individuals Contaminated in the Goiânia Accident, in Proc. Int. Conf. on Radiation and Health, Ber Sheva, November 1996.

SELIDOVKIN, G. D., Medical Assistance for the 1987 Brazil Radiation Accident, in Proc. of Int. Conf. "Medical Aspects of the Chernobyl Accident", Kiev (1988) 180–184 (in Russian).

VALVERDE, N.J.L., CORDEIRO, J.M., OLIVEIRA, A.R., BRANDÃO-MELLO, C.E., "The Acute Radiation Syndrome in the Cs-137 Brazilian Accident", Medical Basis for Radiation Accident Preparedness (Ricks, R.C., Fry, S.A., Eds), Elsevier, Amsterdam and New York (1990) 89–104.

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