Jersey Government's response to the Flamanville 3 Public Inquiry.

Submitted on 31st August 2006

Introduction and overview

Notwithstanding the legal requirements that exist for consultation and cooperation under the Directive 96/29/Euratom the Jersey Government welcomes the opportunity that has been extended to make its observations on the proposed third nuclear reactor at Flamanville. We are grateful for the extension that has been granted to the period for making our observations and also for the presentation that was made to the members of our States by representatives from EDF.

We would wish to build on this dialogue to strengthen and improve the arrangement that should exist for co-operation and for notification in the case of incidents. We also wish to return to the matter of compensation payment arrangements in respect of potential damage to our island or economy as a result of failures at French nuclear facilities adjacent to Jersey.

The public of Jersey have lived with the proximity of French nuclear installations at Flamanville and Cap de la Hague for many years now. We must however remain certain that facilities that have the potential for catastrophic impact on our community are designed, built and operated to the highest possible standards

Our overall conclusion is that there are some serious concerns about the proposed plant; including the fact that this is an unproven design with no working example yet completed anywhere. We are also very concerned to note the complete absence of any evidence of post 9/11/2001 resilience being designed into the reactor and associated buildings given that acts of the most appalling terrorism must now be regarded as real possibilities.

Whilst existing nuclear facilities have not been designed to withstand such attacks, any new nuclear facilities to be constructed post-9/11 must surely be specifically designed to withstand the deliberate high speed impact of a civil jet aircraft weighing several hundred tonnes. We are also concerned about the plants design resilience to other acts of a malicious nature.

Our concerns are detailed in the following pages and we would like them to be considered by the Inquiry. We will require satisfactory responses to our comments and questions relating to the documents put forward by EDF, without which ***we must maintain a position of formal objection to this development.***

1. Plant Design.

The EPR design has yet to be constructed and commissioned worldwide. There is an EPR plant presently under construction at Olkiluoto Finland but this plant is now 12 months overdue in only its second year of construction and it is admitted by Finland's nuclear safety regulator, STUK that 20 to 30% of the nuclear safety features had (then 2005) yet to be ratified or indeed submitted by the plant developer AREVA. In fact the AREVA EPR design has yet to be fully licensed anywhere except in France, with the Finnish NPP proceeding on the basis of a Construction Licence, assuming that the design will be satisfactorily completed. In the United States, the Nuclear Regulatory Commission has yet to complete its assessment of the generic nuclear safety case of the AREVA design which, along with the subsequent detailed safety case approval is likely to occupy four or more years henceforth.

We observe that the discharge performance of the proposed Unit 3 EPR is not that much better, if at all, than the N^o 1 and 2 existing units which have been in service for 20 years (Tables B-IV.4-a & b). A point to consider here is that fuel burn-up (irradiation) will be developed further for the EPR and, with this, the radioactive effluent (both gaseous and liquid) discharge rates per MW_e generated would also be expected to rise. This is especially so when MOX fuel is placed in the reactor.

It is not clear if the 0.3 mSv/year dose constraint applies to the whole site or just to the third stream

The Jersey Government would wish to be re-assured that the plant will not be commissioned before a full, internationally recognised, safety case has been completed.

2. Regulatory control limits

It is not clear if the principles of As Low as Reasonably Practicable (ALARP) and Best Practicable Means (BPM) are applied in managing discharge performance. To illustrate the value of this approach ***we recommend that the inquiry consider*** the principles of the British Energy Corporate Radioactive Waste Management Strategy as described below.

"In British Energy, we recognise our duty to care for the environment. We will seek continual improvement in our environmental performance by:

- *Complying with relevant legislation and regulation;*
- *Reducing the environmental effect of our activities to a practicable minimum by the prevention of pollution, reduction of waste and the efficient use of resources;*
- *Promoting the efficient use of energy;*
- *Continuing to develop a sense of environmental responsibility among staff and contractors;*
- *Openly reporting performance against environmental targets."*

The objectives of the British Energy Corporate Radioactive Waste Management Strategy are to:

1. Maintain radiation doses to the workforce and the general public from radioactive waste management operations, including disposal, within legal limits and ***As Low As Reasonably Practicable (ALARP)***,
2. Ensure consistency with Government Policy, regulatory constraints, and the availability of radioactive waste storage and disposal facilities,
3. Minimise the generation of radioactive wastes as far as is reasonably practicable by application of ***Best Practicable Means (BPM),***
4. Dispose of all wastes as soon as practicable where a safe and economic route has been established,
5. Store safely all wastes for which a safe and economic disposal route has yet to be established,
6. Maintain adequate safety cases for all waste management activities including handling, accumulation and storage of wastes on British Energy sites,
7. Develop the technology and processes required for the safe retrieval, treatment, packaging, and interim storage of wastes,
8. Co-operate with other UK waste producers on radioactive waste policy and strategy issues, and manage major stakeholder relationships effectively,
9. Maintain adequate and prudent financial provisions to meet future liabilities,
10. Maintain an inventory and records of radioactive waste accumulated.

The over-arching objective of this corporate radioactive waste management strategy is to ensure that a consistent safe approach continues to be adopted in the taking of decisions on radioactive waste management matters for all British Energy power station sites and in all matters associated with fuel cycle activities.

3. Use of MOX fuel

The Jersey Government is concerned about the lack of consideration in the application with regard to the transportation safety case for i) MOX fuel under delivery to the Flamanville site, ii) spent fuel (including MOX) from the site, both in terms of accidents and malevolent acts, and how a radioactive release could relate to and result in radiological, health and economic consequences to the population of Jersey.

We seek information on the predicted radioactive discharges for the EPR operating with a MOX fuel core (as is expected).

4. Hazard assessment

Whilst recognising that security measures have been increased at nuclear installations worldwide since September 2001, and that details of such measures would not be disclosed in a public document, we do have some concerns about the detail put forward on hazard assessment.

- ***It is inappropriate to assume that the outcome of a terrorist act can be considered to be wholly within a probabilistically derived safety case*** – this might be applied to both intentional aircraft crash and other malicious acts.

- Resistance to aircraft crash is claimed to have been designed into the “aircraft shell” of the containment buildings that contain nuclear fuel (the reactor, fuel ponds and new fuel store), although no details are given of the additional strengthening design changes that have been made since the Terrorist actions of 9/11/2001. We attach for the inquiry's consideration a report prepared for the States of Jersey by John Large Associates which looks in detail into the matter and which challenges the assumptions contained in EDF's 1993 document DGSNR/SD2/033, EDF-SEPTEN CONFIDENTIEL DEFENSE. **We seek categorical assurances and supporting technical information that the design of the plant to be constructed is capable of withstanding deliberate terrorist attack of the type witnessed on 9/11/2001**.

- ***Further regard should be given to the maximum amplitude assumed for explosive pressure waves*** (D-IV.4.5), particularly regarding i) over-pressure or blast damage to equipment, containments, etc., and ii) effect on operating personnel.

- ***The developer should show how the security and safety measures have been proven to be reliable and effective against malicious acts, in terms of a range of defined Design Basis Threats (DBTs) and Operational Safeguards Response Exercises (OSREs)*** in a manner similar to that required by the United States Nuclear Regulatory Authority in its licensing procedures.

- Calculations are for a failure to the EPR only, not to the site as a whole. ***We therefore seek information on a maximum credible accident scenario for the whole site***. (Presumably this has been done for the Units 1 and 2, but no reference to any such studies is provided.)

- The accident scenario models use 'a Gaussian plume model'. There are many such models, and different ones need to be applied to coastal conditions compared with inland ones, and to normal releases compared with catastrophic releases involving large thermal plumes. ***We would wish to be informed which models were used and why they were chosen***.

- ***We note the lack of consideration of the hazards that could be planted by malicious intent*** i.e. a "sleeper" device during the construction phase when security over the many individual construction workers and sub-contractors is difficult.

- An indication that confirms our understanding that MOX fuel will be deployed in the EPR is given in Table D-V.1a with its very significant release rates from fuel pin cladding failure at high fuel burn-up levels. However, there is ambiguity over other data relating to PCC-3 and PCC-4 event triggered accidents, see for example Table D-V.1-b which projects exposures in the aftermath of a number of postulated accidental releases, these being regarded as somewhat low for a MOX fuelled incident. ***Clarification is sought on the fuelling systems adopted for the PCC 3 and 4 event scenarios*** – a detailed source term or fuel inventory should be provided to clear any ambiguity (D-V.1.2.4.2.1),

- For one specific accident scenario where the reactor fuel core melts and the molten fuel burns its way through the RPC, it is assumed that an entirely passive core (corium) catcher will, first, spread and then contain and cool the liquid fuel mass, with the 150 tonne, or thereabouts, fuel load and the entire fission product inventory being contained within the RC – ***this has never been achieved before and not at all demonstrated by trial at any reasonable level of scale***.

5. Emergency planning regime

We note that the French authorities have certain obligations under EC Directive 96/29/Euratom, also known as the BSS96 Directive, laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation.

With respect to preparation for intervention (Article 50) the Directive requires that each Member State shall ensure that account is taken of the fact that radiological emergencies may occur in connection with practices on or outside its territory and affect it.

Each Member State is required to seek to cooperate with other Member States or <u>non-Member States</u> in relation to possible radiological emergencies at installations on its own territory which may affect other Member States or <u>non-Member States</u>, in order to facilitate the organization of radiological protection in these States.

Each Member State shall, in the event of a radiological emergency occurring at an installation on its territory, or being likely to have radiological consequences on its territory, establish relations to obtain cooperation with any other Member State or <u>non-Member State</u> which may be involved.

We therefore look to create a situation where:-

- Jersey is treated as a separate entity to the UK and arrangements between Jersey and France are brokered directly. It is not a credible approach to require chains of communication via Paris and London for the rapid notification of accidental releases for instance.
- A measure of correspondence is established directly between the French and Jersey systems of radiological protection, particularly as Jersey must rely upon such contact for notification of any radioactive release, advice on the radionuclide content of the release, and projection of the whole body effective and organ doses that could potentially arise from the release.

- Details of when and to whom notification of a radiological incident is addressed to the States of Jersey are established. The notification should be incident-specific, particularly in that the nature and severity of the incident that triggers notification should be established (ie there should be an agreed colour-code alert or similar system in place) so that there is no opportunity for ambiguity over what level of preparation and response is required of the States of Jersey authorities
- The foregoing recommendation relating to the fixed NPP site at Flamanville is also applied to transportation of nuclear materials (unirradiated and irradiated fuels) to and from the NPP.
- Full copies of the *Special Emergency Plan* (PPI) are provided to the Jersey authorities by the Flamanville local Prefecture

6. Decommissioning and dismantling

We feel that insufficient attention has been given to this aspect of the reactor's life-cycle and would recommend that the inquiry considers:-

- The projected date and period of dismantling to complete *'green field'* decommissioning of the NPPs at Flamanville should be stated
- The environmental and potential health impacts of decommissioning in the interim and longer terms should be provided.
- The measures and actions required to render the Flamanville site safe (ie by decontamination and containment, etc) in the aftermath of a serious incident that renders the NPP inoperable by damage and/or contamination (for example, the clean-up and radiological management required in the aftermath of a large scale incident).

- The EPR project, as a whole, from cradle to grave, should be evaluated in terms of its sustainability for this present and future generations

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Appendix 1 Report from John Large Associates

ADDITIONAL COMMENTS AND OBSERVATIONS ON THE PRESENTATION NOTE OF THE APPLICATION FOR AUTHORIZATION TO CREATE A 3RD NUCLEAR POWER UNIT AT THE EXISTING FLAMANVILLE SITE

RISK AND HAZARD ASSESSMENT

Obviously, real risks threatening any hazardous plant must include malicious acts (terrorism, sabotage, etc) that intelligently and intentionally seek out the vulnerabilities of the plant and its protective and safety systems. Nuclear plants are no exception to this and, moreover, it might be convincingly argued, that such plants could be considered by those of ill intent to be attractive targets by reason of the public's perception, sometimes and in some respects ill-judged, of radiation and by the extent of psychological, economic and societal damage that such an attack might create. Although and however misguided public perception might be, this should not detract from the fact that a well thought-out attack on a nuclear power plant could, if successfully implemented, result in very severe radiological consequences.

The so-called worst case incident for the EPR nuclear power plant proposed at Flamanville culminates in the melting of the 150 or so tonnes of intensely radioactive fuel held in the reactor core, a small fraction of which is assumed to disperse to atmosphere. The overall target for an *accidental* core melt failure is 10-5 for each reactor for each year of operation for every type of failure and hazard (or initiating events),[1] which being drawn from probabilistic (*a priori*) considerations it cannot possibly relate to malicious acts. Other accidental situations that result in a radioactive release relate to the containment of the irradiated (or spent) fuel held in storage in the nuclear power plant storage ponds; release from the stores that hold the radioactive waste that arises during normal operation of the plant; and/or from transportation incidents involving the delivery of new, unirradiated fuel or with the dispatch of spent fuel from the power plant.

PROBABILISTIC APPROACH TO NUCLEAR SAFETY

So, put simply, the risk to a nuclear power plant is a combination of the

risk of incident ~ severity of the initiating event

If the risk is unacceptable then, it is assumed by the nuclear safety case, the consequences must be tolerable, but if the risk is acceptably low (say one in one million chance) then, because the incident is unlikely to happen by chance, then the consequences can be severe and intolerable. This composite of *Acceptable Risk -v- Tolerable Consequences* is the basis adopted for the probabilistic safety reasoning and engineering design of nuclear power plants worldwide.

If, however, the incident is contrived and not accidental, that is it is a deliberate act, then it is not possible to determine the chance that it will or will not happen so, for malicious acts, the probabilistic risk approach cannot be absolutely relied upon. Similarly, if the initiating incident is contrived to seek out the vulnerabilities of the plant and, perhaps, interfere with the restoration countermeasures to restore stability to the plant, and/or impede the mitigation actions to minimise radiation dose during the aftermath of the incident, then the measure of the consequences cannot be reliably determined.

In effect, malicious acts are beyond the domain of the probabilistic reasoning adopted for the safety and design of nuclear plants. In order to account for malicious acts either the nuclear plant has to be substantially amended in its physical and safety system design and construction or a new order of rigorous and failsafe management to ensure the absolute security of the plant has to be implemented.

APPLICATION TO THE PROPOSED FLAMANVILLE EPR PLANT

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[1] Initiating events, including external hazards, are classified into four groups of *Plant Category Conditions* (PCCs) with each being defined (D-IV.1.2.2.1) PCC1 to PPC4) with PCC4 reckoned to be lower than one chance per million per reactor per reactor year of operation with, similarly, malicious acts seemingly excluded from this fault categorisation. The severity of damage and the magnitude and impact of the radioactive release are defined in terms of three levels of *Radiation Risk Category* RRC-A, RRC-B and Specific Accidents of 3 categories (D-V.1.2.4.1.1).

There is, perhaps quite justifiably, a general reluctance for the nuclear industry worldwide to release any information whatsoever about the vulnerability of and installed defences to protect against terrorist attack of nuclear installations.

Indeed, the defence against terrorist and other malevolent acts is not so obvious in the EPR design. This is most probably because the EPR structural design and layout was committed to well before the September 11 2001 acts of terrorism that highlighted the need for the engineered design of hazardous plants to be resistant against malevolent acts such as deliberate aircraft crash. In this respect the anti-terrorism features will comprise, one has to assume because details have been withheld, mainly:

- means by which ill-intended approach to the plant is restricted by security cordon and, specifically, to safeguard against for commercial aircraft attack, absolute security at national and international airports; and
- by the robustness of the plant generally to withstand physical intrusion (by explosive device, crashing aircraft, truck bomb, boat launched missile, etc);

A second anti-terrorism line of defence is the claim that any reasonably foreseeable malevolent act would not result in severity of damage and consequences greater than that of the nominated design basis accidents.

However, the present state of the first EPR now under construction at Olkiluoto in Finland[2] does not suggest that the original (pre-9/11) structural design and layout of the key nuclear safety issue buildings and plant have been significantly modified to resist acts of terrorism. This is not surprising since major structural engineering amendment to the original design would necessitate fundamental revisions of the buildings, plant and layouts which, in themselves, would require a time consuming review of the detailed and overall nuclear safety cases.

Instead, the original EPR design is largely substantiated to be 'terrorist-resistant' by reliance upon increased security at national and international airports and by the recently introduced concept of *'segregation'*. For segregation the so-called *safeguard* buildings clustered around the most sensitive parts of the plant (reactor, spent fuel, emergency diesel, and seawater intake buildings) that, in themselves, do not fulfil a nuclear safety critical role.

Obviously, to safeguard against intentional aircraft crash the only effective measure (other than security at the departure airports) is to physically enhance the structure of the building enclosures although, since the fundamentals of the building design are committed to at an early stage of the design process, other than a radical change of the building structures and/or layout (for example, building underground), little can be done to improve the resilience of the existing EPR containment design. There are no apparent signs that the post 9-11 EPR designs have undergone such a radical enhancement[3] and, even for the *safeguard* buildings, no details of how these sacrificial structures have been enhanced to protect the nuclear safety critical plants are available.[4,5]

Although, on the basis of not revealing to would-be attackers any aspect of the plants resistance to aircraft crash, accidental or otherwise, EdF excludes any reference to or detail of the measures included in the EPR design and construction that safeguard it against aircraft attack. However, in a leaked document relating the EPR resistance to aircraft impact,[6] EdF argues that the existing

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[2] European Pressurised Reactor at Olkiluoto 3, Finland - Review of the Finnish Radiation & Nuclear Safety Authority (STUK) Assessment, Large J H, R3123-A2, July 2005 - http://www.largeassociates.com/R3123-a2%20final%20Issue.pdf

[3] That is simply thickening the concrete of the structures would not apply for aircraft impact and major changes would be required to strengthen the internal structures (equipment and its supports) to resist shock loading from the considerable impact forces transmitted through the built structure.

[4] The concept of arranging a ring of protective buildings around the key nuclear enclosures, ie segregation, seems to be a new design concept in the EPR introduced since 9/11 2001, although that said, there does not appear to have been any major design and layout changes.

[5] The only example of a specific aircraft-crash resistant reactor design now progressing through the construction stage is the relatively small radioisotope production reactor at Lucas Heights in Australia. In this design the secondary containment dome is augmented with a visually striking frame of triangulated beams which receive and dissipate the impact of a crashing aircraft.

[6] *DGSNR/SD2/033-2003*, *EDF-SEPTEN CONFIDENTIEL DEFENSE* together with an appendix (*Annex 1/Appendix 1*) in all totalling 9 pages - so far as I can tell, the leaked EdF document is genuine and has not been altered or tampered with from its original

nuclear safety case for the *accidental* crashing of a small (fighter) military aircraft is of sufficient severity and damage outcome to cover an *intentional* crash of a fully fuelled, large commercial passenger aircraft.[7] Not only is this postulate is unproven by EdF but there are considerable weaknesses in the argument for the robustness of the EPR plant to survive a crash even of a small military aircraft. The adoption of the military aircraft case in justification of the EPR design is seriously flawed for a number of reasons,[8, 9] but particularly in the assumptions that

i) the impact footprint (against the building structures of the EPR) of a military aircraft is sufficient to adequately represent the impact footprint of a much larger commercial aircraft;

ii) that the total energy dissipated into the building structure by the impact of a commercial aircraft (of say of around 250 tonnes fully fuelled deadweight) would generate no greater induced shock and oscillatory loading into the building and, particularly, to the installed reactor equipment within than that generated by a military fighter aircraft (of 2 to 5 tonnes total deadweight); and

iii) that the very much greater volume of aviation fuel[10] released upon impact of a commercial aircraft would burn in a predictable manner and not form an explosive fuel-air mixture or be forced into the building enclosure where the vapour could ignite with explosive and severely damaging results.

EdF goes further to mitigate the consequences of an aircraft mounted terrorist attack against a nuclear island by arguing that

iv) the four levels of safety system intervention and passive containment levels of the EPR would be sufficient to provide complete surety of the nuclear island.

Further justification that the EPR design is sufficiently resilient against attack by a large commercial aircraft is taken from the assertion that the would-be terrorist pilot is unlikely to have the skills necessary

v) to fly the aircraft at the low angle of attack required to crash into the EPR complex of buildings; and vi) to manoeuvre around various obstacles present on and around the power station site.

Of EdF's claims and assertions:

v) and vi) Terrorist Pilot Skills

The international nuclear industry's approach to *accidental* aircraft crash generally derives from the guidelines and principles set out by the US Department of Energy. Essentially, this approach assumes some form of loss of control of the subject aircraft, its subsequent deviation from the intended flight path and the chance of it crashing into the target nuclear plant. The nuclear plant is defined as a *crash area* and the parameters relating to this are calculated from the *effective fly-in*, *footprint*, *shadow* and *skid areas* that are determined from established codes[11] - it is these aspects of a terrorist attack that form the basis of approach of EdF rationale.

The argument that the shallow glide path necessary to home in on the nuclear island would not be available to a terrorist pilot is not particularly convincing because it is quite clear from the

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[7] In this respect there is some confusion over test work conducted in the United States wherein a small aircraft was crashed against a monolithic concrete block. The purpose of this test was not to determine the strength of concrete structures but to enable the dynamics and thus the generation of impact forces of a crashing aircraft (its progressive crumpling) which could be then applied to the mathematical modeling of an aircraft impact with a building structure (concrete or otherwise).

[8] The nuclear industry's approach to aircraft crash generally derives from the guidelines and principles set out by the US Department of Energy *Accident Analysis for Aircraft Crash into Hazardous Facilities*, DOE-STD-3014-96, 1996 see also for practical application *NUREG-0800, Section 3.5.1.6 Aircraft Hazards*, Nuclear Regulatory Commission, 1981

[9] For example, on page 8 of the EdF Document there is reliance upon past experience (REX - *retour d'experience* or feedback) yet there is no reference cited for the data relied upon.

[10] For example a fully laden Boeing 747 has a 173,477 kg fuel capacity at take-off, and similarly a Boeing 767 72,831 kg, a Boeing 777 135,360 kg, an A340 108,000 kg and an A330 74800 kg.

[11] STD-3014-96, US Department of Energy, 1996

recently released film of the 9-11 Pentagon attack that the aircraft approaching the Pentagon was at very low altitude and maintaining a very shallow flight path up until the moment of impact.[12]

Similarly, the necessity to manoeuvre to avoid building and other obstacles nearby or on the nuclear site could be mainly overcome by approaching most nuclear islands from the seaward side, with it unobstructed and direct line of vision into the plant from 30 km or more.[13]

Indeed, the fact that the 9-11 terrorists were dedicated to their objectives, so much so that they specifically trained in pilot skills for more than a year does nothing to presuppose that the terrorist intent on attacking an EPR installation (or indeed any other existing nuclear reactor installation) would undertake similar intensity of specific training to meet that objective.

iv) EPR Safety Systems:

The assumption is that the four levels (safety equipment and containments) intervening would be sufficient to isolate the key nuclear safety functions, etc., of the EPR from failure and/or loss of control during and in the aftermath of an aircraft impact.

The delineation of the nuclear safety case for the EPR comprises four groups according to the projected frequency of occurrence of the initiating event, these being i) *Anticipated Transients* at higher than 10-2 per year (frequency per reactor year of operation),[14] ii) and iii) *Classes 1 & 2 (Design Basis) Accidents*[15] at between 10-2 - 10-3/y and less than 10-3/y respectively, and iv) *Severe Accidents*.[16]

The point here is that the four levels of safety and containment systems (redundancy and diversity) relied upon by the EdF document are justified in terms of probabilistic occurrence which includes for the remote possibility of an *accidental* aircraft crash. In fact, the possibility of an accidental crash of a commercial aircraft is reckoned to be so remote that there is no need to prepare for it,[17] being that the chance of an untoward *accidental* event is reasonably

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[12] The EdF Document Appendix refers to the need for a 'horizontal stabilised flight at a very low altitude (less than 50m) for a successful attack – this seems to be about the approach pattern adopted for the Pentagon attack of 9-11 and, in any case, large commercial aircraft are extremely stable at the low (typically 3.5o) landing approach descent.

[13] The studies for the impact of a heavy military aircraft and commercial airliners, although cited for the Sizewell B assessment were not then and remain unavailable to the public domain. However, it is interesting to note that the title dealing with the military aircraft scenario refers to

> *'The Effects of Impact Heavy Military Aircraft Adjacent to* ***but Not Directly on*** *the Vulnerable Buildings'*

with the emphasis suggesting that somehow the pilot of this hypothetical aircraft was able to retain some degree of control (and also possess the knowledge of the critical parts of the plant) to avoid the most vulnerable parts of the plant. It is on the basis that the heavy military aircraft would not impact directly, that the Sizewell B operator claims that the likelihood of an unacceptably severe fire or explosion following the impact is sufficiently low to be discounted. In other words, the nuclear industry considers there to be little justification in installing additional features (ie beefing up) to provide aircraft crash resistance. In fact the NUREG-0800 based analysis permits the introduction of the mitigation that the pilot will retain sufficient control to avoid striking the nuclear plant – for military pilots this is assumed to be for 95% of the time or that, independent of all other considerations, the P_{hit} probability is equal to 0.05.

[14] 10-2/year is a chance of one in one hundred years for each year of reactor operation.

[15] These are the definitions of the Finnish regulator STUK for the Olkiluoto EPR - *Class 1 & 2 Accidents* are defined by severity with, for example, loss of coolant accidents (LOCA) of less than 20cm2 breach being *Class 1* and breach areas larger than this being *Class 2* – the largest LOCA is assumed to be a double guillotine failure of a main primary coolant circuit pipe. Similar *Class 1 & 2* classification of accident severity is applied to reactivity excursions, etc., reactor scram failures, and so on.

[16] These are as described for the Finnish Olkiluoto EPR but are most probably applicable to all other EPR designs originating from AREVA – see also Footnote 1 of the EdF document – *'This definition, consistent with the EPR classification, corresponds normally to the term « design extension » which is found in some countries'*. - Under the Finnish nuclear regulatory system, extraordinary situations such as *accidental* aircraft crash require separate assessment and certain event circumstances are not classified solely on the predicted frequency of the initiating event, being considered to be *'Design Extension Conditions'* (DEC).

[17] Applied to a civil airliner operating at altitude and passing along a prescribed flight path, this *a posteriori* probabilistic approach adopts rates drawn from actual crash incidents, yields a very low accidental crash probability. Essentially, the whole probabilistic assessment outcome is determined by the chance of a very small missile, the aircraft, accidentally hitting a small target, the nuclear plant, located in a very large geographical space. Applying this to nuclear plants suggests that accidental aircraft crash rates are sufficiently low (<107 per year) to satisfy the requirements that the hazard of occurrence is so remote that it cannot be expected to affect the plant. In application this means that for the UK Sizewell B pressurised water reactor (PWR) safety case (of 1987) aircraft crash onto the power station site was identified and considered as an external hazard that had the potential to initiate events that could lead to an accidental release of radioactivity. The expected frequency of impact of all

foreseeable, whereas potentially severely damaging the possibility of occurrence is so remote that it may be discounted.

The point here is that a terrorist attack is a planned event, so it cannot fall within the risk-damage severity composite relied upon for *accidental* events. That is although the airborne terrorist attack is reasonably foreseeable (9-11), its frequency of occurrence cannot be reckoned *a priori*, so its potential radiological consequences cannot be dismissed on an assumed low frequency of occurrence.

Again as a reference to the EPR design, for the Finnish Olkiluoto EPR[18] the assessment of the plant to large commercial aircraft impact has been withheld for, according to STUK, security reasons. However, it is interesting to note that the *design extension aircraft crash* is an 'add-on' to the EPR safety case, suggesting that the original EPR containment design, being pre September 11 2001, was not specifically designed to resist any impact loading greater than a light aircraft crash which was then (pre 9/11) the universally accepted design basis case drawn from the improbability (pure chance) of a civil airliner accidentally crashing onto a nuclear power plant.

This is much the same reasoning applied by EdF that the design of the safety and containment systems for a light military aircraft impact, just by chance, are sufficient to cater for the impact of a large commercial aircraft. In fact, the EdF document goes further by stating that impact of a large, fully fuelled passenger aircraft would not result in radiological consequences that would exceed the present Category 4 level of foreseeable *accident*.[19]

iii) Aviation Fuel Burn:

EdF claims that the aviation fuel released during the impact would result in a fire ball of 90m diameter, a temperature of 1,200oC which would be completely exhausted and extinguish within 2 minutes.

There are a number of difficulties with this claim with, for example, unless ignition is immediate and efficient, the fuel is likely, indeed almost certain, to form a vapour which will be available for dispersion and explosive ignition and deflagration which has to be set against the overriding EdF assumption that all of the fuel spill will be uncontained (in open air) and that ignition will be uniform. These relatively crude EdF assumptions have to be examined in the light of how past fuel fires have developed and burnt through to completion with, for example the recent fuel complex fire at Hemel Hempstead in the UK which initiated with a massive air-vapour explosion.

Although it not entirely clear from the EdF document how the EPR structures are intended to resist pressure waves generated by vapour deflagration, it seems that an inappropriate impulse model is deployed to determine the structural response of the building containments to an explosive overpressure, particularly for comparing the structural response of military and civil aircraft impacts.

i) and ii) Impact Loading and Penetration:

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classes of aircraft onto identified vulnerable areas of the power station site was reckoned to be extremely low, at around 7x10-7 per year and, of these, impact of aircraft and helicopters less than 2.3 tonnes was not expected to penetrate the containment structures. Thus the design criteria for Sizewell B translated into a construction that provided defence against only the first and lightest level of aircraft impact, that from a small aircraft such as a Piper Cherokee.

Of course the probability or chance of the occurrence of a malicious human act, such as the terrorist attack of 11th September, cannot be determined by classical *a priori* probabilistic means. Thus, it is only realistic to apply chance to the success of the attack once it has been initiated. Put another way, applied to the terrorist attack of 11th September the *Phit* or <u>success</u> rate was 3 out of 4 airborne aircraft, (*Phit* = 0.75).[17] If the aircraft that crashed in Pennsylvania is discounted, the *Phit* for those aircraft on their target run was 3 out of 3 or 100%. In other words, the hijackers had obtained sufficient flying skills to ensure that, once that the aircraft has been commandeered, the mission would have a high, almost certain rate of achieving its objective. Whereas the military or civil pilot would not be expected to have been trained to identify the vulnerable parts of a nuclear plant (even though it is assumed that the pilot will strive to avoid certain parts of the plant), it would be in the hijacker's interest to identify the most vulnerable parts of the selected target. Hence, the same NUREG-0800 mitigation applies, but in this case in reverse with the terrorist intent of striking the plant with, perhaps, a *Phit* of 95% of success once committed to the final run to the target.

[18] Again there is no reason why this should not apply equally to a French AREVA EPR.

[19] See p1. Footnote 1 of the EdF document.

Obviously, the effect and outcome of an aircraft crash and fuel explosion/burning on any one of the active plant buildings of the EPR nuclear island will be subject to how each of the individual target buildings would perform under the impact and fire conditions.

As a result of impact (kinetic) energy is transferred from the aircraft to the building[20] by being absorbed in the building components in the form of strain energy whilst each component is deforming elastically and beyond up to the point of permanent yielding. The impact can be segregated into two regimes: First, at the moment of impact the aircraft can be considered to be a very large but relatively 'soft' projectile which, by self-deformation' will dissipate some fraction of the total kinetic energy being transferred during the impact event. Second, some components of the aircraft will be sufficiently tough to form rigid projectiles that will strike and commence to penetrate, again by kinetic energy, components of the building fabric and structure.

The first of these damage regimes involves quasi-impulsive loading, so the response of the structure is obtained by equating the work done by the impacting load to the strain energy produced in the structures. Setting aside localised damage in which individual structural components are removed (blasted away), the most probable failure mode of the structure overall is that of buckling and collapse in response to the impact. The types of building structure featured at nuclear power plants, for example the radioactive waste and particularly spent fuel buildings, would not withstand the impulse magnitude delivered by a crashing commercial aircraft.[21]

For impact damage the aircraft, more particularly parts and components of it, have to be considered as inert projectiles. The energy transfer upon impact relates to the kinetic energy (KE) and the key parameter in determining the target (building component) response is the kinetic energy density which relates the KE and the projected area of the projectile. In terms of projectile velocity, a diving civilian aircraft is unlikely to exceed 500 knots so the damage mechanism falls below the so-called hydrodynamic regime where the intensity of the projectile-target interaction is so high that a fluid-to-fluid damage mechanism prevails (as utilised by tungsten tipped and depleted uranium scarab or long rod penetrator armour piercing rounds).[22] In the sub-hydrodynamic regime more conventional strength of materials characteristics (ie strength, stiffness, hardness and toughness) will determine the penetration mechanism.

For uniform, elastic materials, such as low carbon steel used in steel-frame construction such as diesel generator sheds, radioactive waste stores and, sometimes, irradiated fuel storage buildings, a good first estimate of the penetrating power of a projectile can be obtained from the Recht equation which, for certain hard components of the aircraft engines, could be as high as 200mm.[23] For a steel framed industrial building structure, typical web and flange thicknesses of the steel section girders and beams is typically about 20 to 40mm so, even with penetrator break

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[20] Just on the basis of kinetic energy alone the three levels of aircraft crash referred to by the STUK regulator increase from Level 1 (light aircraft) to Level 2 (Jet Fighter) to Level 3 (Commercial) airliner in the ratio 1 to 50 to 1500 or that the energy available from a crashing commercial airline (impact alone) is 1500 times that of a light aircraft.

[21] The maximum impact before yielding commences is given by

$$ir = [2Lim/En]0.5\ \partial y/Ah$$

which (adopting conventional notation) for the a typical rc construction, with a roof slab load per column assumed at 35t, the structure yields at about 1,750 Pa-s. The impulse force arising from a crashing aircraft of, say 200 tonnes all-up weight considered impacting over its projected front end fuselage area (about 30m2) with the event lasting over the entire collapse of the fuselage length, gives an impulse force of about 20,000 Pa-s or about x10 the yield strength of the typical rc structure described above.

[22] At projectile impact velocities below 1000m/s all impacts are sub-hydrodynamic – at 500 knots the closing velocity at impact would be approximately 260m/s.

[23] After R F Recht, *Ballistic Perforation Dynamics of Armor-Piercing Projectiles*, NWC TP4532, 1967. which, for a blunt nose ogive, is

$$x = 1.61M/(bA)[V-a/b\ln([a+bV]/a)]$$

where a and b relate to the material properties of the target, M is the mass of the projectile and V the projectile closing velocity. For an aircraft impact, if it is assumed that a sufficiently robust penetrator will present itself in the form of a main turbine shaft of an aero engine which, with its blades and other attachments, might represent a mass of 0.25 tonnes of 150mm projected diameter (stub end of shaft), typical strength of materials properties give $a = 2.109$ and $b = 10.106$, so that the final penetration thickness into a steel element (ie a building stanchion) is about 200mm.

up, this and other projectiles would be more than sufficient to structurally damage, if not catastrophically collapse the building steel frame.

The failure of reinforced concrete (rc) to ballistic loading applies to the different ways in which this common building structural material is used: For very thick walled structures the concrete is considered to be a semi-infinite mass, for concrete walling and flooring (and roof) slabs the account has to be taken of the flexure of the slab, and to prevent scabbing (where the back face of the concrete surface detaches) the reflective characteristics have to be modelled. The first two of these applications are important in respect to the whole structure remaining intact, and the last that in even where complete penetration is not achieved, the detached scab can form a missile in itself damaging and/or disabling safety critical plant within the concrete containment. The derivation of the ballistic loading of ferro-concrete (steel reinforced concrete) structures is a little more empirically derived,[24] although even with broad brush assumptions about the detailed design of the ferro-concrete structures the hardened projectile striking most of the concrete structures of a nuclear power plant would achieve full penetration. For example, a glancing impact on a typical rc framed building would be sufficient to possibly penetrate the rc roof slabs which are not practicably greater than 400mm thickness, (because of selfweight loading considerations over the 4m spans).

The point here is that the building structures of a nuclear plant require to maintain complete containment during an aircraft crash because even relatively small penetrations will permit the inflow of aviation fuel with the almost certain fire aftermath which would, in itself heighten the release and dispersal of any radioactive materials held within the building structure.

Thus the risk of radioactive release applies not just to the nuclear reactor considered and discounted by EdF, but also to the irradiated fuel ponds and other radioactive waste processing and storage areas. These other sources of potential radioactive release have not at all been considered in the leaked EdF document.

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[24] MOD Assessment, Strengthening, Hardening, Repair and Demolition of Existing Structures, Army Code No 71523, MoD 1992 which, for the same missile adopted for Footnote 23 the slab penetration is about 1,100mm.