VULNERABILITY OF FRENCH NUCLEAR POWER PLANTS TO AIRCRAFT CRASH

ADDENDUM

IDENTIFYING SPECIFIC NUCLEAR POWER PLANTS THAT SHOULD BE SHUT DOWN ON RISK AND NUCLEAR SAFETY GROUNDS

CLIENT: **GREENPEACE FRANCE**

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The main report R3205-A1 reviews the vulnerability of the various designs of the 58 French operating nuclear power plants (NPPs) to a commercial-sized airliner crash. This Addendum reports the inadequacies of the NPPs when challenged by other extremes of external hazards as stipulated by the recent round of European Commission *stress tests*. The pan-European action was undertaken following the Japanese Fukushima Daiichi incident in which three operational light water moderated NPPs were severely damaged in the immediate aftermath of the earthquake and tsunami of 11 March 2011. In France, the national nuclear safety authority, *l'Autorité de Sûreté Nucléaire* (ASN), interpreted the *stress tests* requirement by setting the NPP operator (*Électricité de France* EDF) a series of the *Complementary Safety Studies* (CSAs) covering a number of extreme external hazard scenarios (earthquake, flooding, etc., but which excludes aircraft crash).

In the absence of immediately arising safety problems, in its nuclear licensing role ASN reviews the nuclear safety case for each NPP on a ten-yearly (decennial) safety review cycle. However, events at the Fukushima Daiichi NPPs were considered sufficiently serious to warrant a root-and-branch examination of the individual NPP performance when subject to an extreme external event. In effect, ASN together with the other European nuclear safety regulatory authorities acknowledged that the present assessment and demonstration of nuclear safety at the NPPs (and other nuclear facilities) did not guarantee that the plants would withstand the challenge of *beyond design basis* hazards (hazards beyond those considered in the nuclear safety demonstration). The purpose of the CSAs was to explore and identify those extreme external hazards that could exceed the *baseline safety standard* and, in doing so, identify the safety functions, design features and equipment required to function to ensure continuing NPP safety in those extreme situations, such as earthquakes, flooding, long-term loss of nuclear fuel cooling, loss of electrical power supply. The CSAs specified certain end-points (core meltdown, uncovering of fuel assemblies stored in a spent fuel pool, significant releases, etc.) for which the NPP is required to continue to defend against until the post-incident aftermath was under control and stabilised.

As part of its assessment of the NPP operator's CSA response, ASN instructed *L'Institut de Radioprotection et de Sûreté Nucléaire* (IRSN) to independently evaluate the operator's CSA programme. IRSN identified that, in addition to the current nuclear safety provisions, a new concept of a *hardened safety core* of *structures, systems and components* (SSCs) should be put in place – these SSCs are to be in addition (where warranted) to the existing safety systems and management procedures. This, IRSN argued, would render NPP sufficiently robust and reliable to cope with all considered extreme external hazard scenarios necessary to maintain control of reactivity, heat removal and containment of radioactive materials, applied to both the in-core reactor fuel load and the spent fuel storage ponds.

It follows that the NPPs identified to be in need of a *hardened safety core* are presently at heightened risk of catastrophic failure should they be subject to an extreme external event. In other words, jointly ASN and IRSN acknowledge that the present NPP designs, operational practises and NPP sites are vulnerable to a Fukushima Daiichi type of catastrophic failure and uncontrolled radioactive release.

It is the urgency of the provision of the SSCs for individual NPPs that points to the unsatisfactory condition of a number of the French NPPs that are currently operational and which are remain so until the SSCs have been approved, installed and commissioned. In fact, IRSN emphasised that EdF's response to the CSAs should be considered interim and provisional, inasmuch *'that the elements and demonstrations[of EdF] deemed admissible and acceptable at this stage may require further more in depth analyses'*.[1]

The programme of upgrading the French NPPs may take several years, during which and as acknowledged by ASN and IRSN the risk of failure under extreme external hazards will remain heightened. A number of individual NPPs have been identified as requiring urgent evaluation *'installations et sites prioritaires à traiter en 2011'* by ASN[23] and these are listed together with the specific safety shortfalls as gleaned from the CSA reports. ASN requires EdF to identify the measures necessary to achieve the *hardened safety core* by 30 June 2012, although the programme for practicable implementation of the SSCs in support of this at each affected NPP has yet to be determined.

TABLE 1 lists the specific sites of 43 NPPs that are subject to urgent re-assessment as a result of the Fukushima Daiichi incident and outlines aspects of the design and equipment shortfalls at each NPP – shortfalls in the resilience of these and other French operating NPPs are identified in TABLES 6 - 10 inclusive of the main review R3205-A1.

In Summary: The main Review R3205-A1 considers the results of ASN's own *Complementary Safety Studies* (CSAs), undertaken as part of the post-Fukushima *Stress Tests*, by examining each NPP for response to external initiating events that are in excess of the prescribed *design-basis*. Where the forces and environment generated by aircraft crash appropriately match or exceed the CSA initiating event topic (eg the crash impact force matching or exceeding the safe shutdown earthquake - SSE) then the weaknesses and/or shortfalls of the NPP are taken to *'crossover'* and to at least equally apply to aircraft crash – in some instances, aircraft crash may encapsulate two or more CSA initiating events (for example, SSE^{+} seismic loading and fire exposure). This CSA *crossover* methodology reveals that the ASN's own requirements expose varying degrees of compromise of the *baseline safety standards* for each of the different series of NPP when subject to aircraft crash, either accidental or of malevolent intent – the NPPs so compromised are identified in **TABLES 6** through to **10** in the main review R3205-A1.

This Addendum identifies, again from the CSAs, the weaknesses and shortfalls in the response and resilience to other extreme external events (other than aircraft crash) that could result is a nuclear safety risk below the *baseline safety standards* – this category of fault conditions, like but in addition to aircraft crash, could result in catastrophic failure of the nuclear island, particularly via the plant being subject to a prolonged station blackout (loss of powered cooling of the in-core and stored spent nuclear fuel) and/or loss of the ultimate heat sink.

ASN itself has identified 41 of the 58 operational French NPPs to require some degree of modification to meet the *stress tests* and *baseline safety standards* if external hazards of the severity at Fukushima Daiichi are to be withstood. Certain of the plants are likely to require a substantial programme physical modification (eg Bugey) to be completed, but which may not be economically justifiable when the age and remaining serviceable life of the NPP is taken into account (eg the two Fessenheim NPPs now in the fourth decennial). The SSC implementation programme, in itself, is likely to be challenging because each modification to the existing plant will require trialling and licensing on nuclear safety grounds, particularly if it trespasses into and impairs the normal safety function of the plant, both during the execution of and following completion of the SSC works; and the SSC works will be specalised, possibly with high demands on design, construction and regulatory resources so that the SSC programme overall will stretch out over many years.

Thus, there is likely to remain doubt, at least until the SSCs are fully commissioned, about the resilience of the French operating NPPs to extreme external events.

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TABLE 1 SHORTFALLS IN RESILIENCE AGAINST EXTREME EXTERNAL EVENTS AT THE ASN PRIORITY NPPs[4]

NPP SITE	Nº NPPs PRIORITISED (TOTAL UNITS)	OLDEST NPP YEAR	EARTHQUAKE	FLOODING	SPENT FUEL POND	ULTIMATE HEAT SINK	RADIOACTIVE RELEASE	STATION BLACKOUT
BELLEVILLE	2 (2)	1987	✓ low SSE rating (0.1g)	✓ no account of Strickler coefficient – elevated water flow levels ✓ below CMS flood level				
BLAYAIS	2 (4)	1981	✓ dam burst	✓ previous flood incident (1999) ✓ elevated hatch thresholds required				
BUGEY	2 (4)	1978	✓ flood containment damage loss of ultimate heat sink ✓ requires seismic analysis of dykes, etc protecting against flood ✓ low SSE rating (0.1g) ✓ seismic reinforcement required	✓ cooling canal embankment damage nuclear island below flood level ✓ below CMS flood level	✓ spent fuel flask drop	✓ heat sink higher than NPP platform	✓ local hydrogeology favours groundwater contamination	✓ containment pressure electrical backup
CATTENOM	4 (4)	1986		✓ below CMS flood level				
CHINON	2 (4)	1982		✓ below CMS flood level				

CHOOZ	2 (2)	1996		✓ flood operating rules not applied				✓ lightening strike protection
CIVAUX	2 (2)	1997	✓ seismic qualification under review	✓ cooling canal embankment damage nuclear island below flood level		✓ safety case justified only for single NPP on site	✓ local hydrogeology favours groundwater contamination	
CRUAS	2 (4)	1983		✓ cooling canal embankment damage nuclear island below flood level ✓ thousand year flood peripheral protection issues ✓ flood operating rules not applied and isolation procedures not in place	✓ below CMS flood level	✓ Heat sink 'clogging' review awaited		
DAMPIERRE	2 (4)	1980	✓ low SSE rating (0.1g)	✓ flood operating rules not applied	✓ below CMS flood level			
FESSENHEIM	2 (2)	1977	✓ flood containment damage loss of ultimate heat sink ✓ requires seismic analysis of dykes, etc protecting against flood ✓ seismic reinforcement required	✓ cooling canal embankment damage nuclear island below flood level ✓ below CMS flood level ✓ assessment required of standing water level following embankment failure	✓ spent fuel flask drop	✓ assessment of consequences of Grand Canal d'Alsace embankment failure required ✓ Heat sink 'clogging' review awaited ✓ heat sink higher than NPP platform	✓ local hydrogeology favours groundwater contamination	✓ Grand Canal d'Alsace embankment failure could result in total station blackout ✓ reactor basement reinforcement required

FLAMANVILLE	3† (2)	1985	✓ make-up SEA ponds transfer must be ‘hard cored’ and seismic qualified			✓EPR total loss of heat sinks study required ✓ make-up SEA ponds must be ‘hard cored’		✓EPR 2-hour battery backup requires extending
GOLFECH	2	1990						
GRAVELINES	3 (6)	1980	✓ lack of reactor cavity robustness	✓ below CMS flood level ✓ elevated hatch thresholds required ✓ flood operating rules not applied and isolation procedures not in place		✓ intake channel retaining wall stability under assessment	✓ rupture etc of oil pipeline crossing site requires justification	
NOGENT	2 (2)	1987		✓ cooling canal embankment damage nuclear island below flood level ✓ flood operating rules not applied and isolation procedures not in place				
PALUEL	3 (4)	1984	✓ make-up transfer water must be ‘hard cored’ and seismic qualified			✓ make-up SEA ponds must be ‘hard cored’		
PENLY	2 (2)	1990	✓ make-up SEA ponds transfer must be ‘hard cored’ and seismic qualified			✓ make-up SEA ponds must be ‘hard cored’		✓ lightening strike protection

ST ALBAN	2 (2)	1981		✓ cooling canal embankment damage nuclear island below flood level ✓ below CMS flood level ✓ thousand year flood peripheral protection issues ✓ maximum river flood scenario requires evaluation of embankment structures					
ST LAURENT	1 (2)	1981							
TRICASTIN	2 (4)	1980	✓ flood containment damage loss of ultimate heat sink ✓ Extensive evaluation of embankment structures required particularly with regard to internal erosion and liquefaction	✓ cooling canal embankment damage nuclear island below flood level		✓ heat sink higher than NPP platform	✓ knock-on effect of Tricastin AREVA facilities to the be assessed	

† Includes EPR under construction.

1 *Post-Fukushima Complementary Safety Assessments: Behaviour of French nuclear facilities in the event of extreme situations and relevance of the proposed improvements*, Report No 679, IRSN, February 2012

2 *Présentation des évaluations complémentaires de la sûreté des installations nucléaires au regard de l'accident de Fukushima*, ASN 9 May 2011

3 Appendix II to Nuclear Safety Authority Opinion N° 2012-Av-0139 of 3rd January 2012 - *Provisions to Improve the Robustness of the Facilities to Extreme Situations*, ASN – see Nuclear Safety Authority (ASN) opinion N° 2012-AV-0139 of 3rd January 2012 concerning the complementary safety assessments of the priority nuclear facilities in the light of the accident that occurred on the nuclear power plant at Fukushima Daiichi, ASN 3 January 2012

4 All of the operating NPPs are identified as *Priority Sites* by ASN TABLE 3, but not all NPPs on each site are considered to be rated as *Priority*.