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# Evaluation of External Hazards to Nuclear Power Plants in the United States

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## 6.4 AVIATION ACCIDENTS

The effect of an aircraft of sufficient weight, traveling at sufficient speed, crashing at a nuclear powerplant site may result in physical damage and disruption to the plant to the extent that damage to the reactor core and release of radioactive material from the reactor core may result. Only physical damage to the plant is considered because there is insufficient hazardous material carried by the aircraft, except for onboard fuel, to affect the plant sufficiently to ultimately cause damage to the reactor core. The fuel aboard the aircraft is considered to be covered by physical damage to plant. No sabotage or deliberate "kamikaze" crashes are considered.

### 6.4.1 Aviation Safety Requirements

The movement of aircraft in the United States is controlled by the Federal Aviation Administration (FAA) through Title 14 of the Code of Federal Regulations (14 CFR) [Ref. 6.4.1]. Section 121 of 14 CFR regulates commercial aviation in the United States for aircraft capable of carrying more than 30 passengers and/or a payload of more than 7,500 pounds. Section 125 of 14 CFR regulates commercial aviation in the United States for aircraft capable of carrying more than 20 but less than 30 passengers and/or a payload of more than 6,000 but less than 7,500 pounds. Section 135 of 14 CFR regulates commercial aviation in the United States for aircraft capable of carrying less than 20 passengers and/or less than a payload of 6,000 pounds. Section 91 of 14 CFR regulates general aviation, that is, all aircraft not involved in commercial operations.

### 6.4.2 NRC Acceptance Criteria

The U.S. NRC has issued the following in their Standard Review Plan (SRP) [Ref. 6.4.2] as their acceptance criteria for the siting of nuclear power plants near airports and/or airways. The probability of an aircraft accident resulting in radiological consequences greater than 10 CFR Part 100 exposure guidelines is considered to be less than  $10^{-7}$  per year if the distances from the plant meet all of the requirements listed below:

- (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 edge of military training routes, including low-level training routes, except for those associated with a 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.

The FAA, in compiling airport use statistics, defines an aircraft operation as the airborne movement of aircraft in controlled or noncontrolled airport terminal areas and about given enroute fixes or at other points where counts can be made. There are two types of operations--local and itinerant. Local operations are performed by aircraft which: (a) Operating in the local traffic pattern or within sight of the airport, (b) Are known to be departing for, or arriving from, flight in local practice areas within a 20 mile radius of the airport, and (c) Execute simulated instrument approaches or low passes at the airport. Itinerant operations are all aircraft operations other than local operations [Ref. 6.4.3].

If the above proximity criteria are not met, then a detailed review of the aircraft hazards must be performed. The SRP [Ref. 6.4.2] provides a procedure by which the probability of an aircraft crash can be calculated for various situations.

For Federal airways or aviation corridors that pass through the vicinity of a site, the probability per year of an aircraft crashing into the plant,  $P_{FA}$ , is given by the following equation:

$$\text{Eq. 6.4.1} \quad P_{FA} = C \times N \times A/W.$$

where  $C$  = inflight crash rate per mile for aircraft using airway,

$N$  = number of flights per year along the airway,

$A$  = effective area of plant in square miles, and

$W$  = width of airway (plus twice the distance from the airway edge to the site when the site is outside the airway) in miles.

For civilian and military airports and heliports, the probability of an aircraft crashing into site is given by the following equation:

$$\text{Eq. 6.4.2} \quad PA = S_L S_M C_j \times N_{ij} \times A_j$$

where  $S_L$  = summation over all flight trajectories, for  $i = 1$  to  $L$ , affecting the site,

$S_M$  = summation over all different types of aircraft, for  $j = 1$  to  $M$ , using the airport,

$C_j$  = probability per square mile of a crash per aircraft movement, for the  $j$ th aircraft,

$N_{ij}$  = number (per year) of movements by the  $j$ th aircraft along the  $i$ th flight paths, and

$A_j$  = effective plant area (in square miles) for the  $j$ th aircraft.

The values for  $C_j$  are given by Table 6.4.1 reproduced from Ref. 6.4.2. The data given by Table 6.4.1 for U.S. air carriers and for U.S. Navy (USN)/U.S. Marine Corps (USMC) and U.S. Air Force (USAF) aircraft was first presented by Ref 6.4.4 in 1973. According to Ref. 6.4.4, the bases for this data were aircraft accidents resulting in fatalities that occurred with a few

miles of a runway within a 60-degree reference flight path symmetric about extended centerline of the runway. The U.S. air carrier analysis was based on 80,000,000 movements. The USN/USMC and USAF analyses were based on 55,000,000 and 39,000,000 movements, respectively.

Table 6.4.1

U.S. NRC SRP Probability of Fatal Crash Versus  
Distance from End of Runway [Ref. 6.4.2]

Distance From End of Runway (miles)	Probability ( $\times 10^8$ ) of a Fatal Crash per Square Mile per Aircraft Movement			
	U.S. Air Carrier	General Aviation	USN/USMC	USAF
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	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

NA indicates that data was not available for this distance.

From Ref. 6.4.2, the effective plant areas are calculated including the following: (a) A shadow area of the plant elevation upon the horizontal plane based on the assumed crash angle for the different kinds of aircraft and failure modes, (b) A skid area around the plant, taking into account artificial berms or any other man-made and natural barriers, as determined by the characteristics of the aircraft under consideration, and (c) The areas of those safety-related structures, systems and components which are susceptible to impact or fire damage as a result of aircraft crashes.

#### 6.4.3 Hazard to Nuclear Power Plants from Aviation Accidents

All power plant sites are exposed to aviation accident hazards to some extent due to the ability of aircraft to travel practically anywhere. Because of the increased traffic density near airports, plant sites on approaches to airports face higher exposure rate to aviation accident hazards. Generally, it is commercial aviation traffic, as opposed to general aviation, that poses the greatest hazard to nuclear power plants due to their heavier aircraft that travel at higher speeds. However, given the higher traffic density of general aviation traffic, it is not inconceivable that general aviation could pose a greater hazard given the right circumstances. Military aviation traffic could also pose a hazard to a nuclear power plant if the plant is located near a heavy aircraft base such as a bomber or transport base.

The Three Mile Island site is used as an example in an initial screening analysis to demonstrate a method by which plants could determine if further analysis is necessary in order to meet the first figure-of-merit for probability of core damage from aviation accidents.

The methodology presented in Appendix 6.A.1 is used to perform the initial screening analysis.

The Three Mile Island Units 1 and 2 nuclear power plant site in Londonderry Township, Pennsylvania, is located on Three Mile Island in the Susquehanna River about 12 miles southeast of Harrisburg. According to the Three Mile Island Unit 2 Final Safety Analysis Report (FSAR) [Ref. 6.4.5], the Harrisburg International Airport, formerly Olmstead Air Force Base, is located on the north bank of the Susquehanna River about 2 1/2 miles northwest of the site. This airport has one runway, 130°/310°. The FSAR [Ref. 6.4.5] states that aircraft making their final approaches to 310° could pass near or over the site although this would not be a standard VFR (Visual Flight Rules) approach. Figure 6.1 shows the Three Mile Island Site and the distance and bearing from the site to the Harrisburg International Airport [Ref. 6.4.6].

According to the Three Mile Island 2 Safety Evaluation Report (SER) [Ref. 6.4.6], the risk was judged acceptably low for either unit provided that less than 2,400 operations per year were by aircraft in excess of 200,000 pounds, the postulated design basis aircraft. At the time of the assessment, there was one scheduled flight per day by an air carrier using a commercial aircraft in excess of 200,000 pounds and occasional use of the airport by military flights of cargo aircraft in excess of that weight.

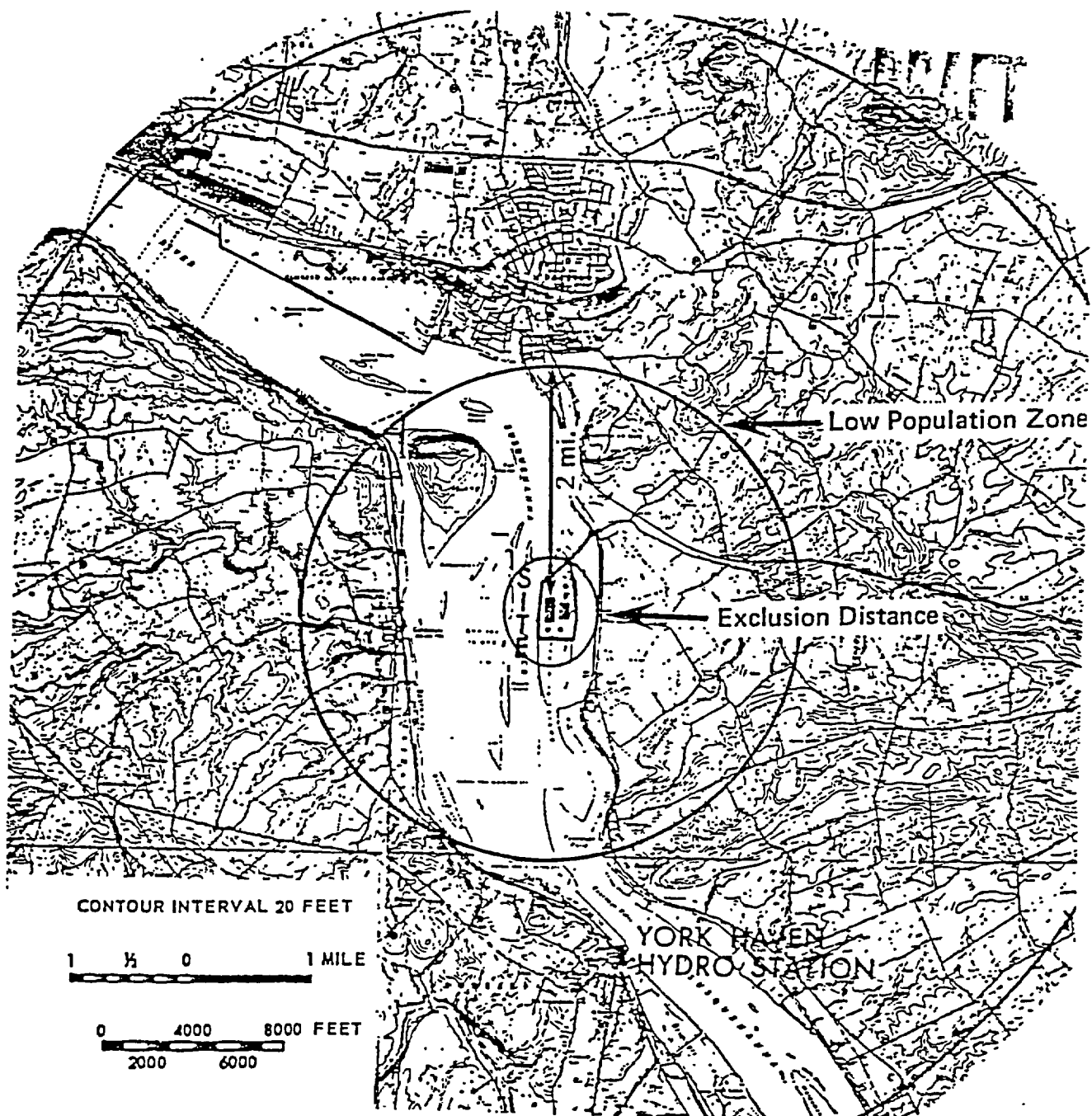


Figure 6.1

Three Mile Island Site [Ref. 6.4.6]

Since the time of that assessment, aircraft types used by U.S. commercial air carriers and traffic density has changed. As Table 6.A.2.6 of Appendix 6.A.2 shows, the earlier models of the Boeing 727, (B727-100); has a maximum takeoff weight of about 169,000 pounds. The later models of the Boeing 727, (B727-200) has a maximum takeoff weight of about 209,500 pounds [Ref. 6.A.2.14 - 6.A.2.15]. Commercial aircraft generally become heavier as new models are introduced due to "stretch-out" of the fuselage for increased passenger capacity, and higher performance engines to compensate for the increased weight and for better fuel economy.

Table 6.A.2.7 of Appendix 6.A.2 shows the type of aircraft used by U.S. commercial air carriers at the Harrisburg International Airport from 1977 to 1985. According to Table 6.A.2.7, an average of 4,687 flights departed from Harrisburg International Airport annually from 1977 to 1985. In 1984, the number of aircraft weighing over 200,000 pounds, departing from the Harrisburg International Airport was 2,075 out of a total of 4,283 for a percentage of 48.4%. In 1985, the number of aircraft weighing over 200,000 pounds, departing from the Harrisburg International Airport was 2,481 out of a total of 5,791 for a percentage of 42.8%.

Also located at the Harrisburg International Airport is the 193rd Special Operations Group of the Pennsylvania Air National Guard [Ref. 6.4.7]. This unit operates the EC-130E, an electronic warfare model of the basic C-130 Hercules, a 4-engined turboprop cargo aircraft. This aircraft has a gross operating weight of 175,000 pounds. The basic design of the C-130 was first developed 36 years ago so its potential replacement by newer, more advanced and heavier aircraft should not be ignored.

Because of the deregulation of the commercial airline industry in 1978, the general trend has been an increase in traffic density. Even small airports, such as Harrisburg, have experienced a general upward trend in commercial airline traffic. Therefore, as 1985 is the most recent year in which data is available for Harrisburg International Airport, it should be most indicative of future operations.

Using 6000 departures per year from the Harrisburg International Airport and assuming that each departure implies a landing and takeoff, there will be 6000 flights that will fly near the Three Mile Island Site each year. If an aircraft lands on runway 130<sup>0</sup>/310<sup>0</sup> towards the Northwest (310<sup>0</sup>), it will probably land from the Southeast which implies a landing approach near the Three Mile Island site. If an aircraft lands towards the Southeast (130<sup>0</sup>), it will probably take off towards the Southeast which implies a takeoff pattern near the Three Miles Island site.

The Harrisburg International Airport is 2.5 miles from the Three Mile Island site. Assuming only commercial airline accidents within 2.5 miles of the plant site can affect the site, then 6000 flights per year times 5 miles (the flight path 2.5 miles northeast and southwest of the Three Mile Island site) gives 30,000 aircraft miles per year within 2.5 miles of the Three Miles Island site. From Table 6.A.2.2 of Appendix 6.A.2, a commercial aircraft



accident rate (aircraft operating under 14 CFR 121, 125 and 127) of 7 is obtained. Multiplying the aircraft miles within 2.5 miles of the Mile Island site with the commercial aircraft accident rate gives:

$$30,000 \text{ ac miles} \times 7.7 \times 10^{-9} \frac{\text{ac accidents}}{\text{ac miles year}} = 2.3 \times 10^{-4} \frac{\text{accidents}}{\text{year}}$$

Assuming half of the commercial aircraft flights departing the Harrisburg International Airport have an operating weight of 200,000 pounds or greater, then the frequency of a commercial aircraft weighing 200,000 pounds or more having an accident within 2.5 miles of the Three Mile Island site is:

$$1/2 \times (2.3 \times 10^{-4} \frac{\text{accidents}}{\text{year}}) = 1.2 \times 10^{-4} \frac{\text{accidents}}{\text{year}}$$

#### 6.4.4 Power Plant Response to Aviation Accidents

Since the NRC regulations regarding aviation hazards to nuclear power plants are only partly probabilistic in nature and do not relate to core damage or large release frequency, to obtain a probabilistic estimate of the frequency of core damage due to aviation accidents, one must turn to probabilistic risk analysis. Unfortunately, the few PRAs that have considered aviation accidents (Indian Point, Millstone 3, Seabrook, Zion [Ref. 6.4.9 to 6.4.12]) have dismissed aviation accidents on the basis of the aviation accident frequency.

The only probabilistic analysis of a power plant's response to an aircraft crash is a 1971 paper by Chelapati, Kennedy and Wall [Ref. 6.4.8] which modeled aircraft engines as projectiles impacting the plant walls. The aircrafts were divided into two categories, small aircraft and large aircraft.

For small aircraft (less than or equal to 12,500 pounds in weight), the aircraft engines were idealized as projectiles ranging in weight from 230 to 800 pounds with the relative distribution of aircraft engine weight determined from aircraft census. Within five miles of an airport, small aircraft engines were modeled with an impact velocity ranging from 67 to 105 miles per hour. Beyond five miles from an airport, small aircraft engines were modeled with an impact velocity ranging from 67 to 280 miles per hour.

For large aircraft (greater than 12,500 pounds in weight), the aircraft engines were idealized as projectiles ranging in weight from 450 to 4200 pounds with the relative distribution of aircraft engine weight determined from aircraft census. Within five miles of an airport, large aircraft engines were modeled with an impact velocity ranging from 95 to 185 miles per hour. Beyond five miles from an airport, large aircraft engines were modeled with an impact velocity ranging from 175 to 610 miles per hour.

From the distribution of aircraft engine weight, impact velocity, and wall thickness, a probability of wall penetration was obtained. Table 6.4.2 presents the probability of wall penetration for various combinations of aircraft weight, wall thickness and plant location. Note that the frequency of core damage or large release was not calculated:

The assumption that large aircraft will impact with a velocity of less than 185 miles per hour within five miles of an airport is probably reasonable. Federal regulations [14 CFR 91.70, Ref. 6.4.1] control the maximum airspeed of all aircraft below 10,000 feet MSL (mean sea level). The requirements are:

- "(a) Unless otherwise authorized by the Administrator, no person may operate an aircraft below 10,000 feet MSL at an indicated airspeed of more than 250 knots (288 m.p.h.).
- (b) Unless otherwise authorized or required by ATC, no person may operate an aircraft within an airport traffic area at an indicated airspeed of more than-
  - (1) In the case of a reciprocating engine aircraft, 156 knots (180 m.p.h.); or
  - (2) In the case of a turbine-powered aircraft, 200 knots (230 m.p.h.)."

The regulations state further that:

- "(c) No person may operate an aircraft in the airspace underlaying a terminal control area, or in a VFR corridor designated through a terminal control area, at an indicated airspeed of more than 200 knots (230 m.p.h.)."

Beyond five miles from an airport, the aircraft impact velocity in an aircraft crash is not easily determined since this speed is not as tightly regulated and terminal control areas vary in their control radius.

Table 6.4.2

Probability of Penetration as a Function of  
Plant Location and Concrete Thickness [Ref. 6.4.10]

Plant Location	Aircraft Type	Probability of Penetration			
		Thickness of Reinforced Concrete			
		1 foot	1.5 feet	2 feet	6 feet
<= 5 miles from airport	Small, <= 12,500 lbs.	0.003	0	0	0
	Large, < 12,500 lbs.	0.96	0.52	0.28	0
>= 5 miles from airport	Small, <= 12,500 lbs.	0.28	0.06	0.01	0
	Large, > 12,500 lbs.	1.0	1.0	0.84	0.32

< = defined as less than or equal to.

> = defined as greater than or equal to.

LINEAR EXTRAPOLATION

2 .84

3 .71

4 .58

5 .45

6 .32

FT Prob. of Penetration  
(Perforation)

engine 450-4200LB

VS 737 = 7400 LB

Speed 175-610 MPH

#### 6.4.5 Aviation Accident References

- [6.4.1] Title 14 Code of Federal Regulations, Aeronautics and Space (14 CFR) Parts 60 to 139, Revised as of January 1, 1987, Office of the Federal Register, National Archives and Records Administration, Washington, D.C.
- [6.4.2] NUREG-0800 (formerly issued as NUREG-75/087) Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, U.S. NRC Office of Nuclear Reactor Regulation, Washington, D.C. July 1981.
- [6.4.3] FAA Statistical Handbook of Aviation, Calender Year 1982, U.S. Department of Transportation, Federal Aviation Administration, Office of Management Systems, Information Analysis Branch, Washington, D.C. December 31, 1982.
- [6.4.4] "Reactor Siting in the Vicinity of Airfields", D.G. Eisenhut, Transactions of the American Nuclear Society, 1973 Annual Meeting, Chicago, Illinois, June 10-14, 1973, Volume 16, pg. 210-211.
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- [6.4.9] Indian Point Probabilistic Safety Study, Consolidated Edison Company and Power Authority of State of New York, Pickard, Lowe & Garrick, Inc. 1983.
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