Annex IV of Technical Volume 5
COMPARATIVE ANALYSIS OF REMEDIATION STRATEGIES AND EXPERIENCE AFTER THE FUKUSHIMA DAIICHI AND CHERNOBYL NUCLEAR ACCIDENTS

Significant environmental contamination by radioactive materials has occurred in some parts of the world due to industrial and military activities, such as nuclear weapon testing, uranium mining and nuclear and radiological accidents. The most well-known sites where large scale remediation has been implemented include: the nuclear test sites in the Bikini and Enewetak Atolls (USA) and Maralinga (Australia); areas contaminated by nuclear accidents at Kyshtym, Chernobyl (former Soviet Union) and Fukushima (Japan); Goiânia (Brazil), following the loss of a radioactive source; and Palomares (Spain), after the B-52 bomber accident. These sites differed in terms of contamination levels, the main dose forming radionuclides and environmental characteristics. Consequently, different remediation criteria and strategies were used to protect the affected population and remediate the environment.

IV–1. RADIOLOGICAL CONSEQUENCES OF THE FUKUSHIMA DAIICHI AND CHERNOBYL NUCLEAR ACCIDENTS

The accident at the Chernobyl NPP has been compared with the Fukushima Daiichi NPP accident with respect to their characteristics and the scale of the deposition which occurred. Both the Chernobyl and the Fukushima Daiichi releases resulted in contamination of the environment, including residential areas, agricultural lands, forests and bodies of water. The total deposition of radiocaesium on the terrestrial environment, which largely determine the potential radiation doses to people in the existing situation and are relevant to environmental remediation, were lower by approximately an order of magnitude for the Fukushima Daiichi accident compared with the Chernobyl accident (see Table IV–1).

TABLE IV–1. COMPARISON OF RADIOCAESIUM DEPOSITION AND DOSE TO THE POPULATION DUE TO THE CHERNOBYL AND FUKUSHIMA ACCIDENTS [IV–1, IV–2]

Accident	Total release of ^{134}Cs and ^{137}Cs (PBq)	Total ground deposition of ^{134}Cs and ^{137}Cs (PBq)	Area with ^{137}Cs deposition above 100 kBq/m^2 (km^2)	Maximum first year settlement — average effective dose (mSv)	Projected collective effective dose (person-Sv)
Chernobyl, 1986	130	100	56 000	~ 90	430 000[a]
Fukushima, 2011	~18	4–6	~ 3000	~ 10	~ 50 000
Ratio Chernobyl/Fukushima, dimensionless	~ 7	~ 20	~ 20	~ 9	~ 9

[a] About 260 000 person-Sv without the contribution of the thyroid dose [IV–3].

For both accidents, the release of radionuclides into the environment consisted of a mixture of airborne fission and activation products, including relatively short lived ^{131}I, which dominated in the early period, and longer lived ^{134}Cs and ^{137}Cs that have the potential to give rise to both external and internal exposure of the public in the existing exposure situation.

There are also distinct differences between the two accidents. The pattern of the spatial distribution of radionuclide deposition in the case of the Fukushima Daiichi accident resulted in a lower contamination of terrestrial environments compared with the Chernobyl accident and reduced the need for remediation of the affected areas. In addition, there are substantial differences in the characteristics of the two areas contaminated by the accidents in terms of population density and its distribution in relation to the siting of the NPPs, landscapes, soil types and intensity of agricultural production.

The areas most affected by the Chernobyl accident are located in Europe, with a moderate population density, constituting mainly flat terrain covered either by forests or agricultural land. Those most affected by the Fukushima Daiichi accident are located at the Pacific coast of Japan and have a high population density, with complex topography mainly covered by forest. The average ^{137}Cs deposition density outside of the 30 km zone of the Chernobyl NPP reached 3.0–6.0 MBq/m^2 in some areas, while in areas affected by the Fukushima Daiichi accident, it was lower — up to 2.2 MBq/m^2 in the evacuated settlements and up to 0.2 MBq/m^2 in areas that were not evacuated. Human habits and utilization of the environment (e.g. food consumption rates, consumption of local foods, time spent indoors/outdoors and construction characteristics of houses) also differ.

These differences resulted in significant variation in the major exposure pathways for the two accidents and the extent to which they contributed to the exposure of the population. Indeed, identification of the priorities in remediation planning depends on the site specific features of the contamination, highlighting the need for adequate analysis of the exposure pathway.

The environmental characteristics of the areas that were most affected by each accident, and the food distribution systems and consumption habits of the local population, were quite different. This resulted in large differences in the significance of the major exposure pathways. In the areas most affected by the Chernobyl accident, the external exposure to the residents from ^{134}Cs and ^{137}Cs distributed in the environment was, and still is, accompanied by comparable doses from internal exposure from the ingestion of foods of both agricultural and semi-natural origin (e.g., wild foods, including forest mushrooms, wild plants and game). Management measures to decrease internal doses to the population received higher priority and are still implemented in some areas affected by the Chernobyl accident. This is partly a consequence of the fact that agricultural remedial measures are more readily implemented with a relatively low cost per unit of averted dose compared with decontamination of residential areas.

In contrast, internal exposure pathways, including consumption of wild food products, were of much lower importance in areas most affected by the Fukushima Daiichi accident. Internal doses were, and are, low because of the low availability of radionuclides in most soil types, the season when the accident occurred, low milk consumption, low consumption rates of local wild foods and restrictions on the use of contaminated lands. Thus, external exposure pathways dominated in areas affected by the Fukushima Daiichi accident.

IV–2. REMEDIATION STRATEGIES FOLLOWING THE FUKUSHIMA DAIICHI AND CHERNOBYL NUCLEAR ACCIDENTS

The significance of exposure pathways and doses can be greatly affected by key factors such as environmental characteristics governing mobility of radionuclides in the environment, living habits of the local population, food distribution mechanisms and dietary habits. There may also be other social and economic differences and perceptions of radiation risks. Thus, experience gained from the Chernobyl and Kyshtym accidents may be useful for informing policy but are not directly applicable to the Fukushima Daiichi accident.

When sufficient resources for remediation activities are available, the justification of remediation may be based more on factors aimed at addressing social concerns among the population, as happened in Japan, than on the weighting of averted dose versus remediation costs, as happened after the Chernobyl accident. The radiological criteria for environmental remediation applied in Japan are generally much lower than those applied in the former Soviet Union countries immediately after the

Chernobyl accident. When external exposure of the public dominates the public exposure, the most relevant remediation measure is the decontamination of residential areas. When ingestion of contaminated foods dominates, or its contribution to dose of the public is comparable to external exposure, agricultural countermeasures may be the preferred remediation option, because they are less expensive and less disruptive to the way of life of the public.

The long-term remediation policies developed for the areas affected by the Fukushima Daiichi accident are tailored to the relevant exposure pathways. Following the accident, the external exposure pathway dominated the dose to the population, and the contribution of internal dose in the areas affected was low and controlled by the widespread and comprehensive food restrictions, as it was for the Chernobyl accident. Remediation strategies in areas affected by the Fukushima Daiichi accident were largely focused on external exposure, while remedial measures directed at a decrease in internal exposure (mainly aimed at the decrease of ^{137}Cs concentration in dairy products) were key elements of remediation in areas affected by the Chernobyl accident. Therefore, in Fukushima and neighbouring prefectures of Japan, the remediation efforts are mostly focused on reduction of ambient dose rates by decontamination of soil and paved surfaces in residential areas.

IV–3. EXPERIENCE OF REMEDIATION FOLLOWING THE FUKUSHIMA DAIICHI AND CHERNOBYL NUCLEAR ACCIDENTS

After the Chernobyl accident, 115 000 people were evacuated from the most affected areas, and their settlements were abandoned without any plans for recovery. After the Fukushima Daiichi accident, a similar number of people were evacuated, and the Government of Japan is remediating the affected towns and offer the evacuated people the opportunity to return.

After the Chernobyl accident, large-scale decontamination campaigns were conducted from 1986 to 1989 in contaminated settlements that partially removed deposited radionuclides. At that time, the radiological criterion applied to these areas (ambient dose rate of 1.4 µSv/h) was less restrictive than that currently used in Japan to define the ICSA (0.23 µSv/h). In total, decontamination was implemented at several hundred settlements, including big cities such as Kiev, with a population of several million people. Although the dose rate reduction factor was between 2 and 5 for different settlement locations [IV–1, IV–4], the reduction of lifetime individual external dose was assessed to be about 10–30% [IV–1].

In Table IV–2, the effectiveness of various agricultural remediation measures for land contaminated after the Chernobyl and Fukushima Daiichi accidents is compared. However, the number of data underpinning the former is much greater than the latter due to the difference in the size of affected area and the length of time since remediation commenced. Furthermore, the reduction factors depend on soil and plant type, which differ between the two affected areas. Despite the expected factors which may impact on effectiveness, the preliminary comparison shows a similar range in reduction for the various remediation measures.

TABLE IV–2. PRELIMINARY COMPARISON OF REDUCTION FACTORS FOR RADIOCAESIUM TRANSFER TO AGRICULTURAL PRODUCTS DERIVED AFTER THE CHERNOBYL AND FUKUSHIMA DAIICHI ACCIDENTS [IV–1, IV–5 TO IV–8]

Remedial option	Chernobyl accident	Fukushima Daiichi accident
Top soil removal[a]	—	4.0–5.0
Normal ploughing	2.5–3.0	1.5–2.5
Deep ploughing[b,c]	3.0–8.0	2–3
Reverse tilling of soils	10–16	—
Potassium application	1.5–3.0	1.5–3.0
Application of organic fertilizers	1.5–2.0	1.3–2.5
Application of sorbents	1.3–2.0	1.5–1.8
Field renovation[d]	—	—
Radical renovation	2.0–9.0	8.0
Simple renovation	2.0–3.0	4.0

[a] Not applied to farmlands in areas affected by the Chernobyl accident.
[b] Deep ploughing to replace topsoil up to a depth of 5 cm with soils taken from a depth of 50 cm.
[c] Reduction of the external dose rate at the height of 1 m.
[d] Renovation means a combination of ploughing, reseeding, fertilization and drainage, if needed.

Along with decontamination of residential areas, significant efforts following the Chernobyl accident were directed at the reduction of long term internal dose by application of systematic soil-, plant- and animal-based agricultural remediation measures. Application of these measures started in 1986 and continued over many years at a decreasing scale because of the natural reduction of radionuclide content in foods. Remediation is still ongoing in some areas where there is still high radiocaesium transfer from soil to vegetation. In Japan, the current application of agricultural remediation is less prevalent than in the areas affected by the Chernobyl accident.

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