The Application of Aircraft Crash Design Requirements to APR+ Design

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1. Introduction

As concerns about an aircraft crash into a nuclear power plant have continually increased throughout the world, especially after the 9/11 terror attacks, the related requirements have been revaluated and reinforced. In case of the nations of EU, designs for aircraft crash accident have been gradually changed according to requirements that have been strengthened since the 1970s. Responding centrally to the movement to reinforce the aircraft crash requirements of the U.S.A and France, the APR+ design has also established related top-tier requirements to cope with requirements considering aircraft crash accident.

This paper reviews nuclear power plant design requirements, and domestic and foreign plant design status about aircraft crash accident. Based on this analysis, the future direction of APR+ reactor building (RB) and auxiliary building design has been established.

2. Design requirements of the Aircraft Crash Accident

2.1 U.S. Requirements

In U.S NRC, the currently valid regulation for aircraft crash accident is 10CFR100 Section 3.5.1.6 Aircraft Hazards. If the probability of aircraft accidents having the potential for radiological consequences greater than the exposure criteria in 10 CFR 50.34(a)(1) is less than about 1×10^{-7} per year, the individual and societal risks of potential plant accidents should be low is met.

Recently, however, more or less reinforced preliminary regulation, 10CFR52 RIN 3150-AI19 'Consideration of Aircraft Impacts for NPP', has been issued in August 2008. This states that the applicant is required to identify the effects of an aircraft impact on core cooling capability, reactor building integrity, spent fuel cooling capability, and spent fuel pool integrity.

2.2 European Requirements

a. 1.2.8 Containment system: In a Standard Design with aircraft crash protection, this will be provided by extra thickness of the walls exposed to the impact and/or by Physical Separation of sensitive equipment from those walls.

b. 2.1.5 Aircraft crash: Protection against aircraft crash shall be based on a probabilistic approach unless the authorities require a deterministic approach.

c. 2.17.6.8 Aircraft Impact: Contribution to the Core Damage frequency shall be derived by considering the potential damage resulting from the impact, the Safety Functions that may be demanded and their conditional probability of failure.

3. Design Status in the ALWR

With the advent of "the era of nuclear renaissance", the world's leading vendors are moving quickly to attract the world nuclear market. From among these, the 4 major PWR (Pressurized Water Reactor) plants were selected and reviewed according to their design features for aircraft crash accident, as shown in Table 1.

Generally, a reactor building (RB) is composed of reactor containment building (RCB) and a reactor shield building (RSB).

Table 1. RB Design features for aircraft crash accident

Plant model	RB Type	Liner Plate	RCB	Annular Space	RSB		
					Inner liner	Wall	Outer liner
AP1000	Double	-	41.3mm	2.30m	8mm	1.3m	8mm
US-EPR	Double	6.35mm	1.31m	1.52m	-	1.8m	-
APWR	Single	6.35mm	1.52m	-	-	-	-
APR1400	Single	6.35mm	1.22m	-	-	-	-

3.1 AP1000

To show what changes have been applied to AP1000 design for aircraft crash accident compared to AP600, which is the ancestor of AP1000, the reactor building design features of the two plants are reviewed in Table 2.

Table 2. AP1000 reactor building design changes

Plant model		AP600	AP1000	Material
RB type		double	double	-
RCB thickness(mm)		41.3	41.3	steel
Annulus space(m)		2.3	2.3	-
RSB	Inner liner(mm)	-	8	steel
	Thickness(m)	0.9	1.3	RC Concrete
	Outer liner(mm)	-	8	steel

It is shown that shield walls of the AP1000 have been reinforced by attaching inner and outer steel liners with greater thickness to the concrete shield walls. In addition, the design of the air inlet hole on the upper shield wall for the annulus space vent has been changed from one large hole to more than 300 small holes in order to strengthen the structural integrity.

3.2 EPR

The changes that have been applied to EPR design for aircraft crash accident compared to its ancestor plant are shown in Table 3.

Table 3. EPR reactor building design changes

Plant model	CP	P4	P'4	N4	EPR
RB Type	single	double	double	double	double
Liner plate (mm)	6.35	-	-	-	6.35
RCB wall thick(m)	0.9	0.9	1.2	1.2	1.31
Annulus space(m)	-	2	1.8	1.8	1.52
RSB wall thick(m)	-	0.55	0.55	0.55	1.80

EPR has the most conservative design for aircraft crash accident of the recent ALWRs. AREVA has continuously applied new countermeasures against aircraft crash accident as shown in Table 3.

Furthermore, it has applied a double-walled structure, called decoupled civil structure, not only to the reactor building but also to the fuel building and the auxiliary safeguard building. And these buildings are separately disposed around the reactor building, in order not to be affected by each other in case of aircraft crash accident.

3.3 US-APWR

The US-APWR strategy for aircraft crash accident, designed by Mitsubishi, is described in DCD 3.5.1.6(Aircraft Hazards), stating likewise that an aircraft crash accident is not required to be considered as part of the design basis and that it is the responsibility of the COL Applicant to verify the site interface parameters with respect to aircraft crash accident as described in S.R.P Sec. 2.2.

And it is stated in the DCD that additional topical reports should be presented, if they are needed, at the request of the new NRC regulations considering aircraft crash accident; but currently the design has not been changed from the reference design of the Japan-APWR.

4. Test Results of Aircraft Crash Accident

To evaluate the resistance capacity to aircraft crash accident, several physical or virtual tests were performed.

The Korea Institute of Nuclear Safety (KINS) carried out a virtual evaluation with a Boeing 767 that crashed into the reactor building of the OPR1000 and CANDU in 2005. The results showed that though some pieces of concrete were detached from the reactor building wall, the structure was sufficient to protect safety functions from the view point of overall safety.

Next, an evaluation of the AP1000 considering aircraft crashes was performed with actual impact tests, which resulted in design changes to the plant. Until 2006, the aircraft crash design of the AP1000 had followed the SRP 3.5.1.6 (Aircraft Hazard). But recently, to meet the new requirements (10CFR52 RIN 3150-AI19), WEC has evaluated the aircraft crash accident with a Boeing 767 and F18C. Based on this analysis, the AP1000 reactor building design has been changed, with modifications such as reinforcing the reactor shield building.

5. APR+ Design Application for Aircraft Crash

The APR+ design scope for aircraft crash is limited to the reactor building and the safety related auxiliary building including the spent fuel handling area. And according to the 'APR+ Top-Tier Requirement', the reactor building will be designed with a single wall and cylindrical PS (Pre-Stressed) concrete. All of these preliminary design features are shown in Table 4.

Table 4. APR+ design features for aircraft crash accident

Plant model	Wall Thickness		Evaluation Airplane
	APR+	APR1400	
Reactor Building	6~7ft (1.8~2.0m)	4ft (1.2m)	- F18 Hornet - Boeing 767-400
Auxiliary Building	5~6ft (1.5~1.8m)	3~4ft (0.9~1.2m)	

These several features have been determined based on an analysis of the foreign design requirements, test and analysis results, and industrial design experience. The tendon in the PS concrete and the liner plate in reactor building could contribute to a prohibition of penetration or cracking of the containment wall.

These preliminary building wall thickness data will be precisely reviewed and checked during detailed design stage.

6. Conclusions

As the concerns about aircraft crash accident have gradually increased since the 9/11 terror, each nation has reinforced its design requirements to prepare for an aircraft crash accident. The APR+ development plan has been undertaken to prepare a countermeasure.

This paper reviewed design change trends and the current status of the ALWRs, such as the AP1000, the EPR, and the US-APWR. And, numerical simulations for aircraft crash accident have been introduced about domestic and foreign plants.

Analyzing this information, the APR+ reactor building design has established a preliminary design value, a design scope, and a direction for the APR+ detailed design for aircraft crash accident.

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