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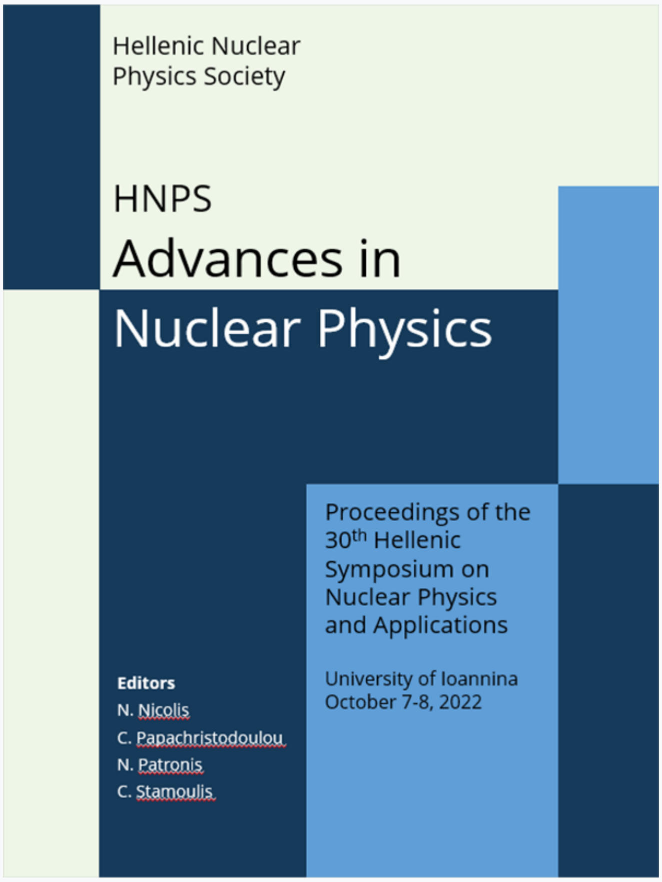

Chernobyl and Fukushima nuclear accidents: similarities and differences

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Chernobyl and Fukushima nuclear accidents: similarities and differences

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Abstract During the almost seven decades of use of nuclear fission for electric energy production, two major nuclear accidents took place, i.e., the 1986 Chernobyl accident and the 2011 Fukushima one. They were caused by reactor power-surge and loss-of-coolant, respectively. Both accidents occurred during hot power reactor shutdown and had identical root causes, i.e., poor safety culture and safety management in nuclear industry and state authorities. A brief comparison of the facility and the accident characteristics, disaster response methods, as well as of the health, social, economic, and political adverse effects is attempted. The radiological impact of the Chernobyl accident was much higher than that of the Fukushima one; however, a similar statement may not hold for the other types of impact.

Keywords: nuclear power, nuclear accidents, Chernobyl, Fukushima, socio-economic impacts

INTRODUCTION

Human history has witnessed several major disasters of either human or natural origin that required mobilization of considerable human and financial resources. Large scale-nuclear accidents are very rare events that affect profoundly individuals, society and environment over long-time. According to the International Nuclear Event Scale rating, a level-7 (or major) nuclear event results in an environmental release corresponding to a quantity of activity radiologically equivalent to a release to the atmosphere of at least 50 PBq of ^{131}I [1]. A level-6 (or serious) accident results in environmental release corresponding to a quantity of activity radiologically equivalent to a release to the atmosphere between 5 to 50 PBq of ^{131}I. Such large releases may correspond to a large fraction of core inventory of a medium or large nuclear power reactor, involving a mixture of short- and long-lived radionuclides and may induce acute and delayed health effects in humans over a wide area. In case of atmospheric releases of noble gases, ^{90}Sr, ^{134}Cs, and ^{137}Cs, the ^{131}I equivalent activity is calculated by multiplying the corresponding activities by a factor of almost 0, 20, 17, and 40, respectively.

During the 68 years-long use of nuclear fission for production of electric energy with nearly zero gaseous emissions to be distributed around- the-clock to many customers, only two accidents were rated at level-7 and none at level-6 due to the lifecycle phases. The level-7 accidents occurred 25 years apart in spring time during hot power reactor shutdown and were initiated by a huge reactor power surge and a major loss of core coolant, respectively. ^{137}Cs was the most important released radionuclide in both.

ACCIDENTS AND THEIR IMPACT

1986 Chernobyl accident: An unauthorized low-power engineering experimental test was carried out at No4 water-graphite unit of the Chernobyl nuclear power plant during a preplanned reactor shut-down for maintenance, just two years after it began its commercial operation (Tables 1, 2). A number of alterations in the planned experimental conditions were decided and carried out during the test that was never brought to its end. Many prescribed operating limits were violated bringing the reactor to an instable state having almost all its safety systems switched off for the shake of the test. As carried out, the test resulted in a huge reactor power surge going to local supercriticality and explosive destruction of the many fuel channels. The overpressured steam and gases destroyed all physical barriers, allowing

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oxygen inrush, leading to extensive graphite fires for ten days and large radioactive releases to the environment (Table 2), despite the heroism of the first responders. During the first post-accident 100 days, the life of 32 first responders were claimed (28 due to acute radiation syndrome, 2 due to the initial explosions or/and fire, and 2 due to a helicopter crash).

Table 1. *Facility characteristics*

nuclear power plant	Chernobyl, Ukraine	Fukushima-1, Japan
plant location	inland site	costal site
operated by	state	private company
plant nominal power (GWe)	4.0	4.5
total number of reactors	4	6
reactors involved	1 x RBMK-1000	1 x BWR-3, 3 x BWR-4

Table 2. *Accident*

nuclear power plant	Chernobyl, Ukraine	Fukushima-1, Japan
time of accident	April 26, 1986	March 11, 2011
reactors at production mode at the time of the accident	4	3
destroyed reactors (MWe)	No4 (1000)	No1 (460), No2 (784), No3 (784)
years in commercial operation	2	40, 37, 35
destroyed reactor buildings	No4	No1, No3, No4
amount of nuclear fuel at the heavily damaged units (tn)	210	854 (included four spent fuel pools)
type of accident	power surge led to supercriticality, core melt, explosions, fires	extended loss of core coolant led to partial core melts, hydrogen accumulation, explosions, fires
triggered mainly by	series of human errors, violations of operation procedures, limitations in design	a huge tsunami following a mega-earthquake hit the aged and inadequately upgraded plant leading to extensive electrical black-out, limitations in design and management
root causes	poor safety culture and safety management	poor safety culture and safety management, collusion between authorities and industry [5]
time of explosions	during the first day	during the second, fourth and fifth day
time to respond and stop it	practically zero	one to four days
first day radioactive releases	large	very limited
^{131}I released/inventory (PBq)	~1.760/~2.950	100-500/~6.000
^{134}Cs released/inventory	~47/ ~140	6-20/ ~770
^{137}Cs released/inventory	~85/ ~280	6-20/ ~770
^{134}Cs, ^{137}Cs ground deposition	~93%	~20%
land areas contaminated with >100 / 1480 kBq/m^2 ^{137}Cs (km^2)	56.000/3.100	3.000/ 272
main routes of human exposure	external, ingestion	external
global life time collective dose (man Sv)	~500.000 [3]	~40.000 [3]

2011 Fukushima accident: The 2011 accident at Fukushima-1 (or Daiichi) nuclear power plant in Japan was triggered by a very severe, but anticipated, natural disaster [2]. At the time, the boiling water reactors No1, No2, No3 that were connected to the electric grid were automatically shut-down due to high ground accelerations (units No4, No5 and No6 were temporarily out for service or testing). Units No1, No2, No3 were in commercial use since 35 to 40 years (Tables 1, 2) and had not been adequately upgraded by the owner and operator (TEPCO), as well as the entire aged nuclear power plant. Lack of adequate electric power supply for the removal of the residual heat from the reactor cores led to overheat and partial core melt. Explosions breached the containment buildings of No1, No3 and No4 units. Large amounts of radioactive fission products were released during the 20 days following the mega-earthquake and the tsunami (Table 2). Most of the released iodine and cesium activity was either deposited over the Pacific Ocean after dispersion in air or was directly released to the sea from the power plant.

Comparisons: The root causes of both level-7 accidents are considered to be identical, i.e., poor safety culture and safety management in both the industry and state authorities. Preoccupation of equipment safety in nuclear industry downplayed the importance of the human element. The total released activity from the Fukushima-1 plant was about twice that from the Chernobyl one· However, the releases substantially differed in radionuclide composition, physical form and release height [3]. For example, the released activities of the main dose contributors to the public, ^{131}I, ^{134}Cs, and ^{137}Cs due to the 1986 accident were about 15, 2.5 and 5 higher than those due to the 2011 one, respectively (Table 2). The countermeasures taken by the Japanese authorities to reduce the population radiation exposure were more stringent that those taken by the USSR ones.

The combination of the meteorological conditions, the geomorphology and the already stated factors led to a lower collective dose to the exposed populations due to the Fukushima accident, thus its radiological impact was smaller than that due to 1986 accident [Table 3]. The number of the caused prompt losses of human life, radiological on not, was 2 and 32, respectively, all first responders. The accidents also caused various non-fatal mental and somatic health effects (e.g. post-traumatic syndrome and radiation induced thyroid cancers treatable, if early diagnosed), as well as a variety of psychologic, social, economic and political adverse effects (there are limitations in their quantification). Besides the heavily occupationally exposed individuals, those who suffered the most were the inhabitants of the heavily contaminated areas, who had to be evacuated and displaced, temporary or permanently. Presumably the induced psychosomatic syndromes constituted the most severe health impact to them.

DISCUSSION- CONCLUSIONS

Since these accidents occurred under very different political, social, legal and financial framework, different disaster response methodologies were used. Their long-term consequences are broad and far-reaching. They caused human life losses, physical injuries, diseases, psychological (mainly due repeated changes in the social and living environment, disruption life prospects and social/economic insecurity), social and financial side-effects, as well as a variety of environmental adverse effects.

In general, full recovery from such large disasters, if possible, is difficult, expensive, and long-lasting. Strong health concerns of the general public were coupled with loss of control in daily life and confidence in the authorities and feelings of helpless and abandonment. Those in-charge often failed to address appropriately questions, such as: “should I continue to live in this contaminated territory, or should I leave?” and “should I return to my home, when and under what living conditions?”.

The radioactive clouds formed after both accidents were coupled with clouds of panic and fear, often obliterating rational thinking, despite the fact that the released radiologically equivalent activities due both accidents were much lower than those released by the atmospheric nuclear weapon testing in 1961 and 1962 of a total of almost 260 Mt yield, under Cold War muting conditions. In particular, the suffering caused by some countermeasures taken by the Japanese authorities in the name of health protection (often under provoked public pressure) were unjustifiable on the grounds of the anticipated radiological health benefit [4]. Public opinion in the country was created and shaped in large by the private-run media. Most of them, enhanced the potential of radiation adverse effects to the population, promoting politically driven misconceptions about them.

Table 3. *Response and impact*

nuclear power plant	Chernobyl, Ukraine	Fukushima-1, Japan
on- /off-site main response actor	USSR/USSR	TEPCO / Japan
initial on-site accident response	massive	limitations in man power and means
crisis management	massive, centralized	ineffective mainly due to inappropriate preplanning in case of multiple failures
disaster evacuation initiated	next day / organized	same day / chaotic
total number of long-term displaced persons	~350.000	~120.000
public compliance with the instructions from the authorities	medium (limited in some rural areas)	high
communication to the public	delayed	immediate, but confusing
initial national media coverage	restricted	extended, but confusing
initial foreign mass media	exaggerated the risks	downplayed the risks
accident medical response	appropriate	inappropriate under natural disaster conditions (e.g., about 2.000 disaster-related deaths [4])
accident-caused somatic impact	substantial	very limited
accident-related mental and psychological adverse effects	limited with regards to the exposure levels	extensive with regards to the exposure levels
guessed monetary costs ($ USA)	~10^{11}	~ 10^{11}
total population (10^6)	282 (1986)	128 (2011)
national gross domestic product per capita ($ USA)	~8.000 (1986)	~38.000 (2011)
type of economy and trends	communistic declining at the time	capitalistic quite stable at the time
nuclear energy production	continued	heavily suppressed – increases in power cost
judicial response / decision reached	five sentenced to 2 to 10 y in labor-camp / one-year post-accident	indicted TEPCO executives were acquitted / eight years post-accident
public confidence	loss of trust in the political system	loss of trust in the decision-makers and experts
political impact	cofounding factor to USSR collapse and the change of the political system	critical role in the return in power of the conservative Liberal Democratic Party

During 2021, 437 civil power reactors provided about 10% of the total global electric energy distributed to customers, increasing the cumulated experience to about 19.000 reactor-years. Based on the accumulated experience on the various lifecycle phases of electric energy production, fission is considered as one of the less dangerous, currently viable, reliable sources for electric energy production per energy unit to the power grid. The two level-7 and the two level-5 accidents (1957 Windscale, UK and 1979 Three Mile Island, USA) that occurred so far in the civil electric power production, had large influence on the world's perceptions of nuclear energy safety; fueling the fear of ionizing radiation has been with us since August 1945. Their main impacts were not radiological, but socio-economic and psychological (e.g. anxiety, helplessness, discrimination, bulling, depression, and anger).

The public discourse on radiation and its manegement by the policy-makers should be based in facts, rather than sensational claims. No one wants to experience another nuclear disaster. However, a zero probability for a large accident is not achievable in nuclear industry, as in any other industry. Its consequences can be environmental, economic, societal, political and most of all, human. We have to further reduce its probability to occur (emphasis could be given on the aged units - average age of about 35 and 40 years of the reactors currently in use in Europe and USA, respectively), and if it occurs, to protect public and workers applying the accumalated experience to react appropriately. Therefore, it is critical to weigh the anticipated benefits against the damage caused by the potentional actions to mitigate radiological consequences to people and the environment during all phases of the accident. Special consideration has to be given to the human dimension, such as by ensuring sustainable living conditions and decent conditions for the affected people.

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