Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Probability of military aircraft crash considering human efforts

Hyungtaek Yoo and Moosung Jae*
Nuclear Engineering Department, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea, 04763
*Corresponding author: jae@hanyang.ac.kr

1. Introduction

After the terrorist attack on September 11, 2001, interest in aircraft crashes against nuclear power plants has increased, and in Articles 8 and 13 of the Rules on the Technical Standards for Nuclear Reactor Facilities, the safety functions are not impaired due to the aircraft crashes. It is stipulated that nuclear power plants should be designed to prevent like aircraft crash.

Section 3.5.1.6 of the KINS light water reactor safety review guidelines states that when the frequency of aircraft accidents for nuclear power plants related to aircraft disasters exceeds 1×10^{-7}/year, the aircraft hazard should be considered in the design of the plant.

In the case of site evaluation of recently constructed nuclear power plants in Uljin-gun(This plant referred to as a reference plant in this paper), the probability of aircraft crash initially submitted by applicant was 2.47×10^{-7}/year.

This value exceeds the standard, and aircraft hazard had to be considered in the design of the power plant unless it can be shown through discussion that it can be lower than the value estimated through a realistic evaluation by securing a significant margin .

Applicant re-evaluated the aircraft crash probability and submitted it as 8.75×10^{-8}/year. This was the result of realistically adjusting the crash rate in the military training airspace (Applying the crash rate of military aircraft during takeoff and landing at the airport → Applying the crash rate of military aircraft operating the route).

As such, the probability of military aircraft crash became a high factor in the site evaluation related to the aircraft hazard. However, the probability of the currently applied military aircraft crash does not consider the pilot's efforts to avoid densely populated areas or nuclear facilities (such as the F-5/E crash that occurred in 2021).

In this study, a methodology for calculating the probability of military aircraft crash carried out considering human efforts for a more realistic calculation of the probability of aircraft crash to nuclear power plant.

2. Literature Survey

This section analyzes the currently applied aircraft hazard assessment procedure(NUREG-0800) and previous model including the probability of aircraft crash related to human efforts which is defined as the aircraft pilot's efforts to avoid(change the direction or adjust the descent angle) the nuclear power plant in an accident leading to an aircraft crash.

2.1 American Standard NUREG-0800 Model

NUREG-0800 (US NRC Standard Review Plan) is a document that provides procedures and standards for evaluating potential accidents around nuclear power plants. This will review the applicant's assessment of an aircraft hazard and evaluate whether the aircraft hazard should be considered in design of plant. First, if the following three conditions are satisfied, it is evaluated as satisfying 1×10^{-7}/year without additional calculation.

A. The plant-to-airport distance D is between 5 and 10 statute miles and the projected annual number of operations is less than 500 D^2 or the plant-to-airport distance D is greater than 10 statute miles, and the projected annual number of operations is less than 1000 D^2
B. The plant is at least 5 statute miles from the nearest edge of military training routes, including low-level training routes, except for those. associated with usage greater than 1000 flights per year or where activities(such as practice bombing) may create an unusual stress situation.
C. The plant is at least 2 statute miles beyond the nearest edge of a Federal airway, holding pattern, or approach pattern.

If the above three conditions are not satisfied at the same time, the aircraft hazard assessment is performed based on the four factors according to the review procedure; Probability of aircraft crash using air route; Probability of aircraft crash related to use civil and military airports and helipads; Probability of aircraft crash related to military or civil aircraft use related aircraft for designated airspace; Probability of aircraft crash related to holding route(Because nuclear power plant is protected as a Danger Area, it is not considered)

2.1.1 Probability of aircraft crash using air route

The probability of aircraft crash using air route(P_{FA}) is calculated using the following formula(eqn.1). [4]

$$P_{FA} = C\times N\times A/w \quad (1)$$

C:in-flight crash rate per mile for aircraft using airway
N:number of flights per year along the airway
w:width of airway in miles
A:effective area of plant in square miles

The C value for commercial aircraft is 4×10^{-10}/mile, which is consistent with the information provided by the US Department of Energy, and the C value for military aircraft is not presented. At the time of review about site of the reference plant, KINS calculated the corresponding C value through a proportional formula (84: 5.7 = 4×10^{-10}: X, X = aircraft crash rate/mile of military aircraft using air routes, USAF applied), and this value is $2.7\text{x}10^{-11}$/mile. The A value is the effective area of the power plant, the shadow area on the horizontal plane of the power plant elevation based on the assumed fall angle and destruction mode for various types of aircraft, safety-related structures, systems and devices that can be damaged from impact or fire as a result of the fall. The formula (eqn.2, refer to DOE-STD-3014-2006 Appendix B.4) is as follows. [7]

$$A_{eff} = A_f + A_s \quad (2)$$
$$A_f = (WS+R)\times H\cot\varphi+(2\times L\times W\times WS)/R+L\times W$$
$$A_s = (WS+R)\times S$$

A_f:effective fly-in area, A_s : effective skid area
WS:aircraft wing span,
R:length of the diagonal of the facility
H:facility height, facility-specific
cotφ:mean of the cotangent of the aircraft impact angle
L:length of facility, W:width of facility
S:aircraft skid distance (mean value)

2.1.2 Aircraft crash related to use civil and military airports and helipads

The probability of aircraft crash related to use civil and military airports and helipads(P_A) is calculated using the following formula(eqn.3). [4]

$$P_A = \sum_{i=1}^{L}\sum_{j=1}^{M} C_j N_{ij} A_j \quad (3)$$

M:number of different types of aircraft using the airport
L:number of flight trajectories affecting the site
C_j:probability per square mile of a crash per aircraft movement, for the jth aircraft
N_{ij}:number (per year) of movements by the jth aircraft along the ith flight ij path
A_j:effective plant area (in square miles) for the jth aircraft

For the C_j value used in the eqn.3 above, the values presented in the table below are used. In 2.1.1, the C value for military aircraft was calculated through a proportional expression using the values presented in this table.

Table 1. Probability of a Fatal Crash per Square Mile[4]

Distance From End of Runway (miles)	Probability ($\times10^8$) of a Fatal Crash per Square Mile per Aircraft Movement			
	U.S. Air Carrier[1]	General Aviation[2]	USN/USMC[1]	USAF[1]
0–1	16.7	84	8.3	5.7
1–2	4.0	15	1.1	2.3
2–3	0.96	6.2	0.33	1.1
3–4	0.68	3.8	0.31	0.42
4–5	0.27	1.2	0.20	0.40
5–6	0	NA[3]	NA	NA
6–7	0	NA	NA	NA
7–8	0	NA	NA	NA
8–9	0.14	NA	NA	NA
9–10	0.12	NA	NA	NA

2.1.3 Aircraft crash related to military or civil aircraft use related aircraft for designated airspace

The probability of aircraft crash related to military or civil aircraft use related aircraft for designated airspace(P_M) is calculated using the following formula(eqn.4). [4]

$$P_M = C\times A \quad (4)$$

C:total probability of an aircraft crash per square mile per year in the vicinity of the site from the airports being considered
A: effective area of one unit of the plant in mile^2

In this regard, if the risk to military air activities is unacceptably high, appropriate airspace or air routes should be changed.

2.1.4 Analysis of current application procedures

NUREG-0800 and DOE-STD-3014-2006 are applied to the KINS examination guidelines for the probability of aircraft crash currently applied in Korea. In these documents, the probability of a military aircraft crash is applied conservatively through a statistical approach, and the human efforts is not considered. However, as seen in recent crashes, pilots try to avoid collisions in densely populated areas and areas that can cause mass disasters.

2. 2. Hornyik Model

This model was developed in 1974 and evaluated the Air Traffic Hazard of nuclear power plants. Air Traffic Hazard were classified into two types(Collision and Crash).

Collsion means a collision accident that occurs by deviating from a predetermined/prescribed route. This is an accident in which the power plant acts as an obstacle in the flight path and leads to loss of the aircraft. This category included all cases of maneuvers such as weapon delivery to ground targets, low-altitude navigation training, and near-ground maneuvers such as landing. Such a flight is supposed to follow the preplanned route, but an event occurs in which the actual flight route deviates from the set route due to various errors(weather conditions, inaccurate navigation system, etc.). A Gaussian function was applied to the deviation from the preplanned path. The probability of collision occurring per flight at each location from the ground target was calculated.

Crash means to an aircraft accident that results in a crash at or near a reactor plant(include potential vulnerable facilities that pose a hazard to the nuclear power plant). When a problem that causes aircraft crashes occurs within an aircraft's route, the distribution from the corresponding location to the crash location is expressed as a probability. Extending this concept, Hornyik calculated the probability of crashing a nuclear power plant aircraft in the Race Track Pattern, a pattern that military aircraft (fighters, bombers) mainly train.

2.2.1 Analysis of Hornyik Model

It is evaluated as the paper that calculates the crash rate based on the nominal flight path, unlike the previous studies based on the historical collision location. And the crash rate was lowered (1×10^{-4}/h inflight→6×10^{-5}/h) considering aerial refueling, formation flight, air combat training were not conducted during the RaceTrack training and pilot's effort to avoid nuclear power plant. However, it was not clearly explained during the calculation process.

3. Model analysis considering human efforts

In order to apply the human efforts, it is assumed that the aircraft crash to the power plant does not occur through human efforts except for the following two situations.

A. Aircraft crash due to loss of control (loss of control system of aircraft, loss of consciousness and position of pilot)

B. Aircraft crash occurs in a situation where visual flight is impossible

3.1 Data

Two types of data are needed to obtain the improved probability of a military aircraft crash. Average number of Instrument Flight Rules (visibility 3 statue miles, cloud height AGL less than 2000ft) days per year for nuclear power plant area and rate of accidents related to loss of control in case of a military aircraft crash.

Data which is used in this model is orginated from two sources.

A. ROK Airforce weather group

B. ROK Airforce Safety inspection department

The aircraft crash rate of the ROK Air Force from 1950 to 2020 was 4.75×10^{-5}/hour, and the rate of crash due to loss of control during the crash was 16.5% [9.3% (loss of aircraft control system) + 7.2%(pilot consciousness and loss of spatial orientation)].

In the case of the site of reference plant, the average IFR weather data are obtained from meteorological data measured at the nearest airfield, Pohang Naval Air Base. The 10-year average IFR weather is 174.9 days.

3.2 Probability of military aircraft crash considering human efforts(C_M)

The probability of military aircraft crash considering human efforts(C_M) is calculated by the next formula(eqn.5) applying to all C values of military aircraft which is applied in assessment of aircraft hazard.

$$C_M = C \times (D_I /365 + L_c) \quad (5)$$

D_I: Annual average IFR (Instrument flight rules) day for nuclear power plant area

L_c: Ratio of loss of control ability among military aircraft crashes

The events of loss of control and crash in non-visual flight situation occur same time should be omitted in the eqn.5 above, but this probability is not considered because it does not significantly affect the overall value.

3.3 Applying the proposed Model for Reference site

Applying the model considering human efforts, the value of C_M is 0.644. In other words, it can be seen that the accident probability of a military aircraft considering the pilot's human efforts has been reduced to 64% compared to the existing probability. This is similar to the accident rate adjustment (60%) suggested by the Hornyik Model.

4. Conclusions

In Korea, since the training airspace of the ROK air force is located near the nuclear power site, the accident rate of the military aircraft has a great influence on the overall frequency value in the aircraft hazard for nuclear power plant. It is necessary to value of the accident frequency of a military aircraft conservatively for safety for the purpose of assessing the aircraft hazard level for a nuclear power plant.

However, if the value is applied too conservatively, that is far from reality. Due to this, the risk is overestimated, which causes unnecessary fear in the construction and operation of nuclear power plants.

Detailed data and calculated values for the aircraft hazard assessment for site of reference plant are undisclosed and cannot be known. If the reduction in the probability of a military aircraft crash to 64% is applied to the previous aircraft hazard assessment, the probability of an aircraft crash against a nuclear power plant will be lower.

For further works, consequence analysis needs to be performed for decision making and risk information.

REFERENCES

[1] Hornyik K, Grund J.E, Evaluation of Air Traffic Hazards at Nuclear Plants, Nuclear Technology Vol 23 pp28-37, 1974

[2] Emma Tan, David Gleave, A Review and Statistical Modelling of Accidental Aircraft Crashes within Great Britain, HSL&Loughborough University,2014

[3] Hornyik K, Airplane Crash Probability Near A Flight Target, Transation of the American Nuclear Society Vol 76 pp209-210, 1997

[4] US NRC, Standard Review Plan, NUREG-0800, US NRC, 2010

[5]Aircraft Considerations - Preapplication Site Review by the Directorate of Licensing , USAEC, in the Matter of Portland General Electric Company, Boardman Nuclear Plant, Project No. 485,1973

[6]UCRL, Data Development Technical Support Document of the Aircraft Crash Risk Analysis Methodology Standard, UCRL-ID-124837,1996

[7]DOE, Accident Analysis of Aircraft into Hazardous Facilities, DOE-STD-3014-96, 1996

[8]NSSC, Permission to operate Shin-Hanul Nuclear Power Plant Unit 1(Plan), 2021