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Nuclear refugees after large radioactive releases

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ABSTRACT

However improbable, large radioactive releases from a nuclear power plant would entail major consequences for the surrounding population. In Fukushima, 80,000 people had to evacuate the most contaminated areas around the NPP for a prolonged period of time. These people have been called "nuclear refugees".

The paper first argues that the number of nuclear refugees is a better measure of the severity of radiological consequences than the number of fatalities, although the latter is widely used to assess other catastrophic events such as earthquakes or tsunami. It is a valuable partial indicator in the context of comprehensive studies of overall consequences.

Section 2 makes a clear distinction between long-term relocation and emergency evacuation and proposes a method to estimate the number of refugees.

Section 3 examines the distribution of nuclear refugees with respect to weather and release site. The distribution is asymmetric and fat-tailed: unfavorable weather can lead to the contamination of large areas of land; large cities have in turn a higher probability of being contaminated.

1. Introduction

1.1. Fatalities

In the literature on disasters and emergency situations, different disasters are often compared on the basis of prompt fatalities, i.e. fatalities occurring only immediately after the disaster. Car accidents or plane crashes can thus be compared with earthquakes or tsunamis on this basis. Nuclear accidents are sometimes included in such comparisons although the number of prompt fatalities in nuclear accidents is quite low: none are attributed to the Fukushima accident whereas about 30 are registered for the Chernobyl accident [1].

Nuclear accidents entail a large number of other damaging consequences; their total cost may reach hundreds of billions of dollars [2]. It has therefore been pinpointed that prompt fatalities are a poor indicator of overall accident severity as far as the nuclear sector is concerned. Total cancer fatalities following exposure to ionizing radiations have therefore been proposed as a more comprehensive and apt indicator. It was argued that considering only prompt fatalities is a way to minimize the total number of casualties [3].

From an economic point of view, this argument is not entirely valid. When attempting to quantify the loss involved in a prompt fatality, economists consider that, from the point of view of the nation, it is the loss of a "statistical life" i.e. the loss of a number of years equal to half the average lifespan, say between 40 and 45 years. In comparison, cancer fatalities induced by ionizing radiation typically take place 20 years after the event and thus entail a loss of life closer to half a statistical life.

In addition, fatalities due to cancer are profoundly different from prompt fatalities: they cannot be counted. They are estimated on the basis of a complex calculation of doses followed by a simple application of the "ICRP coefficients". Relying in this way on the no threshold linear relationship is officially not recommended by ICRP. And in most cases, even 20 years after the disaster, observers will be unable to provide any evidence: the bulk of radiological cancers cannot be distinguished from other cancers and statistics will be inconclusive. Indeed the most severe accident scenarios should "only" cause tens of thousands of cancer fatalities spread out over some 30 years in the worst cases while total deaths attributed to cancers in a country like France are about 150,000 per year. Cancer fatalities due to a nuclear accident should therefore only represent of minor percentage of total cancer deaths each year. It will generally be impossible to detect them.

In brief, fatality statistics are not helpful to gauge nuclear accidents.

Given these assumptions, is there a way to provide a better indicator than fatalities? An indicator that would be easily understandable by each and every one? Which could be readily observed and would describe the extent of human suffering involved?

1.2. Damage indicators in Katarisk

KATARISK is a Swiss tool aimed at understanding all possible sources of disaster [4]. It distinguishes five broad categories of

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events (CE) of increasing severity (disasters manageable at a local, regional, federal or European scale). (Fig. 1).

KATARISK uses a number of damage indicators applicable to a large spectrum of events, ranging from railway accidents to a nuclear accident, including earthquakes, droughts, floods, dam overflows, hurricanes, and epidemics. Indicators are not limited to fatalities: (Table 1).

For each indicator, limit values are suggested for each event category irrespective of the nature of the emergency (see Table 2).

For nuclear accidents, fatalities are not tremendously descriptive as argued in the introduction. The number of persons evacuated is a short term emergency indicator which does not address long term effects. Thus the number of refugees and the "impairment of vital resources" both appear the most relevant in this list. There is a clear difference between these two indicators, however: the number of contaminated km^2 depends on the considered level of contamination —a map of contamination will display several colors—and the resulting figures are more complex and open to interpretation than a single figure. They are more difficult to assess whereas radiological refugees can readily be counted. Therefore, the number of refugees appears as the preferred candidate indicator.

In the nuclear industry, the number of nuclear refugees is a valuable indicator. Its meaning is easy to understand for everyone. The reality it describes is directly observed; it conspicuously exposes the suffering of victims and is necessarily the focus of the media. It is important, however, to keep in mind that these remarkable assets cannot transform it into a comprehensive measure of accident losses: it is a very useful indicator in the context of comprehensive studies of overall consequences.

2. Nuclear refugees: Definition and estimation method

2.1. Definition

After a nuclear accident, inhabitants of the most severely contaminated areas can be exposed to radiation doses whose accumulation over a long time frame could yield particularly significant values. They should be relocated to safer areas to avoid exposition to long term ground shine. If the decontamination process does not succeed in bringing ambient radioactivity back to acceptable levels of doses, those people may not return home for many years: they are "nuclear refugees".

The decision to relocate a population is made by authorities; the threshold level for relocation can be expressed in terms of projected effective dose, or equivalently in terms of levels of ground contamination. After Chernobyl, the criterion for relocation was a ground activity concentration above 555 kBq/m^2 of Cs-137. After the Fukushima accident, Japanese authorities enforced a threshold of 500 kBq/m^2 of Cs-137, although the criterion was expressed in terms of doses. This was broadly consistent with the feedback from Chernobyl. The present study uses the figure of 555 kBq/m^2 of Cs-137. The precise level chosen does not affect the calculation method or the nature of results.

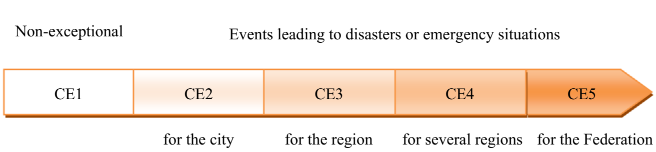

Fig. 1. Classification of events in KATARISK.

Refugees differ from evacuees: they do not refer to identical populations. Evacuation relates to emergency planning; it aims primarily at reducing the potential for large doses resulting from the exposure to the actual passage of the radioactive plume, and to radionuclides deposited on the ground.

Evacuation happens in early phase of a radiological emergency to protect public health and safety in the immediate vicinity of the stricken power plant. After Fukushima, evacuation orders issued by Japanese authorities concerned areas within a 20-km radius of Fukushima-Daiichi NPP. Some emergency plans, as it is the case in the US, include evacuation in a key–hole geometry in which the radius to which evacuation occurs is larger down-wind than in any other directions. Some evacuees may come back home fairly quickly once evacuation orders are lifted provided contamination levels allow.

Conversely, relocation occurs on a longer time frame, usually in the intermediate phase of a nuclear accident. After the radioactive cloud has passed and early phase protective actions have been performed, ground contamination and ambient dose rates are measured to characterize the magnitude and the extent of radioactive fallouts. This information is used to determine those areas in which relocation will occur. After Fukushima, relocation areas were extended northwest of the 20-km radius evacuation zone.

The present study focuses on the number of refugees after a nuclear accident, which better reflects its long term consequences than the number of evacuees.

Estimating the number of nuclear refugees involves combining deposits with population data. Since contamination heavily depends on weather, so does the number of refugees. It is probabilistic in nature.

2.2. Estimation of deposits

Deposits are estimated at each grid point of a predefined grid using atmospheric dispersion models. These require:

1) *A source term* which details the quantity, nature and discharges of radioactive elements into the environment. As far as accident costs and nuclear refugees are concerned, the most important element is Cesium-137 as it contaminates the environment for a prolonged period of time. For this study, this is the only required radioelement (see above definition).
2) *Meteorological data:* the wind direction and its possible changes during the course of the plume determine the areas affected by the fallout. Rain leaches the plume and causes greater deposition of radioactive particles in some places.

In this study, source terms are based on the IRSN level 2 PSA for the French 900 MWe reactors. Activity of released aerosols is the physical indicator used to assess the severity releases. It varies between less than 1E+15 Bq to more than 1E+19 Bq. Two

Table 1
Example of damage indicators proposed by KATARISK.

Fatalities, injuries during events causing serious damage over a wide area (number of people)
Fatalities, injuries, illnesses during epidemics (number of people)
Number of persons evacuated
Persons in need (refugees, homeless, people requiring care)
Impairment of vital resources: damage to agricultural land, water and forest (number of km^2)