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Comparison of occupational radiation protection following the Chernobyl and Fukushima accidents

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Contents

Considered approach for comparison

- Comparison of two major accidents separated by a quarter of century is aimed to clarify similar crucial issues of emergency response and occupational safety in those accidents rather than to judge when applied occupation protection was better or worse.
- Emergency response is multi-dimension process which here divided into three temporal stages as follows: reflex, early and transmit to recovery.
- Only several factors of occupational radiation protection are compared, i.e. on-site radiation situation, emergency regulation, emergency management, applied recovery strategy and individual dose monitoring.

Source term

Chernobyl NPP

Total release more than 12,000 PBq, including 6,500 PBq inert gases, 1,800 PBq ^{131}I, 85 PBq ^{137}Cs.

Radioactive release continued 10 days due to following reasons:

- \- explosions,
- \- graphite burning (6 days) and
- \- fuel overheating as a result of radioactive decay (4 days).

Spatial balance of released nuclear fuel was as follows: 9% - NPP site, 44% - 80-km zone, 44% - rest of the USSR, 3% - outside of the USSR.

Fukushima Daiichi

Organization	IBRAE Russia	NISA Japan	NSC Japan	IRSN France
Considered time period	15.03	12.03–12.04	12.03–12.04	12.03–22.03
^{131}I (PBq)	200	130	150	90
^{137}Cs (PBq)	30	6	12	10
Total (PBq)	1,400	370	630	490

100-500 PBq of ^{131}I and 6-20 PBq of ^{137} Cs (UNSCEAR)

Based on measurements in November 2011, TEPCO has declared that significant gaseous releases have stopped and that the temperatures in all three reactors are <75°C. Perhaps, that time may be identified as the end of emergency exposure situation

On-site radiation situation

Chernobyl NPP

- The NPP site area (around 1 km^2) mainly was contaminated by dispersed nuclear fuel immediately after explosions.
- ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{141}Ce, ^{144}Ce made the main contributions (above 10% each) to total contamination on-site during 100 days
- ^{134}Cs and ^{137}Cs gave only (1 -3) % at that time
- **Average kerma rate**:
- 400 mGy h^{-1} in the first day,
- 200 mGy h^{-1} ten days later and
- 40 mGy h^{-1} one hundred days later

Fukushima Daiichi

- Primary on-site contamination was resulted mainly from deposition of ^{131}I and ^{137}Cs, ^{134}Cs one -few days after tsunami.
- **Average kerma rate** is estimated around (0.1-0.2) mGy h^{-1} during first five days after the accident. Transient sudden changes in exposure rates were observed at the moments of hydrogen explosions and opening out vents of the containment vessel
- Secondary on-site contamination was occurred as a result of long term injection into the reactors and SFPs a large amount of water

Comparison - Source term & On-site radiation situation

1. **Well-known comparable assessment of Chernobyl and Fukushima accidents is based on comparison of ^{131}I and ^{137}Cs releases. Those releases for Fukushima Daiichi were approximately one-tenth of Chernobyl amounts.**
2. **Both radionuclide composition and dynamics of releases were differed. Violent radionuclides of ^{131}I and ^{137}Cs gave the main part of released activity after Fukushima accident. The Chernobyl NPP site area (around 1 km^2) mainly was contaminated by dispersed nuclear fuel immediately after explosions. ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{141}Ce, ^{144}Ce made the main contributions (above 10% each) to total contamination on-site during 100 days. ^{134}Cs and ^{137}Cs gave only (1 -3) % at that time.**
3. **On-site radiation situation at the Chernobyl NPP was three orders of magnitude more severe than at the Fukushima Daiichi. Exposure rates in a range of hundreds – thousands of mGy h^{-1} at working places created real threat of acute radiation injury induction for first responders at the Chernobyl NPP.**
4. **Exposure rate levels outside of Unit 4 building (working places of firemen) were higher that inside premises of Unit 4. Vice versa the relationships were observed in the aftermath of the Fukushima accident.**

Undertaken actions

Urgent (reflex) phase: fire control, saving life, restore power and water supply of cooling system, lube swap, examination of equipment, radiation reconnaissance, vent operations etc

Early phase: decontamination on-site area, machinery shop, roof, covering the reactor with materials by helicopters, building of concrete slab (30mx30mx2.5m) with cooling system under reactor, supplying liquid nitrogen into under-reactor premises; water pumping out bubbler-basin, dust catching, radiation monitoring

Recovery phase: Units 1 - 3 startup, on-site decontamination, construction of the Shelter (named **Ukrytie**) etc

Urgent (reflex) phase: restoration of emergency electrical power, core cooling and decreasing of containment pressure below design level. Unfortunately undertaken attempts to restore control under reactors of Units 1-3 and spent-fuel pool (SFP) of Unit 4 from 11 to 15 March have been unsuccessful.

Early phase: core cooling**,** on-site decontamination near destroyed buildings and waste management

Recovery phase: cleanup and management of the water that was injected into the reactors and SFP

Cohorts of EWs and ROWs

Chernobyl NPP

Cohort	Number, thousands	Dates
First responders	1	April, 26
Early responders	35	27.04 –20.05
Recovery operation workers (ROWs)	89	21.05 – 30.11
Total	**125**	26.04 - 30.07

Typical operating schedule in 1986

Subcohort	Type	Duration
NPP personnel	Shift works	15w+15rest
Early civil EWs	Single mission	Till15 days
Early military staff	Single mission	3min -15days
RQWs-**Ukrytie**	Single shift work	2 months
ROWs military	Single/rptdmission	3 or 6 months

Fukushima Daiichi

- Personnel of the NPP were evacuated in 15th March except of 50 EWs who concentrated their efforts on problems of Units 5 and 6.
- Total number of early EWs was about 4 thousand, including 2,300 of contractors in March 2011. Self-Defense Force personnel and others were engaged in these works.
- Average number of recovery workers from April to November 2011 was around 3,500 - 2,500 in a month. Part of TEPCO employee was reduced from 42% in March to 17% in April and 10% in May 2011.
- Total number of EWs and ROWs was **25,000**

Comparison - Undertaken actions & cohorts of EWs and ROWs

1. **Undertaken emergency response and applied recovery strategies were completely different in Chernobyl and Fikushima-1 cases.**
2. **General approach was "the end justifies the means" from reflex stage to recovery phase of Chernobyl accident. More careful approach was realized after the Fukushima accident. Key issue of emergency response is to reach a balance of Courage vs Safety.**
3. **Both radiation workers and common people who had no radiation experience were brought into action on-site during the aftermath of the accidents. This circumstance led to economic, social and psychological consequences, which connected with national features. Special legislation concerning social protection of EWs and ROWs were adopted after the Chernobyl accident.**
4. **Cohorts of EWs and ROWs were independent groups and met certain tasks within their own management and dose control.**

Emergency regulation

Chernobyl NPP

Before the accident basic regulatory requirements on emergency response included the following:

- overexposure of EWs above dose limits may be justified for the purpose of saving life, averting a large-scale public overexposure, and preventing the development of catastrophic conditions;
- elevated planned exposure (EPE) shall be below double dose limit for single undertaken action and fivefold over dose limit for all emergency period of time (i.e. 100 and 250 mSv);
- written permission of administration and personal consent of EW to EPE is required.

After the accident "temporary dose limit of external exposure - TPL" of 250 mSv was adopted instead of EPE. However TPL for military participants was 500 mSv (more precisely 50 Roentgen) till 21 May 1986.

Many derived TPL on radioactive contamination had be adopted both regulatory and other governmental bodies for zoning, sanitary check points etc

Fukushima Daiichi

Before the accident the emergency dose limit (EDL) was set at 100 mSv year^{-1}

On March 14, the Ministry of Health, Labour and Welfare raised the allowable EDL to 250 mSv (sum of external and internal exposure). Comprehensive organizational scheme of the disaster response was established. Application of EPL both for EWs and ROWs was considered

From 1 November 2011 until 30 April 2012 EDL of 250 mSv was applied only for the radiation workers who possess highly specialized knowledge and experience that are essential for maintaining functions for cooling reactor systems and others and cannot be easily replaced.

Comparison - Emergency regulation

1. General approach to a problem of radiation protection for rescuers and EWs by the time of the Chernobyl accident and currently not undergoes a change. However detailed requirements on emergency preparedness are developed and introduced for nuclear facilities.
2. The use of terms “temporary dose limit” and “emergency dose limit” differ from guidance values recommended by the IAEA.
3. Formally, large-scale application of TPL and EPL both for EWs and ROWs was disagreed with IBSS (only for rescuers and EWs involved in specific tasks 4.15 and Table IV-2), but was necessary for realization of adopted recovery strategy

Key issues of emergency management

Reflex phase

1. *To clarify situation and arising threats*
2. *To introduce emergency plan into action*
3. *To limit the number of involved EWs*
4. *To measure exposure rate and surface radioactivity contamination*: for emergency zoning
5. *To prevent radionuclide carrying over*

Early phase

1. *To identify list of actions, available means and man power*
2. *To use graded approach for operational planning*
3. *To estimate resources for planned measures*
4. *To apply system of emergency management in proper manner*

Transition to recovery phase

1. *Strategy planning based on holistic approach*
2. *Stakeholder involvement*
3. *Transition from emergency management to recovery management*
4. *Implementation of analytic ALARA procedure*
5. *Design and application of optimized technologies and protective means*

Comparison - Management

1. Large uncertainties are inherent attributes immediately after of a severe accident.
2. Important issues in reflex and early phases are risks of decision making. Range of alternative decision options was very wide: to do any available actions or to do nothing except actions directed on reducing uncertainties. Simple and robust decisions are optimal in a case of great total uncertainty.
3. Change of routine managers to the emergency managers and hierarchy of decision making from facility to national level was unavoidable and sometimes useful.
4. Recovery strategy (the USSR) and road map (Japan) have resulted in highest political considerations and partially were placed outside pure radiological scope. Analyzed actions and strategies demonstrate relevance of this statement.

Dose monitoring

Chernobyl NPP

- **Reflex phase - 26 April**

  Individual dose monitoring has not been carried out . Only film badges (the upper level of registration of 20 mGy) were present

  Actual external doses for witnesses were in the range of 40- 15,000 mGy. Minimal dose of 40 mGy was received during one trip to the NPP

- **Early phase**

Level	Description	Percent
High	Only instrumental data. Less than 10% of gaps and mistaken records	13%
Satisfied	Mixture of high and low quality levels	4%
Low	Both instrumental and calculated techniques. Incomplete or/and doubtful records	58%
Zero	Absence of personal dose monitoring procedure	25%

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- **Urgent phase**: Due to tsunami the exposure control systems became unavailable, a significant amount of manual work emerged, which delayed regular work in the radiation control department of the power plant
- **Early phase**: many personal alarm dosimeters (PAD) were unavailable. Due to the shortages of PADs, they were distributed to some of the workers at a rate of only one per work group during the period of 15-30 March

Individual and collective doses

Chernobyl NPP

Subcohort	Individual dose, mSv		Collective dose, person Sv
	Average	Median	
ARS patients	3400mGy	2400mGy	
Witnesses	550	450	550
Early civil EWs	115	56	2,500
NPP personnel	87	48	200
RQWs-Ukrytie	82	50	3.280
EWs+ROWs military	110	95	6,820
Total	**105**		**13,450**

Fukushima Daiichi

- **The maximum external dose recorded is 199 mSv, and the maximum internal dose that has been calculated is 590 mSv. The maximum total dose recorded to one worker was 670 mSv, and six workers have received doses in excess of the EDL established**

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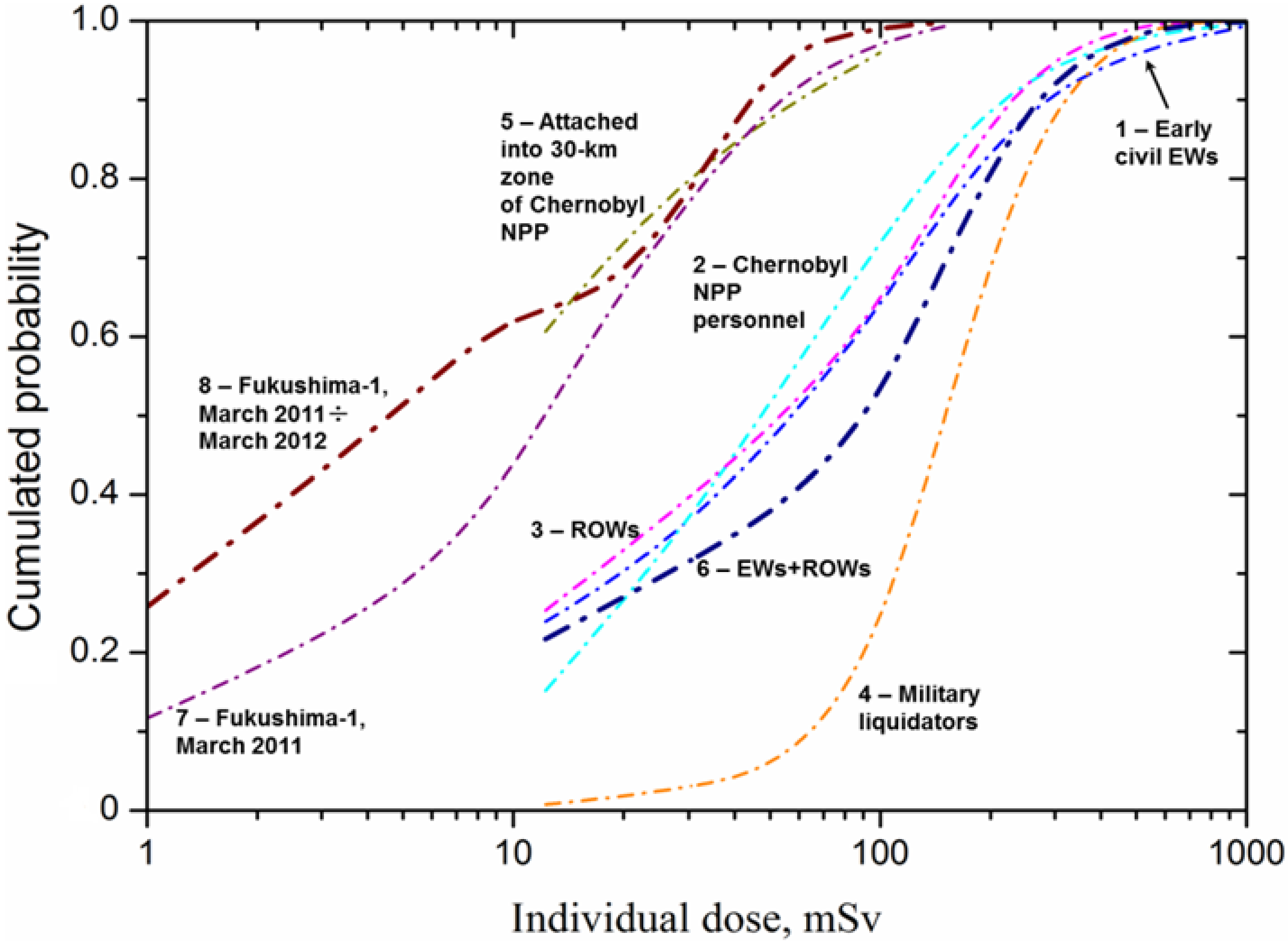
- **Although 408 workers have received doses above the normal annual limit of 50 mSv, the average dose for emergency workers is still relatively low and has decreased steadily during the months following the accident.**

- **Average individual dose is estimated as 22.4 mSv in March 2011, 12.4 mSv during the first year and annual collective dose was 263 person-Sv.**

Comparison - Dose distributions



Conclusions

- **Transition from planned exposure situation to emergency exposure situation in a case of major accident continues to be the crucial issue of occupational radiation protection.**
- **Analysis of applied actions in Chernobyl and Fukusima-1 accidents showed two alternative outcomes. The first one is to achieve results through the big man-power and large values of individual and collective doses of EWs. The second one is to provide radiation safety of EWs but not to prevent threats for public and environment.**
- **Interaction of utilitarian and egalitarian ethics should be considered in emergency management as precisely as reasonably achievable.**.