FINAL
TOPICAL REPORT ON THE EFFECTS OF POTENTIAL AVIATION ACCIDENTS AND NATURAL PHENOMENA AT THE PROPOSED PA'INA HAWAII, LLC, IRRADIATOR FACILITY

Prepared for

U.S. Nuclear Regulatory Commission
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Prepared by

J. Durham
A. Ghosh
J. Stamatakos
K. Das
C. Dinwiddie

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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ABSTRACT

In accordance with 10 CFR Part 36, Pa'ina Hawaii, LLC, submitted a license application to the U.S. Nuclear Regulatory Commission (NRC) for the possession and use of sealed sources in a proposed commercial pool-type industrial irradiator to be located near Honolulu International Airport on the island of Oahu, Hawaii. To meet its responsibilities in accordance with the National Environmental Policy Act as determined in a settlement agreement (NRC, 2006), NRC agreed to prepare an environmental assessment to evaluate the potential for significant environmental impacts of the proposed irradiator. The objective of this report is to assess the potential effects of natural phenomena (seismic events, tsunamis, and hurricanes) and potential aircraft crashes on the proposed irradiator facility. The analyses presented in this report are based on data available to the general public on the geology of Hawaii as it pertains to earthquakes, tsunamis, and hurricanes. The analysis of the hazard associated with a potential aircraft crash uses the methodology described in NUREG–0800 (NRC, 1981) to determine the annual probability of an aircraft crash into the proposed facility based on flight data from Honolulu International Airport. It is concluded that the potential for a tsunami or a storm surge to remove a Co-60 source assembly from the irradiator pool is negligible. Additionally, there are no historical data that support an earthquake at Honolulu International Airport being large enough to cause a source assembly to be removed from the irradiator pool by ground motion. The annual probability of an aircraft crashing into the proposed facility was estimated to be 2.1×10^{-4} yr^{-1} or one such accident every 5,000 years, and this value is believed to be an overestimate. It was further determined that a loss of control of radioactive material as the result of an aircraft crash into the facility is not feasible.

References:

NRC. "Memorandum and Order (July 26), Docket No. 30–36974–ML: In the Matter of Pa'ina Hawaii, LLC—Material License Application." CLI–06–18. Washington, DC: NRC. 2006.

———. NUREG–0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants. Standard Review Plan Section 3.5.1.6—Aircraft Hazards." Washington, DC: NRC. June 1981.

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ACKNOWLEDGMENTS

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No CNWRA-generated original data are contained in this report. Data used in this report are from other publicly available sources. Each data source is cited in this report. The work presented in this report is documented in Scientific Notebook numbers 765 E and 834E. Figures 2-2 through 2-5 were created by GRAY*STAR, Inc. using the TOPO! Digital Mapping Software (National Geographic, 2007).

ANALYSES AND CODES:

None.

Reference:

National Geographic. “National Geographic Hawaii TOPO!.” 2007. <http://www.swiftmaps.com/servlet/the-243/National-Geographic-Hawaii-Topo%21/Detail> (4 May 2007).

1 INTRODUCTION

1.1 Background

In accordance with 10 CFR Part 36, Pa'ina Hawaii, LLC, submitted a license application to the U.S. Nuclear Regulatory Commission (NRC) for the possession and use of sealed sources in a proposed commercial pool-type industrial irradiator to be located near Honolulu International Airport on the island of Oahu, Hawaii (NRC, 2005). The license application states that the irradiator will be used primarily for research and irradiation of food, cosmetics, pharmaceutical products, and a wide range of other materials.

To meet its responsibilities under the National Environmental Policy Act as defined in a settlement agreement (NRC, 2006), NRC agreed to prepare an environmental assessment to evaluate the potential for significant environmental impacts from the proposed irradiator. The environmental assessment must include evaluation of the environmental impacts and potential consequences of natural phenomena and aircraft crash hazards associated with the proposed irradiator facility. This topical report assesses the effects of potential aircraft crashes and natural phenomena, including tsunamis, hurricanes, and seismic events.

The proposed Genesis II Irradiator™ is designed, manufactured, and marketed by GRAY*STAR, Inc. The Clayton H. Landis Company, Inc. provides engineering support and the fabrication of the irradiator under contract to GRAY*STAR, Inc. The Genesis II Irradiator™ is classified as an underwater, self-shielded, Co-60 irradiator. The Genesis II Irradiator™ design qualifies as an underwater irradiator because the source remains in the shielded position during irradiation, and the item to be tested is lowered in an airtight container into the radiation field.

The proposed irradiator uses multiple source assemblies that consist of an inner capsule containing nickel-coated activated-cobalt metal discs and slugs. The inner capsule is either stainless steel or zircalloy and has two fusion-welded end plugs. This capsule has an inner diameter of 6.35 mm [0.25 in], a wall thickness of 0.6 mm [0.24 in], and a length of 449 mm [0.39 in]. This capsule is sealed in a stainless steel outer capsule with an outer diameter of 12.7 mm [0.5 in], a wall thickness of 0.7 mm [0.028 in], and a length of 455 mm [17.9 in]. The weight of a typical source assembly is 0.26 kg [0.57 lb]. The source assemblies are tested to meet 10 CFR 36.21 requirements for leak tests, corrosion, temperature shock, pressure, impact, vibration, puncture, and bending. Of particular importance to this report is the ability of the source assembly to withstand the forces exerted during the pressure, impact, puncture, and bending tests. As required by 10 CFR 36.21, prototype source assemblies have been shown to pass the following tests:

- The test source must be twice subjected for at least 5 minutes to an external pressure (absolute) of 2 million newtons per square meter
- A 2-kilogram steel weight, 2.5 centimeters in diameter, must be dropped from a height of 1 meter onto the test source
- A 50-gram weight and pin, 0.3-centimeter pin diameter, must be dropped from a height of 1 meter onto the test source

- If the length of the source is more than 15 times larger than the minimum cross-sectional dimension, the test source must be subjected to a force of 2000 newtons at its center equidistant from two support cylinders, the distance between which is 10 times the minimum cross-sectional dimension of the source

In addition, in accordance with the requirements of 10 CFR 36.21, the sealed source has a certification of registration issued under 10 CFR 32.210. According to the source registry (MDS Nordion, 2002), the source design has passed ANSI test E65646 (U.S. Department of Commerce, 1978), which includes

- A temperature test of −40 °C [−40 °F] for 20 minutes, 800 °C [1,472 °F] for 1 hour, and a thermal shock of 800 °C [1,472 °F] to 20 °C [68 °F] by immersion in a large volume of water within 15 seconds. Fire tests within the furnace use an industry-accepted 800 °C to simulate hydrocarbon fires.

- An external pressure test from 25 kN/m^2 [3.63 lb/in^2] absolute to 70 MN/m^2 [10,153 lb/in^2] absolute.

- An impact test of 20 kg [44 lb] dropped from a height of 1 m [39.37 in].

- Three vibration test cycles of 30-minutes duration each from 25 to 80 Hz at 1.5 mm [0.6 in] amplitude peak to peak and from 80 to 2,000 Hz at 20 g.

- A puncture test from a 1-kg [2.2-lb] pin dropped from a height of 1 m [39.37 in].

The irradiator main components include a pool, a source-holding mechanism and stainless steel plenum for holding the source assemblies in place, a surge tank, and a hoist and rail transfer system for moving product into place during irradiations. The surge tank and hoist and rail system are above the pool water level, while the source-holding mechanism and source plenum are located within the pool. The top of the pool is at ground level. A 107-cm [42-in] protective barrier rail, which serves to prevent personnel from accidentally falling into the pool, extends above the facility floor (Figure 1-1). The pool extends to a depth of 5.4 m [18 ft] below the facility floor, and the source assemblies are held in place at the bottom of the pool by a source plenum. The source plenum covers the sources and is designed to distribute helium around the sources such that water does not come into direct contact with the sources. The depth of the water table is 2.4 m [8 ft] below the facility floor; thus, the source assemblies normally reside below the water table (Wiedig Geoanalysts, 2005). During routine operations, the source assemblies are placed in a source holder contained within the stainless steel plenum. The source assemblies are mechanically isolated from the plenum or other structure within the pool. Thus, any forces that impact the plenum or other structure will not be directly transferred to the source assemblies. In addition, the pool structures are mechanically isolated from the facility, the surge tank, and the hoist and rail system. In the event of damage to the plenum structure, the source assemblies would either remain in the source holder or fall to the floor of the irradiator.

It is planned to house the irradiator in a building made of standard construction materials that has a length of 19.5 m [64 ft] and a width of 35.3 m [116 ft]. The planned building will be significantly larger than the footprint of the irradiator pool, which is approximately 2.05 × 2.41 m [81 × 95 in] (NRC, 2005), or 1 percent of the planned building floor area. The remaining area of the building will house the hoist and rail transfer system, the surge tank, offices, and product handling areas.

1.2 Scenarios To Be Considered

The consequence to be avoided in the event of an aircraft accident or natural phenomenon is loss of control of radioactive material, which occurs when source material is physically removed from the pool or when water becomes contaminated above some concentration limit and is released from the pool. To remove source material from the pool, a mechanical source retaining mechanism and lock (not shown in Figure 1-1) must be overcome, the plenum must be removed, the source must be removed from the source rack, and the source must be lifted 5.4 m [18 ft] out of the pool. For the irradiator pool water to become contaminated, the inner and outer capsules must be breached to expose the radioactive Co-60 slug, and the slug must be allowed to corrode in the water. Even if the building is destroyed and the pool damaged by the accident or natural phenomenon, control of the source is not lost unless the source material is removed from the pool. Similarly, the loss of operating monitoring equipment during an accident or natural phenomenon does not lead to the loss of control of radioactive material. Finally, a reduction in the water level may result in increased dose rates in a well-collimated beam directly above the pool. However, the increased dose rate can be readily shielded and would not have an environmental effect on the area around the proposed facility. In addition, if the water level drops, worker doses are not expected to be significantly increased in the area around the pool.

For pool water contamination to occur, the source must be removed from the source plenum, and the inner and outer containment capsules must both be breached. The cobalt slugs inside the source capsules are plated with nickel—a material that is not radioactive and does not readily corrode in water. Therefore, corrosion of the cobalt can occur only if a slug is cracked or split, exposing the cobalt to the pool water. Then, a significant amount of the cobalt source material must corrode to the extent that corroded cobalt metal significantly contaminates the water.

Two aspects of corrosion must be evaluated to determine whether the cobalt will corrode. First, the thermodynamic aspects must be evaluated. Below a pH of 9, cobalt metal forms cobaltous ions, which are a form of corrosion. Because the pool water is anticipated to have a pH of about 7, it is thermodynamically possible for cobalt to corrode. Thus, it is necessary to consider the kinetics of the corrosion reaction. In other words, the corrosion rate must be determined. In general, corrosion rates are higher at higher temperatures {typically greater than 100 °C [212 °F]} and are higher when ions are present in the solution. The quantity of ions in the water is measured indirectly as the conductivity of the water. In the irradiator pool, the conductivity is continuously monitored to ensure that the level is low (i.e., low concentrations of dissolved ions). Since the pool water will be maintained at a low temperature and at a low conductivity, the cobalt corrosion rate is anticipated to be very low. Although no data were found on the corrosion rate of cobalt in water, corrosion rates in highly acidic solutions with high conductivity are less than 108 μm/yr [0.004 in/yr] (Kim, et al., 2003). The corrosion rate in a solution with low conductivity is typically one to two orders of magnitude less. Thus, it is not feasible that a significant amount of contamination can be released into the pool water and lead to contamination of the surrounding environment in the timeframe of days to weeks considered in the case of an aircraft accident or damage by natural phenomena. For the remainder of this

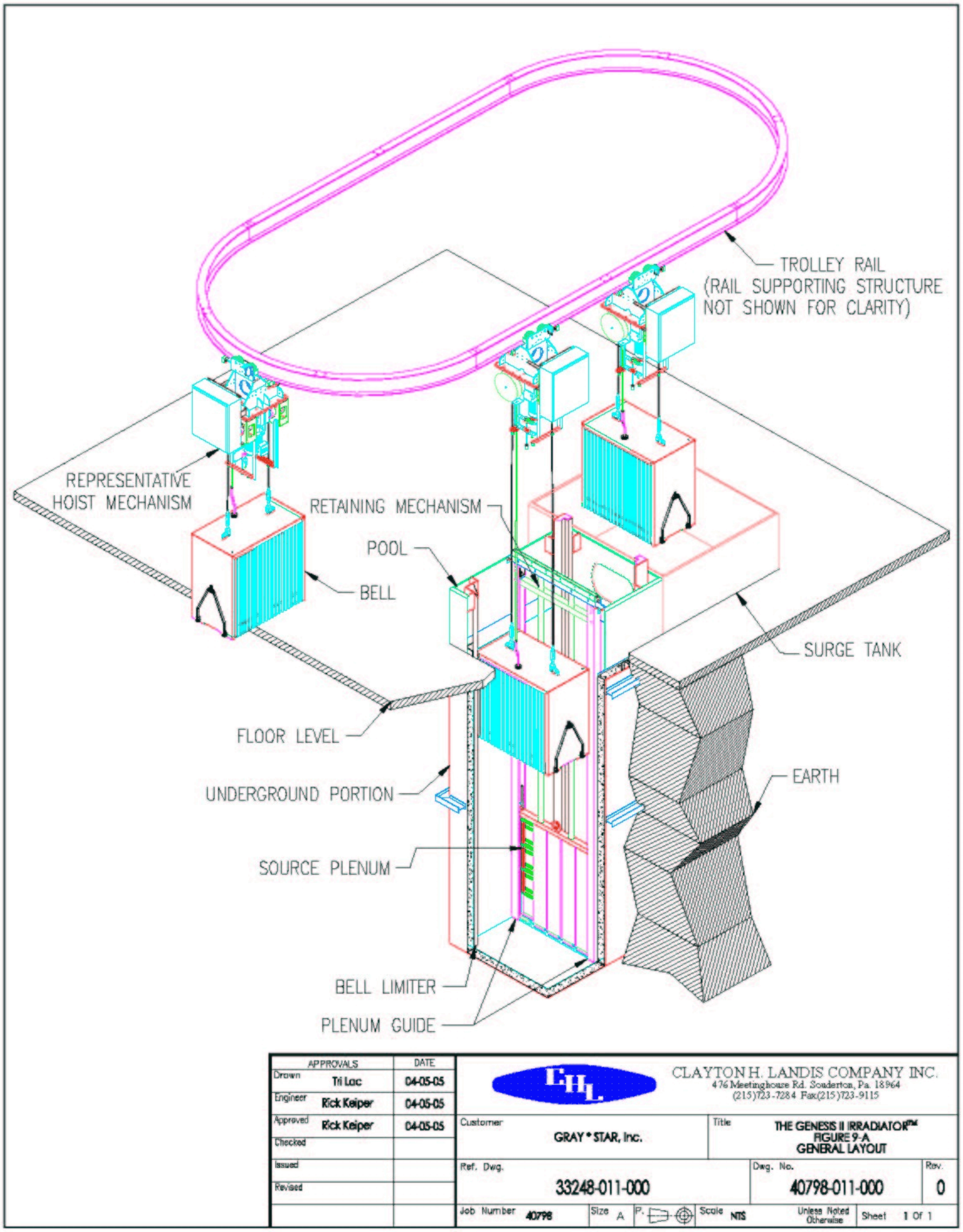


Figure 1-1. Schematic Drawing of the Proposed Irradiator Showing the Source Plenum, Pool, and Hoist and Rail System (GRAY*STAR, Inc., 2005)

report, release of contaminated pool water to the environment is not considered as a possible outcome.

1.3 Objectives and Scope

The objective of this report is to assess the potential effects of natural phenomena (tsunamis, hurricanes, and seismic events) and potential aircraft crashes on the proposed irradiator facility. The conclusions in this report are based on a review of the license application and supporting reports submitted by Pa'ina Hawaii, LLC (NRC, 2005) and on a review of existing public data on airport activity, seismic activity, tsunamis, and hurricanes that are applicable to the irradiator facility. No new data were measured or derived in preparing this report.

The scope of this report is to compile public data and perform basic analyses to determine the potential for a radiological release from the proposed irradiator. This report does not offer a comparison to the risks associated with other nuclear facilities. However, this report provides a technique for assessing whether an aircraft crash or natural phenomena may lead to the loss of control of radioactive material.

1.4 Methodology

The analysis of the hazard associated with a potential aircraft crash in Chapter 2 uses the methodology described in NUREG–0800 (NRC, 1981) to determine the annual probability of an aircraft crash into the proposed facility based on flight data from Honolulu International Airport.

A qualitative analysis of the likelihood of the loss of control of a Co-60 source assembly is provided to give an estimate of the potential radiological hazard associated with an aircraft accident.

The analyses presented in Chapter 3 of this report are based on data available to the general public on the geology of Hawaii as it pertains to earthquakes, tsunamis, and hurricanes. A recent history of the frequency and magnitude of each of these events is compiled, and the potential hazard to the proposed facility is determined.

2 ESTIMATION OF ANNUAL FREQUENCY OF AIRCRAFT CRASHES

This chapter describes the methodology and data used to determine the probability of an aircraft crash into the proposed facility. The pertinent aspects of the flight environment and proposed facility are also described, followed by an estimation of the probability of an aircraft crash that damages the facility, including a discussion of the conservatisms that are inherent in the estimation. Finally, the potential impacts to the environment are summarized.

2.1 Flight Environment and Proposed Facility

To estimate the probability of an aircraft crash into the proposed facility, information about the flight environment and the proposed facility must be collected. The flight environment includes flights originating and terminating at Honolulu International Airport and Hickam Air Force Base (which share the same runways) as well as a description of the types of aircraft that use these facilities and the number of flights. In addition to the description of the facility given in the previous section, this section presents information that is needed to complete the probability estimation.

2.1.1 Honolulu International Airport and Hickam Air Force Base

Honolulu International Airport is one of the busiest airports in the United States. Domestic and international flights use the main terminal of this airport as the principal aviation gateway to the State of Hawaii. In addition, interisland flights use the interisland terminal, and commuter flights use the commuter terminal. This airport is the principal hub of Aloha Airlines and Hawaiian Airlines. These airlines fly to other islands and several other domestic and international airports. Many other domestic and international airlines also use Honolulu International Airport (AirNav, LLC, 2006).

Hickam Air Force Base shares operations facilities and uses the runways at Honolulu International Airport for military flights. The 199th Fighter Squadron of the Hawaii Air National Guard uses F-15 A/B Eagle aircraft for maintaining interceptor capability for the State air defense system. This squadron also augments the active duty U.S. Air Force when needed. The 203rd Air Refueling Squadron uses KC-135R Stratotanker aircraft for air-refueling operations worldwide. The 204th Airlift Squadron uses C-130H2/H3 Hercules tactical aircraft for airlift operations. The 15th Airlift Wing of the Air Force uses C-17 Globemaster III aircraft for worldwide missions in support of the Pacific Air Forces (Hawaii Air National Guard, 2004).

There are four runway surfaces at Honolulu International Airport: Runway Surface 8L/26R, Runway Surface 8R/26L, Runway Surface 4R/22L, and Runway Surface 4L/22R (AirNav, LLC, 2006). The length of each runway surface is provided in Table 2-1. The dual designation for a single runway surface indicates that a single runway surface serves as two runways in opposing 180° directions. For instance, Runway Surface 8L/26R is designated Runway 8L when aircraft are landing from the west and Runway 26R when aircraft are landing from the east. For the remainder of this report, Runway 8L will be considered a separate runway from Runway 26R, even though they both refer to the same concrete slab.

Due to predominant northeasterly trade winds (Barnes, et al., 2001), Runway 8L is used for instrument landings and is the primary daytime runway for landing wide-body jet aircraft.

Table 2-1. Length of Runways*			
Runway	Length		
	m	ft	Statute mi
8R/26L	3,658	12,000	2.27
8L/26R	3,749	12,300	2.33
4R/22L	2,743	9,000	1.70
4L/22R	2,119	6,952	1.32
*AirNav, LLC. "Runway Information." 2006. <http://www.airnav.com/airport/PHNL> (December 14, 2006).			

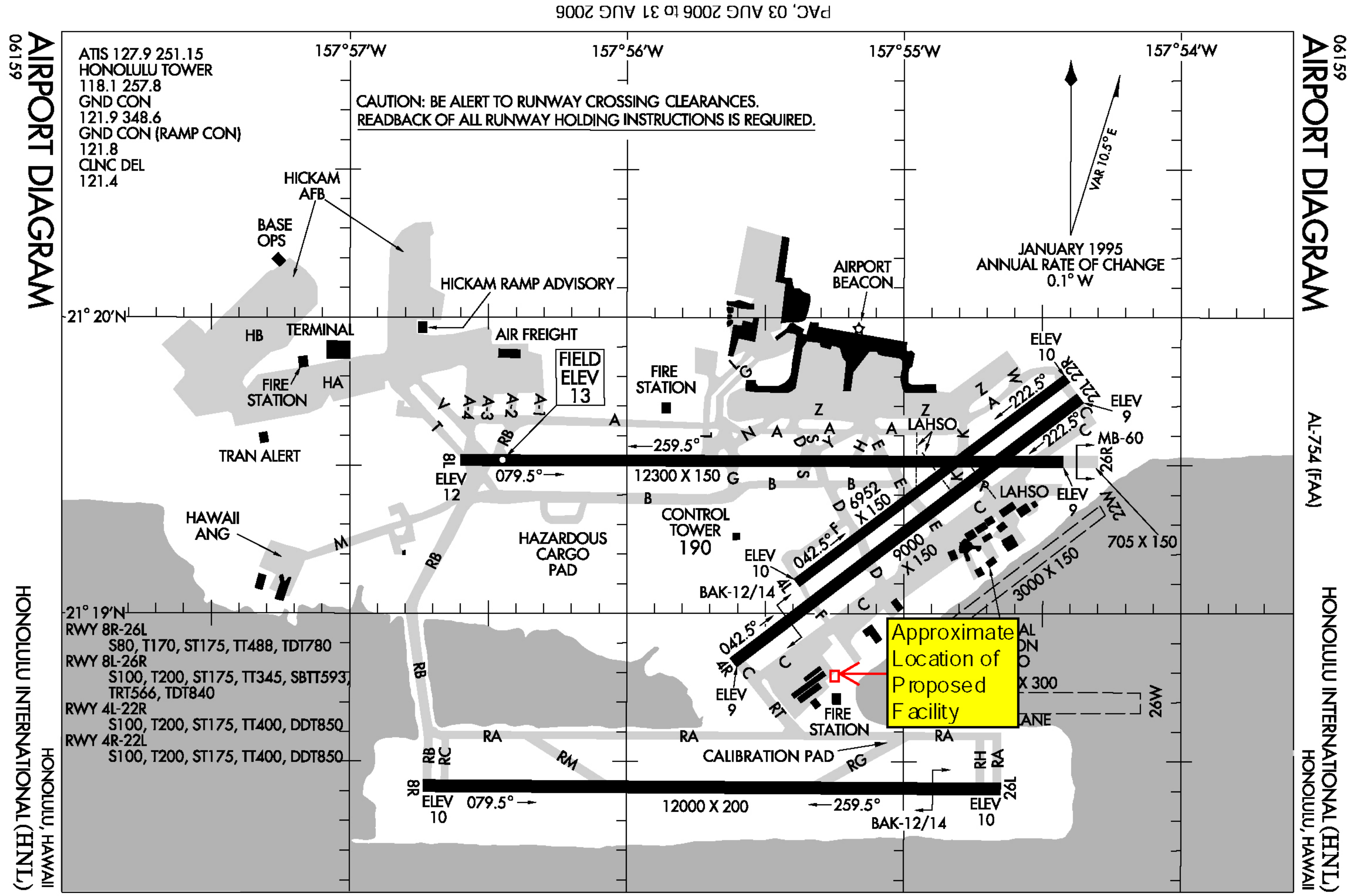
Runway Surface 8R/26L is known as the Reef Runway, and it has a left-hand traffic pattern. The Reef Runway is used for instrument landings and takeoffs by wide-body jet aircraft to reduce the effects of noise on the city (Barnes, et al., 2001). Runway Surface 4R/22L has a left-hand traffic pattern, and Runway 4R is used for instrument landings. Runway Surface 4L/22R has a left-hand traffic pattern, and only visual landings are conducted on this runway. In addition, there are two designated offshore (water surface) waterways, 26W/8W {length 1,524 m [5,000 ft]} and 22W/4W {length 914 m [3,000 ft]} for seaplanes. The location of each runway/waterway is shown in Figure 2-1.

The two waterways were not included in the current analysis for two reasons. First, seaplanes are small aircraft that do not have the mass or fuel capacity to cause extensive damage to the proposed irradiator. Second, the number of seaplanes that use the waterways is expected to be relatively small.

The airspace above Honolulu International Airport is designated by the Federal Aviation Administration (FAA) as Class B airspace, which means that the air traffic control system provides radar sequencing, aircraft separations, and air traffic safety advisories to aircraft flying under instrument and visual flight rules via specific approach and departure routes. Procedures for using these published arrival and departure routes at Honolulu International Airport indicate that aircraft with missed approaches to landings on Runways 8L and 8R will climb and then turn right to a holding pattern over the ocean. Similarly, aircraft with missed approaches to landing on Runways 4L and 4R will climb and then turn right into a holding pattern, again over the ocean. Aircraft takeoffs from Runways 8L, 8R, 4L, and 4R must complete the right turn to the assigned headings within 3.7 km [2.3 mi] of the departure end of the runway. Similarly, aircraft taking off from Runways 22L, 22R, 26L, and 26R must complete a left turn to the assigned headings within 3.7 km [2.3 mi] of the departure end of the runway (AirNav, LLC, 2006).

2.1.2 Aircraft Operations at Honolulu International Airport

Statistics are compiled on the number of aircraft flights at Honolulu International Airport and, for the purposes of this analysis, are classified into four general categories: commercial, general aviation, air taxis, and military aircraft. Commercial aircraft include large passenger aircraft that typically arrive from overseas. General aviation aircraft arrive in Hawaii from overseas or are



PAC, 03 AUG 2006 to 31 AUG 2006

Figure 2-1. Layout of Honolulu International Airport Showing the Location of the Proposed Facility (National Aeronautical Charting Office, 2007)

licensed in Hawaii. Air taxi is a classification of certified commercial air carriers defined by the FAA as aircraft transporting people, property, and mail in accordance with 14 CFR Part 135 using smaller aircraft than the commercial air transportation system: air traffic controllers classify a particular aircraft operation as air taxi if, in general, it consists of commercial services carrying fewer than 70 passengers (Kimura, et al., 1996). Military aircraft are not distinguished by size and include any aircraft owned and operated by the military.

Statistics on the number of aircraft operations at Honolulu International Airport were obtained from three independent sources: AirNav, LLC (2006), the FAA (2006a), and Schlapak (2006), Oahu District Manager of the Hawaii State Department of Transportation. The flight information from Schlapak includes landings, takeoffs, touch-and-go operations, and flybys. The information obtained from these three sources is provided in Table 2-2 and is consistent from source to source. Therefore, the data from the FAA are used for subsequent calculations because the data are publicly available from a recognized government authority. The differences are small enough that using either of the other two data sources would have only small effects on the results of this analysis.

The direction of flight is an important component of estimating the risk of an aircraft crash because the upwind leg (after takeoff) and the final approach leg (before landing) are the portions of the traffic pattern where aircraft crashes are most likely. Information provided by Schlapak (2006) stated that approximately 45 percent of the traffic at Honolulu International Airport is handled by Runway Surface 8L/26R. Runway Surface 4R/22L handles roughly 28 percent of the traffic. The remaining traffic is handled by Runway Surface 8R/26L (17 percent) and Runway Surface 4L/22R (10 percent). Tropical trade winds blow from the northeast at an angle 40° to 90° from the north for a major portion (about 75 percent) of the year (Schlapak, 2006).

Alternatively, the warm ocean temperature in the central Pacific Ocean reverses the trade wind pattern, and wind blows from the southwest. This is called the Kona wind and lasts from a few days to a few weeks sporadically throughout the year. When the Kona wind contributes a tail wind component of more than 14.8 km/hr [8 knots], landing at Runway 26R is required instead

Table 2-2. Number of Flights Per Aircraft Type at Honolulu International Airport

Type of Aircraft	AirNav, LLC		FAA*		Schlapak†	
	Flights	Frequency	Flights	Frequency	Flights	Frequency
Total	326,640	100%	323,726	100%	330,506	100%
Commercial	177,870	54%	176,755	55%	181,780‡	55%
General Aviation	84,090	26%	84,099	25%	66,100‡	20%
Air Taxis	48,510	15%	47,057	15%	66,100‡	20%
Military	16,170	5%	15,815	5%	16,525‡	5%

*FAA = Federal Aviation Administration
†Schlapak, B. "Aircraft-Specific Information Related to Pa'ina Irradiator." Email communication (October 31) to M. Blevins, U. S. Nuclear Regulatory Commission. ML070110036. Oahu, Hawaii: Hawaii State Department of Transportation. 2006.
‡The number of flights is based on total flights multiplied by the estimated percentage of aircraft types.

of Runway 8L. Approximately 25 percent of the time, the Kona wind blows with enough strength to cause this change in the landing directions. Similarly, Runway 26L is preferred for landing and takeoff when the Kona wind blows. Because the direction of the Kona wind varies from 150° to 270°, it is also expected that the landing and takeoff traffic on Runways 4L/22R and 4R/22L would be similarly affected.

No data are compiled on the number of times each type of aircraft uses specific runways in a year. Flight tracks of aircraft by individual runway are preserved for only 2 weeks and are not summarized (Schlapak, 2006). Based on operations information distributed among the four runways and a 75:25 ratio between the directions of each runway, the estimated number of landings and takeoffs for each runway are given in Table 2-3. Additionally, the FAA and AirNav, LLC, provide the fraction of operations conducted by each type of aircraft. In the absence of other information, the number of landings is assumed to be equal to the number of takeoffs. The estimated number of landings and takeoffs for each runway is given in Table 2-4.

2.1.3 Proposed Facility

The proposed irradiation facility would be located on space 011 109 at Honolulu International Airport. This space is 36 × 36 m [120 × 120 ft]. Space 011 108, adjacent to this space, is available for possible future expansion of the facility although this expansion is not part of the Pa'ina Hawaii, LLC license application. The length of the proposed facility is 19.5 m [64 ft], the width is 35.3 m [116 ft], and the height is 9 m [29.6 ft].[1] The approximate location of the facility is shown in Figure 2-2.

Table 2-3. Estimated Number of Annual Operations for Each Runway

Runway	Estimated Number of Annual Operations
8L	109,258
26R	36,418
8R	41,276
26L	13,756
4R	67,982
22L	22,662
4L	24,282
22R	8,092

[1]Kohn, M. "Draft Request for Additional Information Related to Environmental Review." E-mail communication (October 23) to M. Blevins, U.S. Nuclear Regulatory Commission. Honolulu, Hawaii, Pa'ina Hawaii, LLC. 2006.

Table 2-4. Annual Operations for Each Type of Aircraft (Takeoff or Landing) at Honolulu International Airport								
Aircraft Type	**Runway**							
	8L	**26R**	**8R**	**26L**	**4R**	**22L**	**4L**	**22R**
Air Carrier	59,496	19,832	22,476	7,492	37,020	12,340	13,222	4,406
Air Taxi	16,226	5,408	6,130	2,042	10,096	3,364	3,606	1,202
General Aviation, Turboprop	28,126	9,374	10,624	3,540	17,500	5,834	6,250	2,082
Military Aircraft	5,408	1,802	2,042	680	3,364	1,122	1,202	400

2.2 Estimation of Annual Crash Frequency

The annual frequency of aircraft crashing onto the proposed facility is estimated using the methodology given in Section 3.5.1.4 of NUREG–0800 (NRC, 1981). A brief description of the estimation methodology follows, along with a discussion of the pertinent factors.

2.2.1 NUREG–0800 Methodology

According to NUREG–0800 (NRC, 1981), the annual frequency of an aircraft crashing into a facility, P_A, located at some distance from an airport is the product of three terms: (i) the probability per square mile of an aircraft crash, (ii) the number of aircraft performing landings or takeoffs per year, and (iii) the effective area of the facility. This is expressed mathematically as

$$P_A = \sum_{i=1}^{L} \sum_{j=1}^{M} C_j N_{ij} A_j \qquad (2\text{-}1)$$

where

M = number of different types of aircraft using the airport
L = number of flight trajectories affecting the facility
C_j = probability per square mile of a crash per aircraft movement for the jth aircraft
N_{ij} = number of aircraft movements per year by the jth aircraft along the ith flight path
A_j = effective area of the facility for the jth aircraft

In the following section, these terms are discussed, and the basis for the values used is provided.

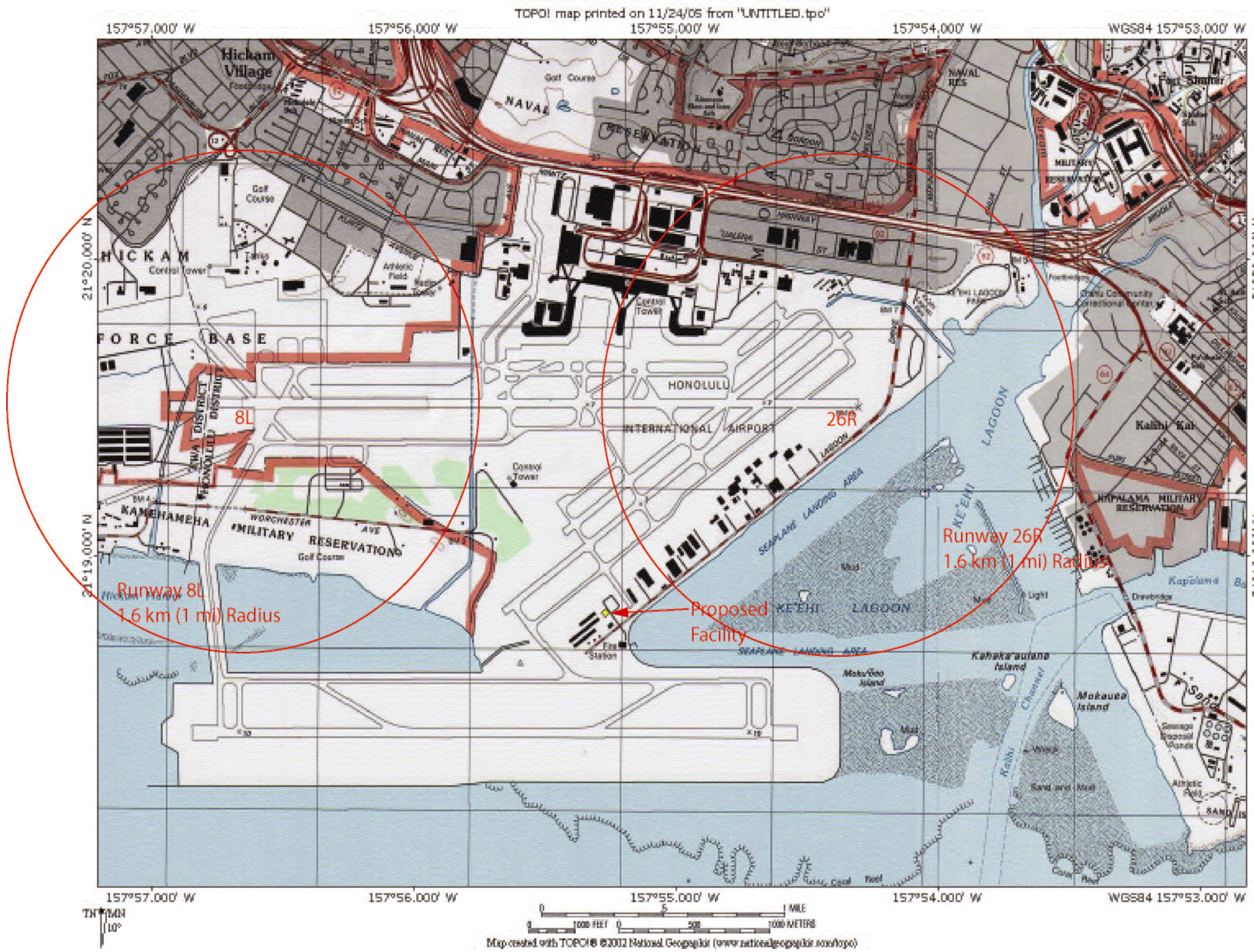


Figure 2-2. Runway 8L/26R With Respect to the Proposed Facility

2.2.2 Probability Per Square Mile of a Crash Per Aircraft Movement

The probability per square mile of a crash per aircraft movement depends on the type of aircraft and the distance from the end of a runway. NUREG–0800 (NRC, 1981) provides the value of C_j for four broad classes of aircraft: air carrier, general aviation, U.S. Navy and Marine Corps, and U.S. Air Force. These classifications differ from the classifications shown in Table 2-2. Therefore, the classifications (and their respective number of flights) were grouped by combining the commercial and air taxi classifications in Table 2-2 to make the air carrier classification in NUREG–0800 (NRC, 1981).

The location of the proposed facility with respect to the four runway surfaces is shown in Figures 2-3 through 2-5. As defined in NUREG–0800 (NRC, 1981), the ends of the runways at Honolulu International Airport are either 0 to 1.6 km [0 to 1 mi] or 1.6 to 3.2 km [1 to 2 mi] from the facility. The methodology described in NUREG–0800 provides equal probability of an aircraft crash regardless of the spatial orientation of the facility with respect to the runway orientation and whether the aircraft is landing or taking off. Values for C_j applicable to the proposed facility are given in Table 2-5 for different aircraft types and for the two distance ranges.

The last factor needed to determine the probability of an aircraft crash is the effective area of the facility, that is, the ground surface area surrounding the facility such that an unobstructed aircraft would affect the facility if it were to crash within the area. The impact could be either by direct fly-in or skid into the facility (DOE, 1996). The effective area of a facility, A_{eff}, for a given type of aircraft is given as the sum of the effective fly-in area, A_f, and the effective skid-in area, A_S (DOE, 1996). This is written mathematically as

$$A_{eff} = A_f + A_S \tag{2-2}$$

where

$$A_f = (WS + R) \cdot H\ cot(\phi) + \frac{2 \cdot L \cdot W \cdot WS}{R} + L \cdot W \tag{2-3}$$

and

$$A_S = (WS + R) \cdot S \tag{2-4}$$

In these equations

WS	=	aircraft wing span
L	=	length of the facility
W	=	width of the facility
H	=	height of the facility
R	=	length of the diagonal of the facility = $\sqrt{L^2 + W^2}$
S	=	mean aircraft skid distance
$cot(\phi)$	=	mean cotangent of the aircraft impact angle

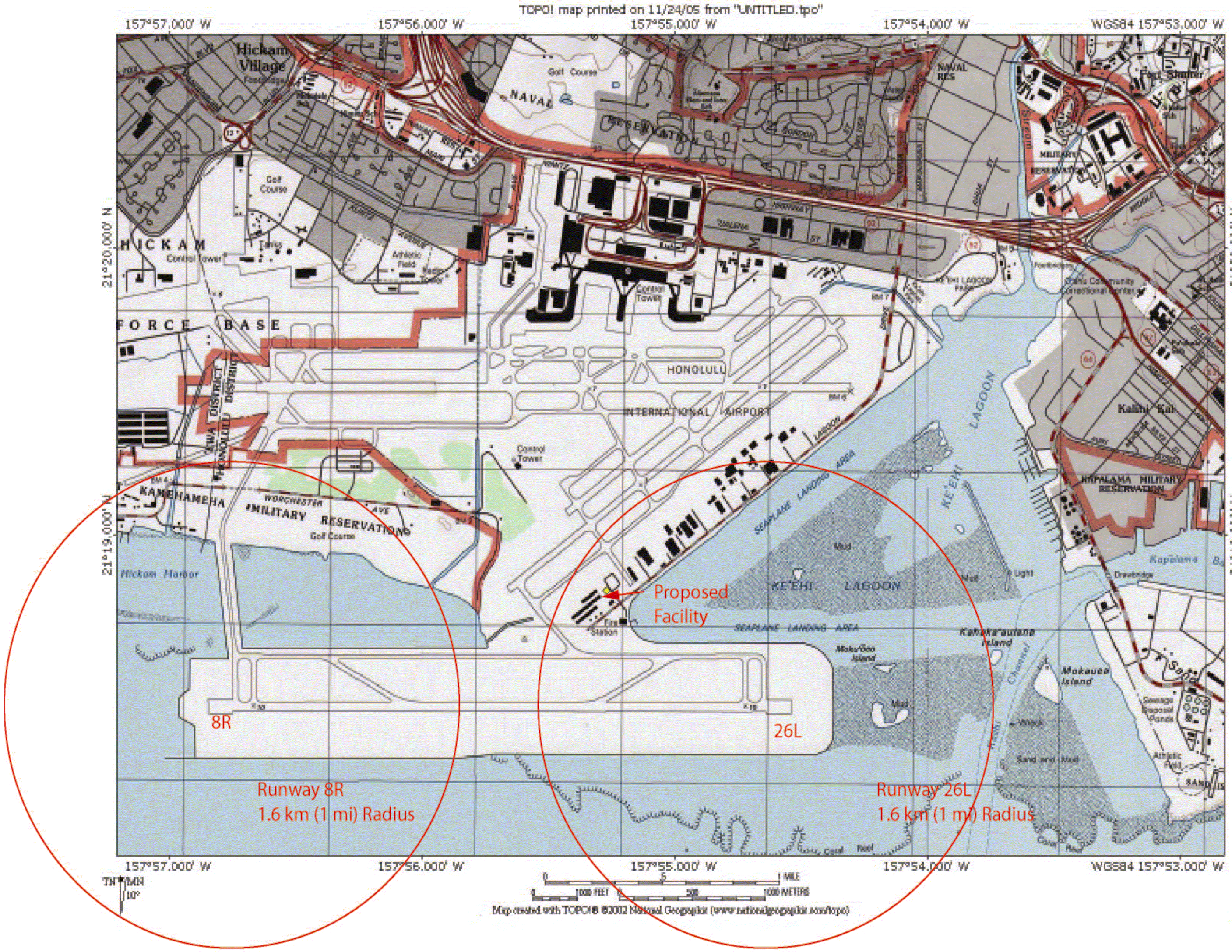


Figure 2-3. Runway 8R/26L With Respect to the Proposed Facility

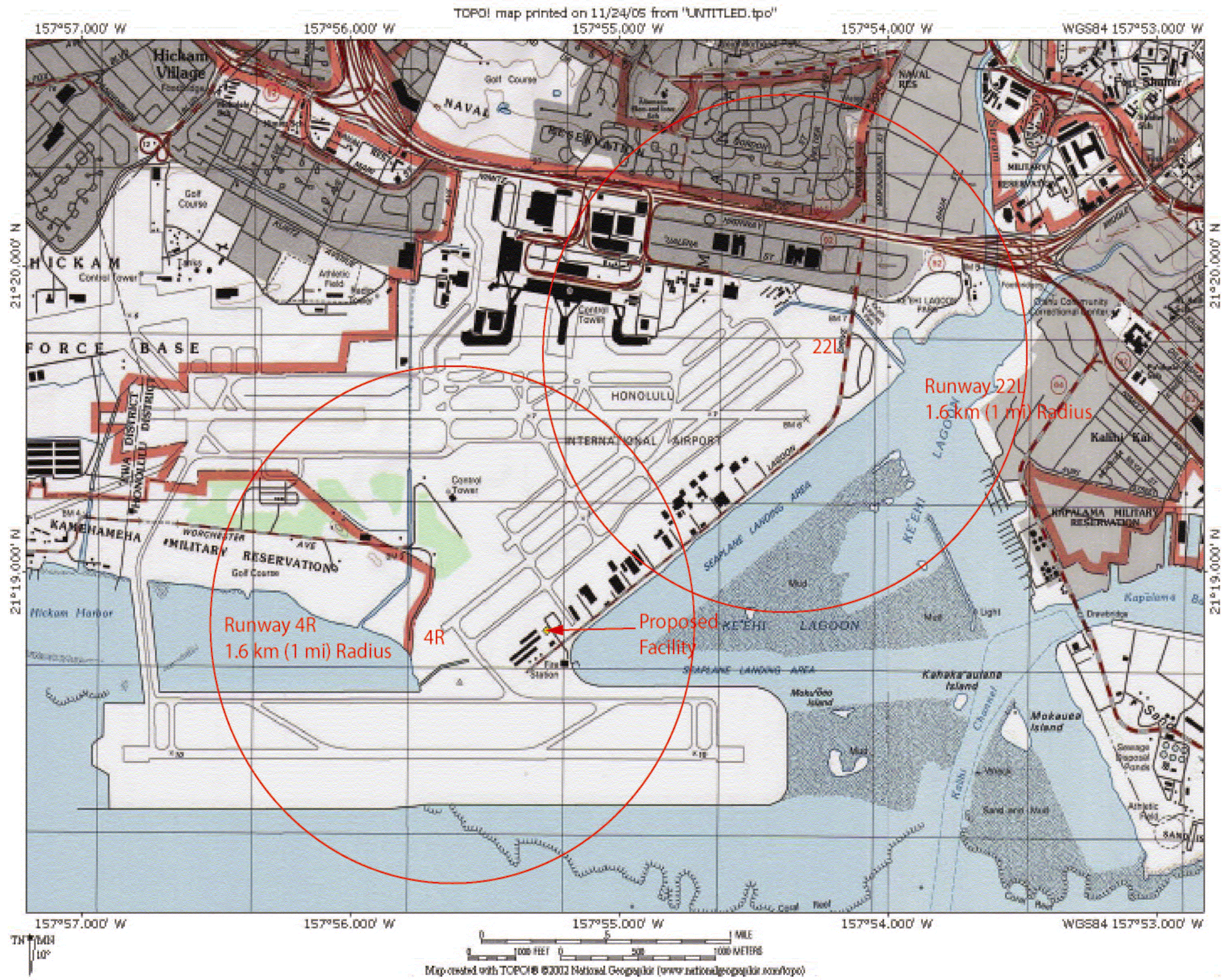


Figure 2-4. Runway 4R/22L With Respect to the Proposed Facility

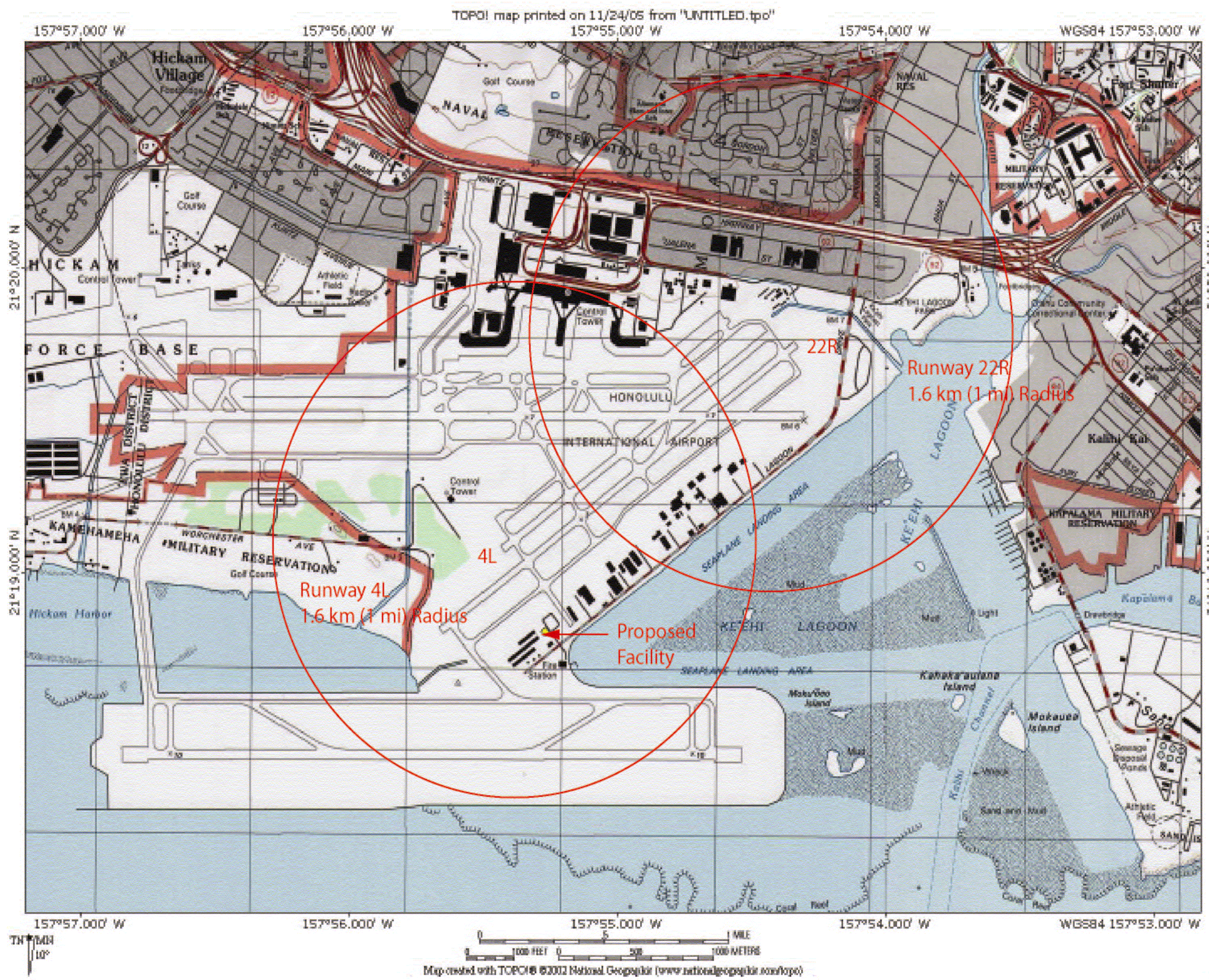


Figure 2-5. Runway 4L/22R With Respect to the Proposed Facility

Table 2-5. Values of C_j from NUREG–0800*				
Distance From End of Runway km [mi]	**Probability of a Fatal Crash Per Square Mile Per Aircraft Movement**			
	Air Carrier	**General Aviation**	**U.S. Navy**	**U.S. Air Force**
0–1.6 [0–1]	16.7×10^{-8}	84×10^{-8}	8.3×10^{-8}	5.7×10^{-8}
1.6–3.2 [1–2]	4.0×10^{-8}	15×10^{-8}	1.1×10^{-8}	2.3×10^{-8}
*U.S. Nuclear Regulatory Commission (NRC). NUREG–0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants. Standard Review Plan Section 3.5.1.6—Aircraft Hazards.” Washington, DC: NRC. June 1981.				

The wingspan, skid distance, and mean cotangent of the impact angle for each aircraft type, obtained from DOE (1996), are presented in Table 2-6. Using Eqs. (2-1) through (2-4) and the information presented in Tables 2-5 and 2-6, the effective area of the proposed facility estimated for each aircraft type is given in Table 2-7.

2.2.3 Evaluation of Runways for Potential for Aircraft Crashes

The final task in estimating the annual frequency of aircraft crashes is to identify the runway events (landings and takeoffs) that have the potential for an aircraft crash that could strike the

Table 2-6. Characteristics of the Aircraft*			
Aircraft Type	**Wingspan *WS*, m [ft]**	**Mean Cotangent of Impact Angle $cot(\Phi)$**	**Skid Distance *S*, m [ft]**
Air Carrier	29.4 [98]	10.2	432 [1,440]
Air Taxi	17.7 [59]	10.2	432 [1,440]
Large Military Aircraft	66.9 [223]	7.4†/9.7‡	234†/110‡ [780†/368‡]
Small Military Aircraft (High Performance)	23.4 [78]	8.4†/10.4‡	74†/134‡ [246†/447‡]
General Aviation, Piston Engine	15.0 [50]	8.2	18 (60)
General Aviation, Turboprop	21.9 [73]	8.2	18 (60)
General Aviation, Turbojet	15.0 [50]	8.2	18 (60)
*DOE. DOE–STD–3014–96, “DOE Standard: Accident Analysis for Aircraft Crash Into Hazardous Facilities.” Washington, DC: DOE. 1996. †Takeoff ‡ Landing			

Table 2-7. Estimated Effective Area (A_{eff}) of the Facility for Each Type of Aircraft		
Aircraft Type	Effective Facility Area (A_{eff})	
	km^2	mi^2
Air Carrier	0.03905	0.01506
Air Taxi	0.03233	0.01247
Large Military Aircraft	0.03604*/0.02467†	0.01390*/0.00952†
Small Military Aircraft (High Performance)	0.01119*/0.01628†	0.00431*/0.00628†
General Aviation, Piston Engine	0.00635	0.00245
General Aviation, Turboprop	0.00724	0.00279
General Aviation, Turbojet	0.00635	0.00245
* Takeoff † Landing		

proposed facility. Landing phase crashes historically occur short of the runway (Glaser, 1996). Based on analysis of data, Kimura, et al. (1996) concluded that a crash during landing occurs on the average approximately 2.3 km [1.4 mi] short of the threshold end of the runway. Similarly, a crash during takeoff occurs on the average approximately 1 km [0.6 mi] beyond the departure end of the runway. Based on information of historical crash locations (Glaser, 1996; Kimura, et al., 1996), each of the runways at Honolulu International Airport were evaluated. The results are provided in Section 2.2.4.

The following discussions provide a brief description of operations and assessment of facility strike potential for each runway at Honolulu International Airport.

Runway 8L

The proposed facility is located closer to the departure end (during takeoff) of this runway in a direction perpendicular to the runway centerline. Barnes, et al. (2001) have observed that wide-body aircraft would land at this runway and exit at taxiway S or H {2,210 m [7,250 ft] and 2,500 m [8,200 ft] from the Runway 8L threshold} near the overseas terminal (Figure 2-1), respectively. Informal Land and Hold Short procedures occur frequently while landing at this runway. However, nearly all narrow-body aircraft in interisland operations would exit the runway at either taxiway L or G {1,495 m [4,900 ft] and 1,645 m [5,400 ft] from Runway 8L threshold}, respectively, to expedite arriving at the interisland terminal of the airport (Figure 2-1). This practice effectively shortens the 3,749-m [12,300-ft] runway to approximately 1,525 m [5,000 ft] from the Runway 8L threshold (Barnes, et al., 2001). An aircraft landing at this runway and skidding from the runway while decelerating toward the proposed facility must pass through a wooded area to reach the proposed building site. The probability of an aircraft crash into the proposed facility while attempting to land at this runway is negligible because of the distance between the landing threshold and the proposed facility. There are no documented cases of such an accident (Glaser, 1996; Kimura, et al., 1996).

An aircraft on takeoff roll on this runway would have to skid off in a direction perpendicular to the runway centerline. The probability of a crash onto the proposed facility after takeoff is calculated in Section 2.2.4.

Runway 26R

The proposed facility is in a direction perpendicular to the runway centerline at the threshold. The probability of an aircraft crashing into the proposed facility is provided in Section 2.2.4. However, it is expected that this probability is an overestimate because an aircraft on takeoff roll on this runway would have to skid in a direction perpendicular to the runway centerline to reach the facility, crossing two other runway surfaces on the way. The skid angle becomes steeper as the aircraft traverses further along the runway, gathering speed. Therefore, the potential for a crash onto the proposed facility while taking off from this runway is negligible.

Runway 8R

This runway is the preferred departure runway for wide-body aircraft. Aircraft make a right turn to a crosswind leg after takeoff to reach the assigned route, which could bring the aircraft in a direction opposite the facility. During its takeoff roll, an aircraft would have to skid to the left through a taxiway and several other structures to reach the proposed facility. Again, as the aircraft gathers speed while moving down the runway, it becomes increasingly difficult to reach the facility because the required angle of travel becomes increasingly steeper. Were air traffic control to direct general aviation/narrow-body aircraft to use a left-hand pattern on takeoff from this runway, there is a nonnegligible probability of a fly-in crash from the crosswind leg.

It is not feasible that aircraft landing at this runway could reach the facility because the facility is almost 3.2 km [2 mi] from the runway threshold. An aircraft would have to skid across a taxiway and perhaps into other structures to reach the facility. A fly-in crash into the facility while landing at this runway is not feasible.

Runway 26L

An aircraft on its takeoff roll on this runway is unlikely to skid into the proposed facility because it would have to skid to the right across a taxiway and perhaps into a fire station before colliding with the proposed facility. The apex of Keehi Lagoon is also between the runway and the proposed facility. The probability of an aircraft crash involving the proposed facility during takeoff is, therefore, negligible.

The calculated probability of an aircraft crashing into the proposed facility on final approach to this runway or on its landing roll is given in Section 2.2.4. However, the probability does not reflect that the accident would require precise positioning for the aircraft to fly into the effective area of the building. The actual probability for the precise positioning necessary to produce a credible scenario would be less than the calculated probability.

Runway 4R

While it is conceivable that an aircraft on takeoff from this runway could collide with the proposed facility, the proposed facility is located beyond the runway threshold and to the right. Further, aircraft skidding from the runway would first traverse a general aviation tie-down area and probably crash into hangar buildings before colliding with the proposed facility. Therefore, the potential for crashing into the proposed facility is negligible. However, the probability of an aircraft crashing into the proposed facility on final approach has been included in Section 2.2.4. This probability does not reflect that this type of accident would require precise positioning for the aircraft to fly into the effective area of the building. Thus, the actual probability would be less than the calculated value provided in Section 2.2.4.

Runway 22L

The proposed facility is not beyond the departure end of this runway. If a landed, decelerating aircraft were to skid off the runway to the left, it would have to pass through a natural area, taxiways, and a general aviation tie-down area before colliding with the proposed facility. Therefore, the probability of an aircraft crashing into the proposed facility while landing at this runway is negligible. An aircraft could crash into this facility while banking its upwind-to-crosswind turn from the departure end of this runway, and this probability is calculated in Section 2.2.4.

Runway 4L

The proposed facility is behind and to the right of the point where aircraft start their takeoff roll. Therefore, the probability of an aircraft crash into the proposed facility during takeoff is negligible. The probability of an aircraft crashing into the proposed facility during final approach for a landing on this runway is given in Section 2.2.4.

Runway 22R

The proposed facility is perpendicular to the departure end of this runway. The probability of a fly-in aircraft crash into the proposed facility during landing is negligible. If a landed, decelerating aircraft were to skid off the runway to the left, it would have to pass another runway, natural areas, taxiways, and a general aviation tie-down area before colliding with the proposed facility. The probability of an aircraft crashing into the facility while banking its upwind-to-crosswind turn from the departure end of the runway is given in Section 2.2.4. By procedure, pilots must complete this left turn within 3.7 km [2.3 mi] of the departure end of the runway.

2.2.4 Estimated Annual Frequency

The annual frequency of aircraft crashing into the proposed facility has been estimated using the methodology given in NUREG–0800 (NRC, 1981). The annual aircraft crash frequency was estimated by multiplying the number of landings and takeoffs in a year by different types of aircraft at each runway (Table 2-4); the crash rate corresponds to the relative location of the facility with respect to the runway end (Table 2-5) and the estimated effective area (Table 2-7). The estimated aircraft crash frequencies are shown in Table 2-8. To ensure that the probability of an aircraft crash is not underestimated, it has been assumed that all general aviation aircraft are turboprop types, because this type of aircraft results in the largest effective area of the facility. Moreover, it has been assumed that all military aircraft are F-15 jets, classified as small

Table 2-8. Estimated Annual Crash Frequency During Landing and Takeoff		
Runway	**Landing**	**Takeoff**
8L	~0	2.8×10^{-5}
26R	9.4×10^{-6}	~0
8R	~0	4.7×10^{-5}
26L	1.6×10^{-5}	~0
4R	7.8×10^{-5}	~0
22L	~0	5.8×10^{-6}
4L	2.8×10^{-5}	~0
22R	~0	2.1×10^{-6}
	Cumulative Total	2.1×10^{-4}

high-performance aircraft. Honolulu International Airport is also used by large military aircraft (e.g., KC-135R Stratotanker, C-130H2/H3 Hercules, and C-17 Globemaster III aircraft). Although the effective area of the facility will be larger for these aircraft, the crash rates for these multiengine aircraft are significantly lower than the crash rate for the twin-engine F-15 aircraft.

2.3 Overestimation in the Estimated Annual Frequency

A certain amount of overestimation is possible in the analysis methodology and data used to estimate the annual frequency of aircraft crashes involving the proposed facility. This section discusses the main assumptions that result in possible overestimations.

- The NUREG–0800 (NRC, 1981) methodology is independent of the radial orientation of the proposed facility with respect to the runway orientation. Information obtained since the publication of the NUREG–0800 methodology (e.g., DOE, 1996) suggests that the locations of aircraft crashes during takeoff and landing are oriented mostly along the extended centerline of the runway. The conditional probability of hitting a location across and away from the runway given a crash has taken place is significantly lower than that of a facility that is located along the extended centerline of the runway. The proposed facility is on the side of the runways at Honolulu International Airport and is at a direction perpendicular to the runway centerline. Therefore, it is expected that the annual frequency of aircraft crashes into the proposed facility will be less than estimated here.

- NUREG–0800 (NRC, 1981) assumes that the aircraft crash probability for takeoff operations is the same as that for landing operations. Recent data suggest that during takeoff, the probability of an aircraft crash is slightly lower than during landing (e.g., DOE, 1996). Therefore, the actual annual crash frequency of aircraft during takeoff from Honolulu International Airport will be less than estimated here. Because half of the annual operations at the airport are assumed to involve takeoff, the calculated crash frequency of half of the annual operations is likely overestimated.

- In the NUREG–0800 (NRC, 1981) methodology, the origin of the coordinate system is at the end of the runway. The positive x-direction is taken along the centerline of the runway and away from it. It is not clear whether the crash rate given in NUREG–0800 for the positive x-direction would be the same in the negative x-direction (i.e., toward the centerline of the runway), as used here in many cases. More recent information from DOE (1996) suggests that the crash rate probabilities are not uniform around the runway end. Therefore, the assumption that the crash rate away from the runway end is the same as the crash rate inside the runway toward the runway centerline probably overestimates the frequency.

- Honolulu International Airport is classified by the FAA as Class B airspace. Therefore, air traffic control provides radar sequencing, aircraft separations, and safety advisories to aircraft flying under both instrument and visual flight rules via specific approach and departure procedures. Based on departure procedures at Honolulu International Airport specified by the FAA, all aircraft taking off from any runway with the exception of Runways 4L and 4R would bring the aircraft away from the proposed facility. Similarly, any missed approach while landing at any runway would take the aircraft away from the proposed facility. Therefore, the crash potential should also have a similar bias toward the ocean side instead of the symmetry assumed in the NUREG–0800 methodology.

- The crash rate of military aircraft is decreasing over time (Government Accounting Office, 1996). Information from Aviation Safety Network (2007) on civilian aircraft shows a decreasing trend in hull-loss mishaps in takeoff and landing phases. No credit has been taken for this trend in this analysis. Since 1962, only two aircraft accidents that involved fatalities have occurred at Honolulu International Airport (Schlapak, 2006).

2.4 Impact of Aircraft Crash on Proposed Facility

The probability that an aircraft will crash into the proposed facility does not reflect the potential for loss of control of radioactive material. For the purposes of this report, loss of control of radioactive material is defined in Section 1.2. A portion of the force generated by an aircraft crash will damage the building and the structures in the pool. Transferring the remaining force vertically through water to the bottom of the pool will also likely result in significant absorption of the force. Finally, the aircraft crash must result in a force large enough to lift and remove the source from the pool to result in loss of control of radioactive material. As shown in the next section, the force required to remove a source from the bottom of the pool is very large. It is not feasible that the source could be removed from the pool as the result of an aircraft crash.

An aircraft crash into the proposed facility could also lead to a jet fuel fire. Jet fuel is less dense than water; thus, burning jet fuel will burn above the water and will not lead to a significant amount of evaporation of the pool water until the fuel is nearly depleted, at which time evaporation will be minimal. Further, it is not possible for the burning jet fuel to damage the source assemblies. Jet fuel burns in air at a temperature of up to 315 °C [599 °F]. In accordance with ANSI test E65646 (U.S. Department of Commerce, 1978), the source assemblies have been tested to withstand temperatures of 800 °C [1,475 °F] for 1 hour. This temperature is selected as the industry consensus standard to simulate a fuel fire. The adiabatic flame temperature of most hydrocarbon fuels, including jet fuels, ranges from approximately 1,980 to 2,080 °C [3,610 to 3,770 °F]. However, these fuels do not produce adiabatic temperatures when free burning, as they do not burn with 100-percent efficiency. For comparison purposes, 10 CFR 71.73 requires shipping containers to be tested in an open fuel fire with an average measured temperature of 800 °C [1,475 °F] for a period of 30 minutes. This average temperature is specified because the measurement junctions of the thermocouples are not always directly in the flame. Thermocouples in the flame measure temperatures averaging 1,100 °C [2,000 °F] with peaks of approximately 1,200 °C [2,200 °F]. This is the industry-accepted value for a hydrocarbon fire (Turns, 2000). In addition, the melting temperature of cobalt is 1,495 °C [2,723 °F] (Bolz and Tuve, 1973). Therefore, it is not feasible for cobalt to melt in a jet fuel fire even when it is immersed in the burning fuel.

In 1998, the FAA projected that nationwide commercial aircraft operations would increase from 28.6 million in 1998, to 36.6 million in 2010, and to 47.6 million 2025. Thus, an increase in U.S. commercial aviation operations of 66 percent was projected for 2025. The projections for general aviation operations predicted an increase from 87.4 million operations in 1998 to 92.8 million operations in 2010 and to 99.2 million operations in 2025, an increase of 14 percent (FAA, 1999). The FAA also estimated that the growth in operations a Honolulu International Airport would increase by one-third from 382,466 operations in 1997 to 510,000 operations in 2012 (FAA, 2006b). However, the data in Table 2-2 show that the annual number of recent flight operations actually decreased by 58,740 operations compared to the 1998 data. Thus, it is difficult to assess if the number of flight operations at Honolulu International Airport will increase during the 10-year period of the license application. Any increase in the number of flight operations will increase the probability of an aircraft crash into the facility, but the likelihood that the source assemblies will be removed from the source pool remains negligible.

2.5 Aircraft Crash Summary and Conclusions

This chapter has provided the data and methodology for calculating the annual probability of an aircraft crashing into the proposed facility. The probability was estimated to be 2.1×10^{-4} per year. One way of interpreting this value is that one aircraft crash into the proposed facility is expected every 5,000 years. Furthermore, as described in Section 2.3, it is expected that the actual crash frequency is less than the calculated estimate of once every 5,000 years. The applicant is requesting a license for 10 years; over such a short period of time, it is unlikely that the facility will be involved in an aircraft crash. Further, it has been shown that an aircraft crash will not be able to impart enough force to the source assembly to remove it from the source plenum and eject it from the bottom of the irradiator pool. In addition, the depth of the pool extends below the water table, making it unlikely that the water would be completely removed from the pool and cause the sources to become unshielded. Even in the event of a jet fuel fire, the source will not melt and will remain controlled. Therefore, the probability of the loss of control of radioactive material as a result of an aircraft crash is negligible.

3 NATURAL PHENOMENA

This chapter discusses the potential effects of natural phenomena on the proposed facility. The natural phenomena considered are earthquakes, tsunamis, and hurricanes; each of these is affected by the natural setting of the Hawaiian Islands.

The Hawaiian Archipelago consists of a series of shield volcanoes that erupted tholeitic basaltic magma from deep within the earth's mantle (e.g., MacDonald, et al., 1983). Wilson (1963) first suggested that the Hawaiian Islands were formed as the Pacific tectonic plate inched slowly northeastward over a hot spot or fixed plume of melted mantle material. Over many millions of years, additional island volcanoes in the chain were formed as the older volcanoes drifted off the mantle plume, eroded, and in some cases subsided to become seamounts below sea level. Only the youngest volcanic island (the big island of Hawaii), which rests above the hot spot, is volcanically active. Morgan (1972) showed that the Hawaiian hot spot chain joins with the Emperor Sea Mount chain near Midway Island, forming a hot spot track that extends northwest and then north for more than 5,000 km [3,100 mi] from Hawaii to the western Aleutian Islands. The Emperor-Hawaiian hot spot track incorporates more than 125 volcanoes and seamounts and comprises more than 70 million years of hot spot volcanism.

The seven principal islands of the Hawaiian chain (Hawaii, Maui, Oahu, Kauai, Molokai, Lanai, and Kahoolawe) incorporate the last dozen volcanoes in the hot spot track. The big island of Hawaii is the youngest and currently rests atop the hot spot. Volcanic activity on this island is ongoing, including two of the largest and most active shield volcanoes in the world, Mauna Loa and Kilauea. Other islands in the Hawaiian chain are no longer active and become progressively older to the northwest. Oahu lies about 240 km [150 mi] northwest of Hawaii and is home to two extinct shield volcanoes, Koolau and Waianae, which formed between 1.7 million and 3.9 million years ago (Clague and Dalrymple, 1988). There has also been a rejuvenated stage of volcanism on Oahu in the past million years that produces small volume, late-stage (posterosional) vents along rifts that cut the older massive shield volcanoes. These late-stage eruptions tended to be very small (compared to the shield volcanoes), explosive, and composed of ash or tuff. Most of the vents are along the coast, including Diamond Head, Hanauma Bay, and Salt Lake Crater. The best dated late-stage vent is at Black Point, dated at 410,000 years (Lanphere and Dalrymple, 1980). According to the U.S. Geologic Survey (USGS) (Crandell, 1975) and the State of Hawaii Hazard Mitigation Plan (Honolulu City and County, 2006), there are currently no active volcanoes on Oahu.

3.1 Earthquakes

Earthquakes on the Hawaiian Islands are produced either from magma ascending in the Earth's crust through dikes or from an accumulation and release of lithospheric stresses due to the accumulating mass of volcanic material that loads the crust as the islands grow. Most of the historic earthquakes have occurred around the big island of Hawaii, with the number decreasing northwest along the Hawaiian chain (Figure 3-1). Klein, et al. (2001) shows that it is 20 times more likely for an earthquake with a magnitude greater than or equal to M = 4.0 to occur nearer Hawaii than Oahu.

The largest earthquake on record in the Hawaiian Islands was the 1868 Great Kau earthquake, with an estimated magnitude of M = 7.9 (Wyss, 1988). This earthquake triggered a relatively

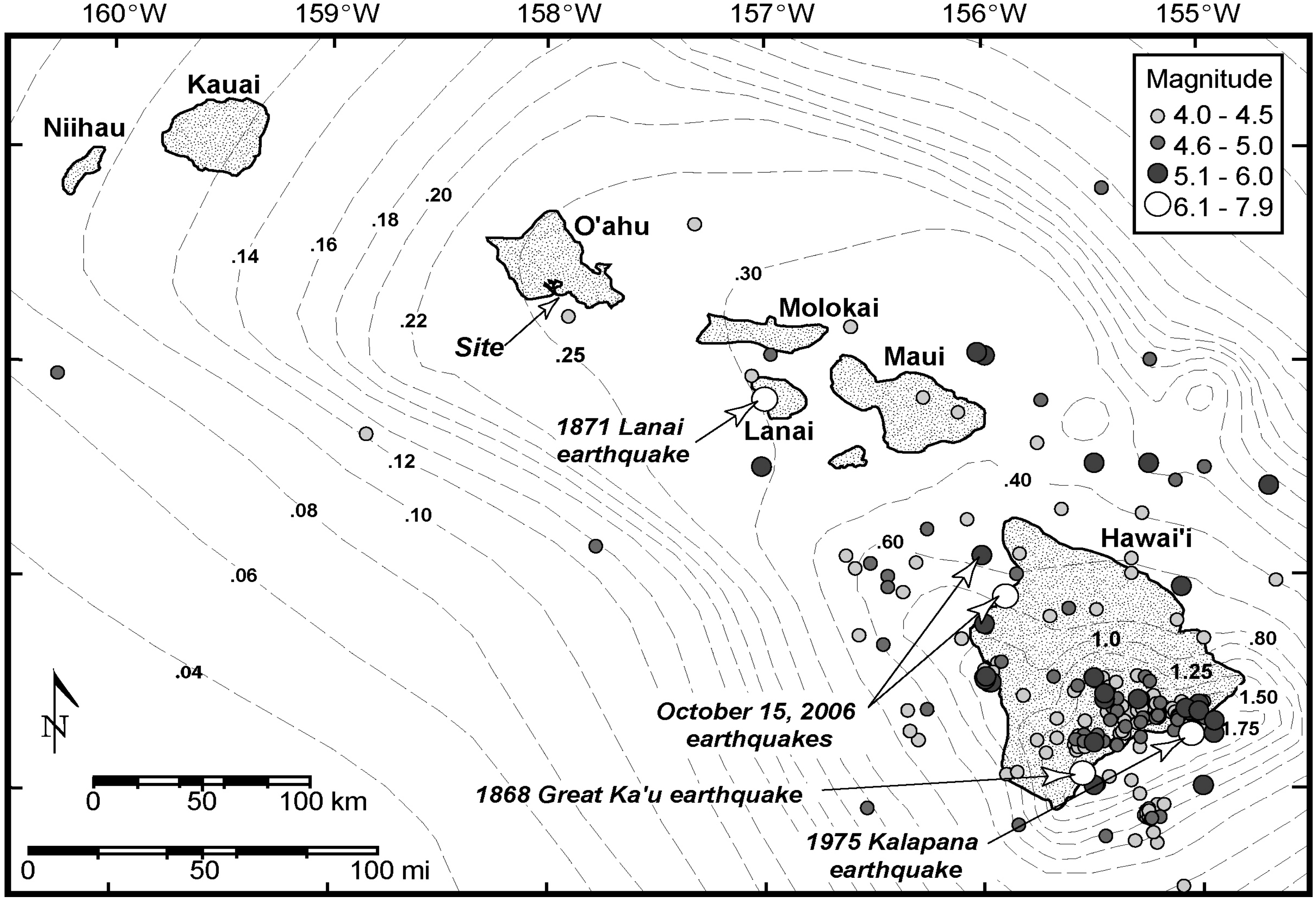


Figure 3-1. Map of the Hawaiian Islands Showing the Location of Earthquakes With Magnitudes Greater Than M = 4.0. Earthquake Data Between 1868 and October 30, 2006, Was Obtained From the USGS Catalog and From Munson and Thurber (1997). Dashed Contours Show the Horizontal Peak Ground Acceleration (% g) With a 2-Percent Probability of Exceedance in 50 Years {Assuming Firm Rock Conditions and a Shear Wave Velocity of 760 m/s [1,700 mph]}.

large tsunami and spawned numerous landslides that killed 77 people. The only other earthquakes with a recorded magnitude greater than M = 7.0 were the 1975 Kalapana earthquake with a moment magnitude[1] of M_W = 7.2 and the 1871 earthquake near Lania (Figure 3-1) with a magnitude of M = 7.0. The 1975 Kalapana earthquake also occurred beneath the south flank of Kilauea. The Kalapana coast subsided as much as 3.4 m [11 ft], generating a tsunami that killed two people near the Hawaii Volcanoes National Park.

Early on the morning of October 15, 2006, two earthquakes shook the northwest side of the big island of Hawaii (Figure 3-1). The first earthquake had a magnitude of M = 6.7 and was located 20 km [12.5 mi] northeast of the Kona airport at a depth of 38 km [23.75 mi]. The second earthquake had a magnitude of M = 6.0 and was located 44 km [27.5 mi] north of the Kona airport at a depth of 20 km [12.5 mi]. While the two earthquakes occurred seven minutes apart, the USGS (2006a) considers them to be independent events rather than part of a main shock and aftershock sequence, in part because of the differences of their focal depths. These two earthquakes produced noticeable shaking across the Hawaiian Islands and were most strongly felt in the North Kona and Kohala areas. Damage was reported on the west side of Hawaii, with minimal structural damage to facilities on the other islands, including Oahu. There were no reported fatalities. Power stations tripped off on the big island of Hawaii, which then triggered power outages on the other islands as all the power stations on the grid tried to compensate for the loss of power on the big island.

Based on damage reports for the October 2006 earthquakes, the Modified Mercalli Intensity on Oahu was measured at Force V (USGS, 2006b). Only two historical earthquakes produced greater force intensities on Oahu. Force VI intensities were recorded in Honolulu after the 1871 Lanai earthquake, with an estimated magnitude of M = 6.8 (USGS, 2006c). In 1948, a small earthquake with an estimated magnitude of M = 4.6 (Cox, 1986) also produced Force VI intensity. The epicenter of the 1948 earthquake was only a few miles south of Honolulu, and the Force VI damage was limited to a region nearest the epicenter.

The Force V Modified Mercalli Intensity for the recent earthquakes is consistent with the current seismic hazard maps for Oahu. In the late 1980s, the Uniform Building Code in Honolulu was upgraded from seismic zone 1 to zone 2A (Oahu Civil Defense Agency City and County of Honolulu, 2003). The USGS probabilistic seismic hazard maps for Hawaii (2-percent probability of exceedance in 50 years or 2,500-year return period) show a horizontal peak ground acceleration for Honolulu of 0.26 g and a 5-Hertz spectral acceleration (5-percent critical damping) of 0.61 g (Klein, et al., 2001). Peak ground acceleration values from the USGS maps are shown in Figure 3-1. Table 3-1 summarizes some of the ground motion measures for Honolulu, based on the USGS seismic hazard mapping information. The data shown in Table 3-1 represent the design basis for seismic compliance with the International Building Code (International Conference of Building Officials, 1997).

After reviewing the available data on earthquakes that could affect Honolulu International Airport and vicinity, it is concluded that the potential for damage to the proposed irradiator facility is small. The irradiator pool will be fabricated and installed in accordance with applicable industry codes, including an evaluation of the sufficient load-bearing capability of the soil during the pool

[1]The moment magnitude, M_W, is a modern term to measure the strength of an earthquake that replaced the Richter Scale (M) circa 1985.

Table 3-1. Potential Horizontal Ground Motions at the Proposed Facility Site (21.34°N, 157.94°W)		
Frequency (Hz)	**10% Probability of Exceedance in 50 years (g)**	**2% Probability of Exceedance in 50 years (g)**
Peak Ground Acceleration	0.13	0.26
5 Hz (5% of critical damping)	0.28	0.61
3 Hz (5% of critical damping)	0.27	0.58
1 Hz (5% of critical damping)	0.08	0.17

excavation phase. Although the irradiator pool will be installed to mitigate the consequences of a seismic event, including liquefaction, it is emphasized here that the proposed facility is not mechanically connected to the source assemblies. Any damage sustained by the facility during an earthquake would not be transferred to the sources; the forces could damage the facility and potentially damage the source holder and source plenum, but the sources would simply fall to the bottom of the irradiator pool. The forces generated during an earthquake are not strong enough to remove a source assembly from the bottom of the pool, and it is unlikely that the water would be removed from the pool because most of the pool is below the water table and the source assemblies would be shielded throughout the event. Thus, the probability of loss of control of a radioactive source during an earthquake is negligible.

3.2 Tsunamis

3.2.1 Tsunami History in Hawaii

In addition to earthquakes and volcanoes, Hawaii is susceptible to tsunamis from local earthquake and submarine landslide sources, as well as large magnitude distant teleseismic earthquakes from elsewhere in the Pacific Basin. The Catalogue of Tsunamis in the Hawaiian Islands (Pararas-Carayannis and Calebaugh, 1977) lists 85 tsunamis since the earliest reported tsunami in 1813 or 1814. Fifteen tsunamis have caused significant damage. Only four of these originated from earthquake or submarine landslide activity near Hawaii. The rest were triggered by distant earthquakes due to subduction zone earthquakes in the Pacific Northwest, Aleutians, or western South America.

One of the largest and most devastating tsunamis affecting Hawaii was in 1946, triggered by the Unimak, Alaska, earthquake with a moment magnitude of M_w = 8.6. The most extensive damage was at Hilo and Pololu Valley on the northeast shore of the big island of Hawaii, which incurred $26 million in damage and 159 fatalities. Runup heights on the big island reached a maximum of 12 m [39 ft] (Pararas-Carayannis and Calebaugh, 1977). Other significant tsunamis include one generated by the 1960 earthquake in southern Chile, with a moment magnitude of M_W = 9.5 and one generated by the 1964 Good Friday earthquake in the Gulf of Alaska, with a moment magnitude of M_W = 9.2. The 1960 Chile earthquake generated a 10.7-m [35-ft] wave at Hilo, causing 61 deaths and $23 million in damage. The Good Friday tsunami generated only small runups in Hawaii. On the island of Oahu, maximum runup was 4.8 m [16 ft], but the Honolulu tide gauge on the south side of Oahu only measured a 0.5-m

[1.6-ft] change in sea level. At Kahului, Maui, maximum runup was 3.7 m [12 ft]. On the big-Island of Hawaii, the maximum runup was 3 m [9.6 ft], and the tide gauge at Hilo recorded a 2.1-m [6.9-ft] change in sea level.

The historic record of tsunami activity shows that the tsunami hazard for Honolulu, Oahu, Hawaii, is small. Although the tsunami hazard is a significant threat to the Hawaiian Islands in general, especially the big island of Hawaii, large tsunamis are not considered a significant threat to Honolulu or Oahu. Teleseismic tsunamis on record in the Pacific basin did not produce runups that would significantly affect the proposed irradiator. As stated in a May 2005 letter[2] from the State of Hawaii's Transportation Department, "the south shore of Oahu has never sustained more than a 3 [foot] wave from any tsunami since 1837." For Hawaii, the Pacific Tsunami Warning Center issues tsunami warnings for local earthquakes with a M_w >6.9 and a focal depth of <100 km [62 mi].

3.2.2 Force Calculations for Loss of Control of Radioactive Material

To further constrain the potential for tsunami-generated runups to lead to a loss of control of radioactive material, the CNWRA staff conducted a stylized fluid dynamic calculation. This calculation was made to determine the wave velocity necessary to pull a radioactive Co-60 source assembly out of the pool. This wave velocity was then evaluated with respect to potential tsunami-generated waves. The calculations are considered to place reasonable limits on velocity because they assumed a pool in which the incident caused the irradiator plenum and source holder structure to fail. Radioactive Co-60 source assemblies were thus released as single bodies inside the pool.

In the calculations, the irradiator pool was modeled as a two-dimensional deep cavity of the appropriate dimensions with an intact Co-60 source assembly resting on the bottom of the pool. The model assumed a wave of water will induce a shear force that will create a vortex inside the pool. This vortex will exert forces on the Co-60 source assembly and cause it to be displaced in the water. Under limiting conditions, the weight of a source assembly must be the same as the drag induced by the rotating fluid to be displaced. This drag force depends on a number of factors, including the effective area and orientation of the source assembly with respect to the fluid. Calculations were performed on a cylindrical source with an outer diameter of 1.27 cm [0.5 in], a length of 45.5 cm [17.9 in], and a mass equal to the mass of an intact capsule. The source was oriented as lying lengthwise on the bottom of the pool.

The calculations showed that for a cylinder equivalent to a full-sized source assembly, a vertical velocity of 0.9 m/s [2 mph] is required to induce a drag force sufficient to lift the 0.26 kg [0.57 lb] source assembly. It has been determined that this vertical velocity would be generated by a shear velocity of between 90 m/s [203 mph] and 180 m/s [406 mph]. The drag coefficient for the source assembly was determined from standard drag curves (Fox, et al., 2006), and the correlation between the shear velocity and critical drag velocity were obtained from accepted published values (Bouffanais, et al., 2006).

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[2]Schlapak, B.R. "Response to Fax Dated May 4, 2005, Asking Whether Lots #011109 and 011108 Are in a Tsunami Flood Evacuation Zone." Letter (May10) to M. Kohn, Equipment Team Hawaii, Honolulu, Hawaii. Honolulu, Hawaii: State of Hawaii Department of Transportation, Airports Division. 2005.

At the shore, tsunami waves up to 10 m [32.8 ft] can reach velocities up to 13 m/s [29 mph] (Chen, et al., 2003; National Aeronautics and Space Administration, 2006). This velocity is less than 15 percent of that necessary to remove the source assembly from the bottom of the pool. Water velocities for smaller tsunami waves more typical for the southern shore of Oahu would be substantially slower than for the large waves and may not reach the southern shore of the facility. Regardless, the calculations show that it is not feasible for tsunami waves to have sufficient velocity to remove the Co-60 source assemblies from the irradiator pool.

In summary, tsunamis are known to affect the Hawaiian Islands. However, the wave velocities associated with the largest historical tsunamis would not be sufficient to remove a source assembly from the bottom of the pool, even if the facility has sustained enough damage that the source holding equipment and source plenum were destroyed.

3.3 Hurricanes

Hurricanes form over warm, tropical oceans and are accompanied by enhanced thunderstorms. The National Weather Service classifies tropical cyclones and typhoons (hurricanes) into several classes based on the Saffir-Simpson scale (National Oceanic and Atmospheric Administration, 2006a) shown in Table 3-2. Hurricanes are generally rare in the Hawaiian Islands, although strong winds from major storms and depressions in the central Pacific Ocean have affected these islands. Historic records indicate that no Category 5 hurricanes have made landfall on the Hawaiian Islands.

Because of its location in the central Pacific Ocean, the Hawaiian Islands are susceptible to infrequent but potentially damaging tropical cyclones or hurricanes. Detailed recordings of these storms began in 1950, and Hurricane Hiki, which occurred in August 1950, is the first officially named hurricane to cross Hawaiian waters. Based on a few written records and ship reports, there were at least 19 tropical cyclones or tropical storms between 1832 and 1949. The National Oceanic and Atmospheric Administration reports that an average of four to five tropical cyclones are observed in the Central Pacific every year. The maximum number in any year since 1950 was 11, which occurred in 1992 and again in 1994. Most of these storms traverse

Table 3-2. Saffir-Simpson Scale of Tropical Cyclones and Typhoons

Class	Description
Tropical Depression (TD)	Wind speed less than 62 km/h [39 mph]
Tropical Storm (TS)	Wind speed 62–117 km/h [39–73 mph]
Category 1 Hurricane (H1)	Wind speed 118–152 km/h [74–95 mph]
Category 2 Hurricane (H2)	Wind speed 153–177 km/h [96–110 mph]
Category 3 Hurricane (H3)	Wind speed 178–208 km/h [111–130 mph]
Category 4 Hurricane (H4)	Wind speed 209–248 km/h [131–155 mph]
Category 5 Hurricane (H5)	Wind speed above 248 km/h [155 mph]

Hawaii from southeast to northwest. Based on the National Hurricane Center and National Oceanic and Atmospheric Administration online databases, 20 hurricanes or tropical storms have passed within 322 km [200 mi] of Honolulu International Airport since 1950 (Table 3-3); dominant storm trends tend to be such that these storms make landfall to the west of Oahu. As a point of reference for Table 3-3, the proposed irradiator site is located at 21.34°N, 157.94°W.

Table 3-3. Tropical Cyclones Within 322 km [200 mi] of Honolulu International Airport With Maximum Water Levels Above Mean Sea Level*

Storm Name	Date	Closest Approach		Peak Winds (KTS)†	Storm Category‡	Water Level (m above MSL)§
		Lat. (°N)	Long. (°W)			
Hiki	8/18/1950	22.50	−166.50	75.0	H1	0.447
Della	9/11/1957	22.70	−169.40	100.0	H3	0.386
Nina	11/30/1957	14.40	−161.30	75.0	H1	0.417
Nina	12/2/1957	21.40	−161.40	75.0	H1	0.417
Not Named	8/8/1958	20.30	−157.50	25.0	TD	0.478
Dot	8/4/1959	16.30	−150.40	120.0	H4	0.569
Irah	9/15/1963	21.10	−139.00	45.0	TS	0.539
Diana	8/14/1972	17.20	−130.20	95.0	H2	0.478
Gwen	8/14/1976	23.80	−134.40	35.0	TS	0.008
Jova	9/18/1981	20.10	−138.60	65.0	H1	0.575
Daniel	7/12/1982	15.50	−116.80	100.0	H3	0.505
Gilma	7/30/1982	16.00	−137.50	105.0	H3	0.505
Gilma	8/1/1982	18.00	−154.20	35.0	TS	0.481
Iwa	11/24/1982	23.30	−158.40	80.0	H1	0.63
Gil	7/29/1983	17.50	−123.50	65.0	H1	0.514
Gil	8/3/1983	22.20	−157.90	40.0	TS	0.606
Raymond	10/15/1983	17.60	−143.50	120.0	H4	0.414
Gilma	7/30/1988	16.10	−136.80	35.0	TS	0.606
Gilma	8/3/1988	20.60	−156.00	20.0	TD	0.597
Dalilia	7/19/1989	15.80	−152.50	65.0	H1	0.581
Iniki	9/12/1992	21.50	−159.80	115.0	H4	0.776
Eugene	7/20/1993	16.80	−127.60	100.0	H3	0.456
Daniel	7/28/2000	17.20	−138.20	100.0	H3	0.606
Daniel	8/1/2000	22.90	−156.10	45.0	TS	0.503
Barbara	6/22/2001	16.50	−139.00	35.0	TS	0.473

*Hurricane data from the National Hurricane Center, water levels referenced to Honolulu Station 1612340 Mean Sea Level (MSL) over Epoch 1983–2001 as recorded by the National Water Level Observation Network.
†Peak winds reported in knots (KTS). To convert to km/h, multiply by 1.853.
‡Storm category is based on the Saffir-Simpson hurricane scale. TD = tropical depression; TS = tropical storm; H1 = Category 1 hurricane; H2 = Category 2 hurricane; H3 = Category 3 hurricane; H4 = Category 4 hurricane; H5 = Category 5 hurricane.
§MSL for this location and epoch is 1.412 m. To convert m to ft, multiply by 3.281.

Four storms that caused significant damage to property on one or more of the Hawaiian islands are discussed next.

(1) Hurricane Nina (November 29–December 7, 1957) produced record winds in Honolulu. Honolulu International Airport recorded all-time record gusts of 131 km/h [82 mph] on the evening of November 30. Oahu experienced moderate rains along with a 72 km/h [45 mph] sustained wind. The highest wind speed of 147 km/h [92 mph] was on Kauai at Kilauea Light on December 1. A very high surf {height of 10.7 m [35 ft]} was reported on the south coast of Kauai.

(2) Hurricane Dot (August 1–8, 1959) passed across the island of Kauai on the night of August 6. The wind at Kauai had gusts of 165 km/h [103 mph] with sustained wind speeds of 130 km/h [81 mph]. On Kauai, the wind speed may have locally exceeded 200 km/h [125 mph]. This hurricane brought more than 5.1 cm [5 in] of rain in Oahu. Although the highest recorded wind speed at the Waianae coast was only 64 km/h [40 mph], the wind gusts at Barbers Point locally exceeded 96 km/h [60 mph]. Although this was a Category 4 hurricane, it had reduced to a Category 3 hurricane when it affected Kauai and Oahu.

(3) Hurricane Iwa (November 19–24, 1982) caused severe property damage on Kauai. The south shore of Kauai experienced severe surf damage. In addition, all islands reported surf damage along their southwest-facing shores. Pockets of Oahu suffered wind damage. The sustained wind speed of this Category 1 hurricane was recorded at 147 km/h [92 mph] at a location 400 km [250 mi] southwest of Honolulu.

(4) Hurricane Iniki (September 5–13, 1992) made landfall at Kauai with a sustained wind speed of 208 km/h [130 mph] and caused approximately $3 billion in property damage. On the morning of September 10, a top wind speed of 184 km/h [115 mph] was recorded when the hurricane was 656 km [410 mi] south of Honolulu. A wind speed of 230 km/h [144 mph] with gusts up to 276 km/h [173 mph] for this Category 4 hurricane was recorded 208 km [130 mi] southwest of Lihue. The estimated maximum sustained wind when it crossed Kauai was 224 km/h [140 mph] with gusts reaching 280 km/h [175 mph]. This was the most powerful hurricane to strike the Hawaiian Islands in recent history. The coastal areas from Barbers Point to Kaena Point suffered damage on Oahu.

Information from the Central Pacific Hurricane Center of the National Weather Service for locations where all cyclones (tropical depressions, tropical storms, and hurricanes) first developed maximum sustained winds was used to develop Figure 3-2. Information presented in Figure 3-2 is summarized in Table 3-4 in terms of the recorded maximum wind speed.

Figure 3-2 shows that the first occurrence of maximum wind speeds was generally recorded far from Honolulu International Airport and the rest of the Hawaiian Islands. Information presented in the web publication of the Central Pacific Hurricane Center of the National Weather Service (National Oceanic and Atmospheric Administration, 2006b) also supports this conclusion. This publication indicates that no tropical cyclones classified as major hurricanes have developed or made landfall near Honolulu International Airport since 1950.

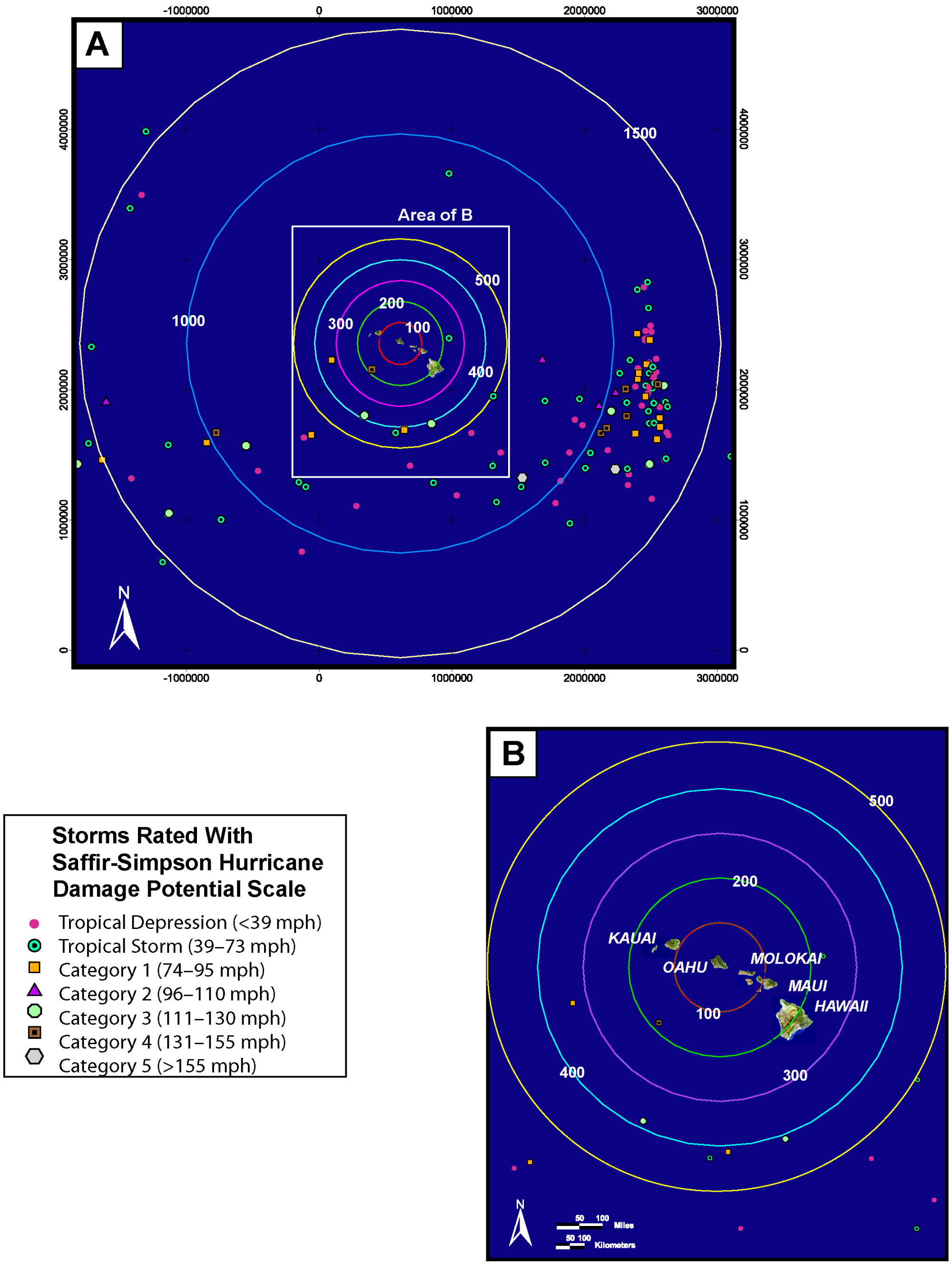

Figure 3-2. Locations Where Hawaiian Cyclones (Depressions, Storms, or Hurricanes) First Developed Maximum Sustained Wind Speeds Recorded by the National Weather Service (National Oceanic and Atmospheric Administration, 2006b)

Table 3-4. Distribution of Tropical Cyclones in 1980–2005		
Cyclone Type	**Total Number From 1980–2005**	**Percentage of All Cyclones**
Tropical Depression	44	35.5
Tropical Storm	43	34.7
Category 1 Hurricane	13	10.5
Category 2 Hurricane	7	5.6
Category 3 Hurricane	7	5.6
Category 4 Hurricane	7	5.6
Category 5 Hurricane	3	2.4

Information presented for major hurricanes affecting the Hawaiian Islands and information on all tropical cyclones since 1980 suggest that the island of Oahu and Honolulu International Airport in particular, have not experienced cyclonic wind speeds in excess of 160 km/h (100 mph) in the recent past (at least since 1980). Information from the National Weather Service also suggests that this may be true for conditions recorded since 1950. The American Society of Civil Engineers Standard SEI/ASCE 7-02 (2003) suggests a value of 168 km/h [105 mph] should be the nominal design for the facility, with a 3-second gust wind speed at 10 m [33 ft] above ground for Exposure Category C. Honolulu International Airport has a flat open surface including an open water surface (ocean). Therefore, the proposed facility site could be classified as Exposure Category C. The recommended design wind speed value is for the 50-year return period. This standard also gives the annual probability of exceeding this wind speed value. For other return periods, conversion factors are provided to estimate the peak gust wind speed.

The tsunami analysis discussed in Section 3.2.2 of this report is considered to appropriately capture adverse safety concerns related to storm surges associated with tropical cyclones or tropical storms. Since the 1950s, there have been a number of hurricanes that have passed near Oahu, but none have produced a storm surge that would pose a hazard to the facility. The maximum water-level rise in the database compiled for this evaluation was 0.78 m [2.6 ft] above mean sea level, produced by Iniki in 1992. Based on this information, storm surge effects from tropical cyclones or tropical storms at the proposed facility in Honolulu do not appear to pose a sufficient risk of loss of control of radioactive material; the potential effects of storm surges associated with these storms appear to be bounded by the greater wave heights that could be generated by tsunamis. The wave velocity associated with a wind-generated storm surge of this size is, therefore, less than that associated with a tsunami. As shown in Section 3.2, even a hypothetical large tsunami with a 10-m [33-ft] wave height is not capable of removing a Co-60 source assembly from the bottom of the proposed irradiator pool. Therefore, a likely smaller storm surge associated with a hurricane resulting in the loss of control of a Co-60 source assembly is not feasible.

4 CONCLUSIONS

This report analyzes the hazards associated with aircraft accidents and natural phenomena on a proposed irradiator facility to be located near Honolulu International Airport. The sources in the irradiator are irradiated Co-60. They are robust, undergo rigorous testing for certification, and are not dispersable. The outcome to be avoided from these hazards was shown to be the loss of control of radioactive material, which is defined for this report as the removal of a source from the irradiator pool. Given this scenario, damage to buildings and surface facilities by themselves is not enough to result in loss of control of radioactive material. It was further shown that radioactive contamination of the pool water by the sources is not feasible.

The aircraft crash analysis assessed the number and types of aircraft involved in flight operations at Honolulu International Airport, the annual crash rate of each type of aircraft, the effective size of the proposed facility, and the potential that the facility could be involved in an aircraft crash given its location relative to the position and direction of each of eight runways located at the airport. The probability that an aircraft will crash into the proposed facility was determined for each runway and in total using the methodology described in NUREG–0800 (NRC, 1981). The calculated annual probability of an aircraft crashing into the proposed facility was estimated to be 2.1×10^{-4} yr^{-1}, or one such accident every 5,000 years. The actual probability is expected to be lower for a number of reasons discussed in the report. Given the 10-year license term, it is unlikely that an aircraft crash into the proposed facility will occur. The impact of an aircraft crash on the source assemblies located in the irradiator is reduced because the source assemblies are located at a depth of 5.4 m [18 ft] in a water pool that is not mechanically connected to the surface facility. It was determined that the probability of a loss of control of radioactive material as the result of an aircraft crash into the facility is small. In addition, even if the aircraft crash resulted in a jet fuel fire, the testing and source certification indicates that control of the source would not be jeopardized.

This report also assessed natural phenomena that have the potential for posing a hazard to the proposed facility, including earthquakes, tsunamis, and hurricanes. The discussion included the geological history of Hawaii; historical data on the number and severity of earthquakes, tsunamis, and hurricanes; and an analysis of the speed of a tsunami or storm surge that would be required to remove a Co-60 source assembly from the bottom of the irradiator pool into the unshielded environment, given that the source plenum had been previously destroyed. The wave velocity required to remove a Co-60 source assembly from the bottom of the pool is larger than the wave velocity of any historical tsunami in Hawaii. It was therefore concluded that the potential for a tsunami or a wind-generated storm surge to remove a Co-60 source assembly from the irradiator pool is negligible. Additionally, there are no historical data that support an earthquake near Honolulu International Airport large enough to cause a source assembly to be removed from the irradiator pool by ground motion alone. Effects of seismic activity are mitigated by compliance of the facility with the International Building Code (International Conference of Building Officials, 1997) and the design of the source to minimize the amount of force that is transferred to the source.

Based on the best available information, the potential is negligible for natural phenomena (tsunamis, earthquakes, and hurricanes) or an aircraft crash to result in a loss of control of radioactive material that would have an adverse impact on public health and safety or the environment.

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