Massive radiological releases profoundly differ from controlled releases

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Abstract:
Preparing for a nuclear accident implies understanding potential consequences. While many specialized experts have been working on different particular aspects, surprisingly little effort has been dedicated to establishing the big picture and providing a global and balanced image of all major consequences. IRSN has been working on the cost of nuclear accidents, an exercise which must strive to be as comprehensive as possible since any omission obviously underestimates the cost. It therefore provides (ideally) an estimate of all cost components, thus revealing the structure of accident costs, and hence sketching a global picture. On a French PWR, it appears that controlled releases would cause an "economical" accident with limited radiological consequences when compared to other costs; in contrast, massive releases would trigger a major crisis with strong radiological consequences. The two types of crises would confront managers with different types of challenges.

1 COST ESTIMATES SHOULD BE COMPREHENSIVE AND THUS PROVIDE A GLOBAL VIEW

IRSN developed nuclear accident cost estimates under pressure from the licensee. The dominant culture in the nuclear power sector being technical, this field of investigation was not envisaged. However, economic pressure is ubiquitous and licensees worldwide tend to include more and more economic arguments in safety discussions with authorities. This is how IRSN undertook nuclear accident cost estimation as early as 2005.

1.1 Cost estimates should be comprehensive

The first crucial point with respect to methodology is that estimates should be comprehensive and no element of cost should be left out. Because, at one point or other down the line, accident costs will be balanced against expenses spent on accident prevention. If one cost component is overlooked, cost estimates are underestimated and if accident costs are underestimated, the value of prevention will also be underestimated. Prevention expenses will then be lower than what would be optimal and excessive risk will be retained. This point is therefore crucial indeed.

There are several (bad) reasons why cost components could be overlooked. One important such reason is that certain costs appear quite difficult to estimate and resulting figures may lack the precision of those provided by such sciences as astronomy. Therefore, why acquire the know-how and spend precious time and money for such meager and contestable outcome? These arguments may contain an element of truth… but they nevertheless would result in a <u>zero</u> estimate, which is definitely biased and generally significantly inferior to a "bad" figure. A poor estimate is better than no estimate at all. In addition, a poor estimate can be turned into a parametrical estimate…

Another reason sometimes put forward is that decisions would be purely political and would not really consider cost estimates. In fact costs estimate themselves would be purely political in this view, and any sort of figure could be produced for political purposes. So why should experts bother when they can only expect to be disregarded/superseded by politicians anyway? We feel this argument is as valid as saying that because crime will always be present to some extent it would be useless to spend resources on police forces. Of course, the contrary is true! Precisely because poor figures *may* be produced, it should be an explicit objective to contribute to professionalism in this area and because political decisions *sometimes* overlook economic considerations (although fairly rarely…) enlightening and balanced analyses should be produced, made available and largely explained to a vast public.

1.2 Broad cost categories

In the area of nuclear accidents, the classical cost component is what we refer to as Offsite Radiological Costs. These have been closely considered after the TMI and Chernobyl accidents resulting in various consequence computation codes being produced in the early 90s' such as Cosyma in Europe and Maccs in the US. They mainly calculate plume dispersion and consequences for public health; countermeasures such as food bans can be studied by changing concentration standards. But there are many other costs both closer to the affected site and much further away.

On-site costs are not negligible and should be estimated because they correspond to actual losses. Granted, these costs are borne by the utility (see however, the case of Tepco), but they nevertheless correspond to a loss of value for society. The above argument applies: if you don't include on-site costs, you underestimate accident related losses, undervalue prevention efforts and retain risks in excess of what would be optimal.

Agricultural losses due to radioactive pollution are covered under Offsite Radiological Costs but additional losses affect perfectly clean foodstuffs, which are *suspected* of being polluted. Such losses are grouped together with other image costs such as the impact on Tourism; Image Costs and can be quite significant.

Experience has shown that nuclear accidents can have strong effects on electricity production both inside the country and worldwide. After TMI, the US built no further nuclear reactors for more than 30 years; after Chernobyl, Italy renounced nuclear power and never used reactors which were almost ready to produce electricity; after Fukushima, Japan faces very serious difficulties in this area and Germany decided to exit nuclear power production. This should be accounted for.

In the most severe accident scenarios, sizeable areas of land can be strongly contaminated and exclusion zones may be enforced with corresponding costs. Other less severely contaminated territories also imply heavy costs.

These broad cost categories have been retained in the following estimates for France. As we shall see, a vivid description can be derived on this basis and gives precious indications for crisis managers and for safety authorities.

There can be additional costs, for instance Disruption to the Economy. This phenomenon was observed after the Fukushima accident although part of it was attributable to earthquake and tsunami destructions. This situation should be expected in some accident scenarios in France. Yet other costs could include: effects on national debt, effect on the Stock exchange, impact on foreign investments, and so forth. These are not included which implies that estimates − otherwise aimed at being best estimates − are not conservative, but rather underestimated than overestimated. Acknowledging areas not covered in proposed estimates is essential for readers to correctly understand the figures; it also suggests that omitted costs are of limited importance relative to other costs. In the present case, the main argument would be that included cost components are all above € 1b, while other costs should all be below this mark.

1.3 Detailed cost items

Before moving on to results, the following table provides detailed cost items. Indeed each broad cost component is comprised of several items. Each of these being estimated with a view to being unbiased (best estimates), it is expected that estimation errors could compensate at least partially.

Table 1: Detailed costs items

Item	Comments
On-site costs	
Decontamination and decommissioning	Based on lessons learned from TMI
Electricity replacement	Corresponds to the value of the lost reactor and outages experienced by other on-site reactors
Other on-site costs	Marginal in comparison to the above
Offsite radiological costs	
Emergency countermeasures	Marginal compared to other costs
Health costs (radiological)	Strongly depend on the amount of contaminated foodstuffs ingested by the population. Boycott by consumers and retailers is considered possible.
Psychological costs	Mainly lost workdays and long-term treatment costs. No allowance for patient suffering (or social willingness to pay beyond hard costs).
Agricultural losses	Strongly depend on standards or boycott by consumers/retailers
Image costs	
Impact on Agricultural and Foodstuffs exports	Relates to perfectly clean produce; based on experience from such episodes as the Mad Cow Crisis, the Bird Flu or the Spanish Cucumber crisis in 2011 in Europe.
Impact on Tourism	Based on crises in Tourism worldwide during the past 10 years.
Reduction in other exports	Past experience is largely lacking in this area.
Costs related to power production	The most plausible scenario given French procedures is a 10-year reduction in reactor lifetime.
Contaminated territories	
Exclusion zones	Cost of radiological refugees (population of exclusion zones); cost of land considered as a capital (no additional willingness to pay or “value of motherland”)
Other contaminated territories	Based on feedback from Belarus; considers actual costs of contamination and transfers, the latter provinding a measure of the detriment to affected populations.

2 A SEVERE NUCLEAR ACCIDENT IN FRANCE WOULD BE A NATIONAL DISASTER BUT WOULD NEVERTHELESS BE MANAGEABLE

We distinguish two nuclear accident families, both involving a core melt on a French electricity production reactor. A severe accident is defined as a core melt followed by radioactive releases, which are more or less controlled and therefore *not massive*. Source terms can be more or less severe in this accident family; weather conditions can be more or less favorable.

The following figures are estimated from the point of view of France as a nation; estimates would differ if computed from the point of view of the affected region; they would again be different from the point of view of the European Union.

In summary, a representative accident for the family would involve the following costs:

Table 1: Cost of a representative severe nuclear accident in France

	b€	%
On-site costs	6	5%
Offsite radiological costs	9	8%
Contaminated territories	11	10%
Costs related to power production	44	37%
Image costs	47	40%
Total (rounded)	120	100%

2.1 A National disaster

A total cost of € 120b is quite significant for France. Major industrial accident such as the explosion of the AZF fertilizer factory in Toulouse (2001) or the Erika oil spill (2000) have been estimated around € 2b – a quite different order of magnitude.

The annual French GDP being around € 2000b, a representative severe nuclear accident could imply losses around 6% of annual GDP. Costs would not affect one year's GDP but be spread out over a period of time, the greater part of costs occurring within the first three years after the accident.

In total, losses would correspond to 3-6 years of economic growth depending on growth performance. It would, therefore, be a disaster of national significance. Variations in cost due to site location exist but are not major.

A further characteristic makes this disaster national rather than local: image costs and power costs account for 77% of the total and are practically not related to the particular region affected by the accident.

2.2 A manageable crisis

Notwithstanding the high global cost, purely radiological costs would account for less than 20% of total costs (offsite radiological costs and contaminated territories). The number of radiological refugees could be in the order of 3 500 which the country can definitely manage satisfactorily. In addition, the more or less controlled nature of releases makes it possible to apply countermeasures fairly effectively.

Therefore, high-level crisis managers would face media chaos and high economic stakes rather than a full-blown radiological catastrophe.

2.3 Variability

The above cost estimate is an order of magnitude for a representative severe accident; an actual realization of such an accident would likely deviate from this model for reasons outlined hereafter.

In order to impart a feeling for possible variations in cost, we suggest a favorable case could cost € 50b while costs could double in an unfavorable case (€ 240b). This bracket (-55%; +100%) should include most variations but extreme cases can still excedd these figures.

Deviations from the representative accident are to be expected from the combination of the following factors:

- Source term, wind direction, wind speed and possible precipitations determine the radiological profile of the accident; with no wind and heavy rains, long term pollution would be mainly restricted to the vicinity of the NPP; radiological costs would be reduced implying that so would media sensationalism; this in turn would make it easier to manage Image and Energy production;
- The quality of defensive actions taken to saveguard the image of clean products would be an essential parameter; a high level of efficiency in this respect may require a special task force to be set-up very early during the crisis, to be staffed with the adequate blend of specialists and endowed with resources proportional to the high costs at stake. Enforcing pratically zero concentration standards in contaminated foodstuffs could be an option for the protection of perfectly clean exports even if clearly uneccessary from a narrow sanitary point of view.
- Realism in political moves concerning the Electricity production sector would also be of paramount importance in reducing costs to society.

3 A MAJOR NUCLEAR ACCIDENT IN FRANCE WOULD BE AN UNMANAGEABLE EUROPEAN CATASTROPHY

The term major accident here designates any accident affecting one electricity production reactor and producing *massive* radioactive releases. Again, source terms can be more or less severe within this accident family; weather conditions can be more or less favorable. The following estimate considers a representative accident scenario for major accidents on a French 900 MWe PWR and considers reactor lifetimes of 40 years.

Table 3: Cost of a representative major nuclear accident in France

	b€	%
On-site costs	8	2%
Offsite radiological costs	53	13%
Contaminated territories	110	26%
Image costs	166	39%
Costs related to power production	90	21%
Total (rounded)	430	100%

3.1 A major radiological catastrophe

Radiological consequences could cost more than € 160b after a major nuclear accident, i.e. 8 times more than for a typical severe accident and more than the *total* cost of a severe accident. Offsite radiological costs would be multiplied by 6. Costs related to contaminated territories exceed 5% of annual GDP. Such figures suggest the extreme radiological severity of such accidents.

Perhaps an easier way to give a feel for the extent of contamination is to estimate the number of radiological refugees, i.e. the population of exclusion zones, people who need to be permanently relocated. They could typically number 100 000 persons[i] − which would be extremely difficult to manage.

Expected numbers of cancers would be high. Psychological impacts would be significant. Quantities of lost agricultural produce to be disposed of would be considerable. Management of contaminated territories (apart from exclusion zones) would remain an on-going challenge for many years. Neighboring countries would often also suffer from contamination.

Such extensive radiological impacts would impose widespread suffering to affected populations. Corresponding costs could be termed “human” costs and could elicit among decision makers a high level of willingness to pay for prevention. In total, “human” costs would represent about 40% of total costs but might weigh more heavily in decisions.

3.2 High “economic” costs

Other costs are more diffuse and shared among the entire population; they could be called “economic” costs and mainly include Image costs and Costs related to power production.

Image costs would be multiplied by 3.5 compared to a representative severe accident, reaching the staggering figure of more than € 160b, as much as radiologically related costs. Such an estimate is obviously more uncertain than for a severe accident because there is little corresponding experience (mega-crisis + widespread radioactive contamination).

Compared to Fukushima, areas contaminated after a major accident on a French nuclear reactor are likely to be much more intensely agricultural. Symbolic productions are likely to be affected such as wine. Highly popular landmarks/monuments could be contaminated and harm Tourism activity. Extensive media coverage would exacerbate image problems in the direct accident aftermath but also every year at anniversary dates, regularly reinforcing the difficulties for concerned activities and the livelihood of people who depend on them.

Costs related to electricity could typically be twice as high as after a sever accident; this accounts for a faster replacement of nuclear power by other production means and for a longer period. This again is a reasoned estimate of possible political decisions and suggests an order of magnitude of corresponding costs.

3.3 Huge losses

In total, a typical major accident could cost more than € 400b, i.e. more than 20% of annual French GDP, more than 10 years’ economic growth. For lack of other references, this can be compared to the cost of waging a regional war. The country would durably be stunned by such a blow, History would remember the catastrophe for many years, Western Europe would be affected.

Two impacts would combine: the country would be irradiated and, in addition, would face extremely heavy losses. In all probability, this would lead to profound political and social transitions.

Typical costs of major accidents could vary by -60% or +120% making the two accident families comparable with respect to variability as measured by such percentages. Nevertheless, deviations from the representative case are different in the two accident families:

- Extreme major accidents with costs outside the proposed bracket would be totally disastrous, mainly because severe pollution of large urban centers cannot be ruled out leading to a fat tail phenomenon much more pronounced than for severe accidents.

- Extreme cases of severe accidents would not only be “less extreme” but could be mitigated by good crisis preparation. In other words, unfavorable weather conditions would have limited effects while good image management and sound post-crisis energy policy would definitely have significant impacts on social costs. When combined with adequate communication, these qualities should make the crisis tolerable.
- In contrast, wind and rain strongly influence the extent of radiological consequences of major accidents and therefore of total accident costs since they account for about 40% of cost in a typical case. Massive releases typically leave very little time for emergency management; in general, high-level crisis managers would find themselves faced with widespread contamination ex-post and their contribution would be limited to mitigating a largely hopeless situation. Good image management and sound post-crisis energy policy would help but the accident would still be largely intolerable.

4 CONCLUDING REMARKS

The first conclusion from such figures has inspired the title of this paper: massive radiological releases profoundly differ from controlled releases. The latter lead to a largely economic crisis, most costs being borne by the entire population in a diffuse fashion. The main victims are local farmers who suffer economically because of land and produce contamination, may have to leave their homes, change or restart their activity and, on top of all this, may develop health problems. Quite to the contrary, massive releases result in massive radiological consequences and the number of victims can be considerable and include people from all walks of life.

This type of information should be useful for crisis managers. The vision they could derive should help them avoid major errors in the early stages, errors which can be quite costly in the long run. Crisis preparation could be improved if it is realized that radiological consequences are only part of the crisis – and may be a minor part in economic terms.

Safety decisions may also be informed by this picture, in particular if it is realized that the most severe cases actually carry huge stakes for the nation and therefore that their lower probability may not balance their catastrophic potential.

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[i] Exclusion zones are defined as contaminated by cesium 137 at levels higher than 15 Ci/km² (based on experience from Chernobyl). This level is equivalent to 555 kBq/m². The Fukushima exclusion zones are based on dose considerations which correspond to similar levels of activity. The figure of 100 000 refugees corresponds to a rounded average of medians computed for three different French sites.