

**ASSESSMENTS OF THE RADIOLOGICAL CONSEQUENCES OF  
RELEASES FROM EXISTING AND PROPOSED EPR/PWR NUCLEAR  
POWER PLANTS IN FRANCE**

**SUMMARY**

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## RISKS AND HAZARDS OF THE PROPOSED AND EXISTING EPR/PWR NPPS IN FRANCE

### SUMMARY

France is advancing its plan to construct a pressurised water reactor (PWR) at Flamanville in the Manche on the site of the existing nuclear power station. The new plant, a Generation III European Pressurised Reactor (EPR), has been approved by the Autorité de Sécurité Nucléaire (ASN) and is to be built by the nuclear group Areva and operated by Electricité de France (EdF).

In preparing the way for this development at Flamanville, EdF has published its claims that the EPR design is failsafe and that its operation, even if subject to the most severe accident or terrorist attack, will not result in intolerable consequences for the local communities, France and the region as a whole.

This assessment rejects EdF's claims.

Using European Community Standard modelling software (COSYMA), this assessment compares the proposed Flamanville EPR to the radiological consequences of a severe radioactive release arising from a containment-bypass or containment failure at each of a number of existing NPPs in France, including Tricastin, Nogent-sur-Seine and Fessenheim. Because France has in place a programme to utilise reactor-grade plutonium fuel (MOX) in certain of its existing NPPs and specifically in the EPR development at Flamanville, the impact of a radioactive release of MOX is examined in comparison with a low enriched uranium (LEU) fuelled NPP. The assessment includes account of the type of nuclear fuel, both LEU and MOX that is currently in use in French NPPs, and it projects the higher radiological consequences should the Generation III European Pressurised Reactor (EPR) proposed at Flamanville be subject to a severely damaging incident

In presenting its nuclear safety case to the public, EdF declare that any untoward event that could credibly occur to the EPR and the existing NPPs located throughout France would not result in unacceptable radiological consequences to members of the public. EdF claims that all reasonably foreseeable accidents and external hazards will not jeopardise the fundamental nuclear safety of the plant, so much so that there are no foreseeable circumstances under which the radiological containment structures of the nuclear island will be breached. Indeed, with the severely damaging incidents '*practically eliminated*', so EdF argues, the resilience of the plant to accidents and external hazards is sufficient to safeguard against terrorist and malicious acts, including the crashing of a fully fuelled commercial airliner on the nuclear island.

However, the history of technological development is littered with examples of unforeseen failures of hi-tech systems with, for example, with the *Challenger* and *Columbia* shuttle failures reverting NASA's one-in-a-million design criterion to a chance of just 1:57; the *World Trade Center* towers designed to withstand a Boeing 707 crash were to be defeated by the advance in aircraft design over the years; and, of course, the unsinkable ship *Titanic* sank on its maiden voyage. The axiomatic fact is that all engineered systems are at risk of catastrophic failure and that, moreover, it may not be possible at the time of design to foresee all possible causes and mechanism that could initiate and cascade through to failure: an iceberg so far South, a detached piece of polystyrene insulation damaging a ceramic tile, and suicidal terrorism successfully pitting one technology against another. Moreover even those events that might be reasonably foreseen, not all are entirely predictable in terms of frequency or chance of occurrence and, of course, acts of terrorism are totally beyond prediction by *a priori* and probabilistic analysis upon which the NPP nuclear safety case so heavily relies.

There is nothing exceptional about nuclear power plant technology that excludes NPPs from the risk and actuality of catastrophic failure so, on this basis alone, the EdF-Areva conjecture that it is possible to design, build and operate a failsafe and terrorist proof NPP is not accepted.

This assessment examines the radiological consequences following a catastrophic failure at each of a number of NPPs. The potential mechanisms leading to and through the failure are not examined in great detail, other than to muse that such an event, should it occur would probably centre about human failings or some form of terrorist act, suffice that the event involves an operational nuclear reactor and that the containment building is breached. The assessment examines the severity of the radiological impact in terms of amounts of the radioactive fission products (the release fractions) that could expel from the reactor fuel core, with these deduced from those adopted for a number of nuclear industry consequence analyses and from factual information on the actual release at Chernobyl. The immediate, interim and longer term aftermaths of the incident are modelled and analysed using the European Community standard software COSYMA to provide a probabilistic based projection of the individual risks, extent of land area and population numbers requiring countermeasure actions, and the early and late radiological health consequences for the specific locations of NPPs at Flamanville, Tricastin, Nogent and Fessenheim. The trajectory of the radioactive release plume and the footprint of radioactive fall-out are also projected at each location using satellite archived meteorological data (NOAA) to graphically illustrate the tracts of land and communities at risk.

France has in place a programme to utilise reactor-grade plutonium fuel (MOX) in certain of its existing NPPs and specifically in the Generation III NPP EPR development at Flamanville. MOX cores have greater quantities of plutonium and other actinides than LEU cores so the amount of radioactivity potentially available for release will differ and the health impact, particularly because of the increased plutonium content, will be greater for a radioactive release from a MOX-fuelled reactor. The assessment of MOX fuel releases includes account of the so called *reactor-grade* plutonium used in the French MOX programme and, in outline, an explanation of the greater risk of malfunction that the introduction of MOX fuelled reactor cores brings about.

The EPR targets to attain much higher levels of LEU fuel irradiation (burn-up) than hitherto achieved in commercial PWR power generation. Higher fuel burn-up not only increases the quantity of fission products available for release, and hence a greater potential radiological impact, but it introduces uncertainty over the amount of radioactivity released from the individual fuel pellets and pins in a reactor core degrade or melt down. Recent research programmes have shown a significant increase in release fractions for both LEU and MOX fuels at higher levels of burn-up so, in this respect, the release fractions assumed for this analysis may result in an under-assessment of both the LEU and, particularly, MOX fuel cases.

The results of this assessment are disturbing.

Presented in terms of probability fractile (but see TABLE B in APPENDIX I for full results and range of NPPs assessed):

NPP SITE	HEALTH EFFECT/COUNTERMEASURES	NUMBER OF HEALTH EFFECTS		
		MAXIMUM	MEAN	50 <sup>th</sup>
<b>Flamanville</b> EPR 100% LEU core Target 65GWed/tU Fuel Burn-Up	EARLY Death	381	81	42
	LATE Fatal Cancer	26,430	6,212	5,623
	Thyroid Cancer DEATHS	1,454	309	263
	LAND Area (ideally) Evacuated km <sup>2</sup>	16,930	7,214	6,475
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	1,541	361	257
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	1,246,000 68,050	313,000 14,570	239,900 11,750
FLAMANVILLE EXISTING 1330MWe PWR 100% LEU core	EARLY Death	179	41	23
	LATE Fatal Cancer	15,020	3,748	3,311
	Thyroid Cancer DEATHS	824	184	158
	LAND Area (ideally) Evacuated km <sup>2</sup>	13,320	4,796	4,365
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	1,445	318	2,512
	NUMBERS Persons (ideally) evacuated Persons (ideally) sheltered Persons (ideally) I-131 Prophylaxis	725,300 869,500 65,380	176,800 125,800 12,990	151,400 35,480 10,470
FLAMANVILLE EPR 100% MOX core	EARLY Death	650	147	85
	LATE Fatal Cancer	60,760	8,055	7,586
	Thyroid Cancer DEATHS	1,307	161	110
	LAND Area (ideally) Evacuated km <sup>2</sup>	44,810	13,300	11,750
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	7,3214	2,360	2,138
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	3,319,000 376,000	662,200 69,260	549,500 33,110
FLAMANVILLE EPR 30% MOX core Thyroid Prophylaxis limited to 10km	EARLY Death	322	67	34
	LATE Fatal Cancer	29,260	6,295	5,754
	Thyroid Cancer DEATHS	984	212	186
	Thyroid Cancer Incidence	9,630	2,116	1,862
	LAND Area (ideally) Evacuated km <sup>2</sup>	36,540	11,660	10,000
	Area (enforced) Iodine Prophylaxis km <sup>2</sup>	314	78	63
NUMBERS Persons (ideally) evacuated Persons (enf d) I-131 Prophylaxis	3,246,000 13,070	567,600 3,228	537,000 2,570	
<b>Tricastin</b> EXISTING 915 MWe PWR 100% LEU core	EARLY Death	28	6	2
	LATE Fatal Cancer	11,890	3,234	3,020
	Thyroid Cancer DEATHS	530	165	166
	LAND Area (ideally) Evacuated km <sup>2</sup>	6,320	2,261	1,995
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	1,281	275	209
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	712,000 100,900	181,600 18,610	123,000 15,490
<b>Tricastin</b> EXISTING 915MWe PWR 30% MOX core Higher Release Fraction for Group 7 Radionuclides	EARLY Death	123	22	11
	LATE Fatal Cancer	29,330	10,290	10,470
	Thyroid Cancer DEATHS	753	240	246
	LAND Area (ideally) Evacuated km <sup>2</sup>	23,990	8,704	8,318
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	3,142	72	60
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	2,341,000 25,290	652,600 2,258	602,600 2,042
<b>Nogent sur Seine</b> EXISTING 1310MWe PWR 100% LEU core	EARLY Death	434	41	15
	LATE Fatal Cancer	109,900	11,510	4,898
	Thyroid Cancer DEATHS	4,670	354	257
	LAND Area (ideally) Evacuated km <sup>2</sup>	13,530	4,841	4,365
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	1,445	320	251
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	6,386,000 88,530	424,000 22,000	263,000 17,380
<b>Fessenheim</b> EXISTING 880MWe PWR 100% LEU core	EARLY Death	194	258	10
	LATE Fatal Cancer	36,010	10,340	8,913
	Thyroid Cancer DEATHS	2,599	492	479
	LAND Area (ideally) Evacuated km <sup>2</sup>	6,188	2,206	1,950
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	1,268	273	200
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	2,960,000 502,900	563,300 90,180	331,100 31,150

Using precisely the same modelling and analysis methods, this compares to the worst case incident proposed by EdF for the EPR at Flamanville:

<b>Flamanville</b> EPR 100% LEU High Burn- Up Target & EDF Release Fractions English Version x10 <sup>6</sup>	EARLY Death	0	0	0
	LATE Fatal Cancer	11	4	4
	Thyroid Cancer DEATHS	1	0	0
	LAND Area (ideally) Evacuated km <sup>2</sup>	123	57	50
	Area (ideally) Iodine Prophylaxis km <sup>2</sup>	12	10	10
	NUMBERS Persons (ideally) evacuated Persons (ideally) I-131 Prophylaxis	2,952 630	2,458 560	2,239 562

The striking difference between the two sets of results for the Flamanville EPR (ie blocks coloured ■ in the main table) results from EdF's assertion that all seriously damaging incidents, including terrorist acts, can either be 'practically eliminated' or contained within the absolutely failsafe secondary containment of the EPR. This claim, which is not at all substantiated by information and data available in the public domain, is not accepted for this assessment which adopts the pragmatic approach that accidents can happen and that NPPs are vulnerable to both unforeseen accidents and external events, including extreme acts of terrorism.

Moreover, as the output size of successive generations of NPPs increase, so does the amount of fuel held in the reactor core, and as the utilisation of this fuel is increased by greater irradiation, or burn-up, the radiological impact of a radioactive release also increases. However, the public tolerance to radioactivity, the acceptable radiological health impact, sensibly remains constant or, indeed, may reduce in line with changes of public perception and tolerability of radiation specifically and health harm generally. To satisfy this covenant, the potential for radioactive release from each successively larger generation of NPPs has to be more effectively contained or, where this is not at all practicable, the type of fault condition or incident has to be eliminated. For its latest and largest NPP, the 1,600MWe, high burn-up fuelled Flamanville EPR, EdF claim that the radiological impact of an accident will be no greater than that for the existing 880MWe, modest burn-up NPP at Fessenheim. EdF's claims for the EPR in this respect are not at all convincing nor, indeed, have these been factually demonstrated, proven and tested in a commercially-sized NPP.

Another unproven conjecture is forwarded by EdF on the resilience of the EPR design against acts of terrorism, with the claim that whatever the nature of any well planned and implemented terrorist attack, the radiological consequences would be no worse than those arising from the nominated and tolerable *design basis* accident. Even if applicable to the EPR, which is extremely doubtful, this new fangled resilience would not apply to the earlier, pre-9/11 NPPs at Nogent, Fessenheim, Tricastin and Flamanville.

Second and should there be a radioactive release, this assessment confirms that there is marked radiological penalty accompanying the use of *reactor-grade* MOX in the existing NPPs and for the EPR NPPs planned for Flamanville. For example, at Flamanville the (statistically mean) projected early deaths following exposure increase by one-quarter over the LEU fuelled reactor for a 30% MOX core load, and by about threefold for a 100% MOX fuelled reactor core. For those individuals caught within the overhead plume and fall-out regions downwind, the greater plutonium content of a MOX fuelled release results in an increase of the contribution of the inhaled dose pathway from about 80% for an LEU core to 96% for the first few hours of exposure. This particular finding emphasises the crucial importance of implementing countermeasures to mitigate public dose but, that said, the reduction afforded by sheltering only has an hour or so of worth because the building space itself fills with contaminated air. Since it is not practicably possible to provide respiratory protection to the numbers of population likely to be at risk, a speedy evacuation is the only practicable dose reduction option available.

In fact, the numbers of public requiring countermeasure action can be very large depending of the rural/urban mix downwind of the NPP. At Flamanville the analysis projects that for a 100% LEU fuelled EPR operating at current levels of fuel irradiation (burn-up) a (statistically mean) area of about 5,600km<sup>2</sup> entailing about 230,000 individuals would require evacuation tailing off over the first week following the release. If the EPR is fuelled with MOX the land area requiring evacuation expands to about 13,500km<sup>2</sup> involving about 660,000 evacuees. For the existing NPP at Nogent sur Seine the land tract qualifying for evacuation, although smaller at about 4,800km<sup>2</sup> but of greater urban settlement could require upwards of 424,000 evacuees and at Fessenheim, because of its greater population density in France, together with the populations of the neighbouring states of Germany and Switzerland, upwards 560,000 individuals would require evacuation on the basis of the intervention levels of dose adopted by the French (100mSv at 7 days and not, for example, at the lower German intervention levels)).

The COSYMA modelling arrives at these numerical projections because it slavishly adheres to its instructions which are in accord with the French emergency planning regime and its prescribed levels of dose that trigger specific countermeasure actions but, clearly, confronted with such a onerous evacuation requirement in a real situation, the emergency response would have to be modified (ie increasing the tolerated dose before evacuation) to stave off ensuring chaos that would accompany a collapse of state organised public control. In this and other respects, the COSYMA analyses reported here are not intended to provide precise forecasts of the radioactive releases and consequences at the exemplified nuclear power plants. This is because not only is a much greater detailed input required to define the near field data, population density and meteorological conditions, for each locality and how the population would react, particularly if left uninformed, lacking essential information and direction on what to do and when best to do it. That said, the results do provide reliable indicators of the trends and indices of the probability and magnitude of the health impact a radioactive release, accidental or otherwise, from any of the nuclear power plants examined.

MOX fuelling increases the resources needed to be held in reserve if effective post-release countermeasures are to be implemented. For example, the projected EPR at Flamanville when fuelled with a 30% MOX core (the present level achievable in France) will have to provide for a doubling of the land area requiring evacuation than for the EPR fuelled with LEU to the present fuel burn-up levels (12,000 over 6,000km<sup>2</sup>).

Administration of prophylactic measures (stable iodine or iodide tablets) would also present similar demands on the emergency services, although there is no significant different between LEU and MOX fuelled cores. For both fuel cores, if the present French emergency reference trigger or intervention levels for prophylaxis are maintained, downwind of Nogent sur Seine, for example, the (statistically mean) numbers involved would reach upwards of 22,000 individuals based on the trigger thyroid dose of 100mSv. However, if the World Health Organisation (WHO) intervention dose of 10mSv for the critical group composed neonates, children and nursing mothers were to be adopted then the qualifying catchment area would be much more widespread and the numbers making up these critical groups very much larger.

Another disturbing result is that the analysis shows that the societal cost varies considerably. This societal cost is expressed as the health detriment in man-Sv arising from the collective dose over the populations downwind of each of the NPPs assessed. For example, the NPP at Fessenheim, although of much smaller capacity at 880MW<sub>e</sub> than the proposed 1,600MW<sub>e</sub> EPR at Flamanville and analysed here for a 100% LEU core, has the greatest radiological impact over 10 to 100km downwind – this is because of the high population densities of the region, particularly in the nearby adjacent states of Germany and Switzerland. Nogent sur Seine also generates a significant collective dose detriment, at about twice that of each of the Tricastin and Flamanville (EPR) NPPs when fuelled with LEU and, generally, the introduction of MOX fuel about doubles the collective detriment over the equivalent uranium fuelled reactor.

Also, the Nogent NPP is located about 90km East of Paris so there is risk, although in relatively rare atmospheric conditions, that the suburbs if not the centre of Paris would require sheltering and, perhaps, evacuation countermeasures implemented. The societal cost of any nuclear incident and radioactive release is very high but an incident that drew in the capital of France, however slight and short term the radiological consequences might be, these would have catastrophic consequences that could blight the City, in tourism, prestige and commerce, for many years into the future.

Equally disturbing is the response of the French nuclear industry to change: On one hand, its proposed EPR reactor at Flamanville will be larger than any of the existing French reactors and it will irradiate its LEU fuel cores to levels hitherto untested at a commercial scale, and it is to fuel these reactors with reactor-grade MOX to higher core proportions than presently permitted – all of these changes will render the available radioactive source term and the potential radiological consequences in the public domain larger. The threat to nuclear safety has also changed since 9/11 2001 with the emergence of a form of international terrorism that has no regard for self-sacrifice, and which will adapt and use high technology with brutal disregard for public safety and life. On the other hand, the French nuclear industry continues to claim that its reactor designs are somehow exempt from severely damaging accidents and will withstand the most intelligently contrived terrorist attack and, accordingly, its planning, preparation and implementation of the emergency response to a significant radioactive release, as shown by this assessment, is not at all matched to the potential consequences.

Put simply, because the amount and/or radiotoxicity of the reactor fuel core increases with each new NPP generation, the gravity of the maximum tolerable incident or radioactive release over its predecessor must be correspondingly smaller. This requires each successive NPP generation to have a greater resilience to accidents and external events, thus confounding the claim that each generation of NPPs is '*as safe*

*as can be*'. Put another way, since several of the safety features of the EPR cannot be practicably back-fitted to the existing NPPs, a rationale interpretation is that if the EPR is 'safe' then the existing NPPs are 'unsafe' in comparison.

Overall, my conclusion is that the risk of a severely damaging accident to any of France's highly hazardous nuclear power plants should not be dismissed on probabilistic grounds alone because, as our technological history shows, it is beyond the wit of mankind to forecast all possible types of incidents and the chance of when these might occur. This is doubly certain for malicious acts, including terrorism, which should be considered to be inevitabilities. Accordingly, I am of the opinion that EdF should present its case for the continuing operation of its NPPs, including its venture to construct a series of EPRs, with greater caution and diligence, particularly in that it should make publicly available full analyses of the radiological consequences of severely damaging incidents to its NPPs rather than, as it does now, opportunistically dismiss such possibilities to have been *all but practically eliminated*.

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