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

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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 (tsunamis, hurricanes, and seismic events) 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 figure 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 negligible.

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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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 834E and 765E.

ANALYSES AND CODES:

None.

1 INTRODUCTION

1.1 Background

In accordance with 10 CFR Part 36, Pa'ina Hawaii, LLC, submitted a license application (NRC, 2005) 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. The license application states that the irradiator will be used primarily for research and irradiation of food, cosmetic, and pharmaceutical products. The application also states that the irradiator may also be used for a wide range of other materials. The application indicated that the irradiator will not be used for irradiation of explosives or cryogenic materials that are potentially explosive without specific authorization from NRC. Finally, the irradiator may be used to irradiate only small quantities of flammable materials with a flash point below 60 °C [140 °F].

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 environmental assessment includes evaluating the environmental impacts and potential consequences of natural phenomena and aircraft crash hazards associated with the proposed irradiator facility. This topical report will assess the effects of potential aircraft crashes and natural phenomena, including tsunamis, hurricanes, and seismic events.

The proposed irradiator is distributed by GRAY*STAR, Inc., built by CHL Systems, is marketed under the name Genesis II, and classified as an underwater Co-60 irradiator. The Genesis II design qualifies as an underwater irradiator because the source remains in the shielded position during irradiation, and the product is lowered in an airtight container into the radiation field.

The proposed irradiator is designed to use a source assembly that consists of an inner capsule containing multiple nickel-coated activated-cobalt metal discs and slugs. The inner capsule is either stainless steel or zircalloy and has two fusion-welded end plugs. The inner capsule is overpacked in a stainless steel outer capsule which also has two fusion-welded end plugs to complete the source assembly. The source assemblies have been tested to meet federal regulation 10 CFR 36.21 regarding 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, at a minimum, to withstand a pressure of 2 MN/m^2 for 5 minutes; an impact from a 2.5 cm-diameter, 2-kg steel weight dropped from a height of 1 m; a puncture test of a 50-g weight and pin with a diameter of 0.3 cm dropped from a height of 1 m; and a bend test from a force of 2,000 N applied at the center of the source assembly.

The irradiator has several main components including a pool, source holding mechanism and plenum for holding the source assemblies in place within the pool, a surge tank, and a hoist and rail transfer system for moving the 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 installed at ground level with a 107-cm [42-in] rail extending above the facility floor (Figure 1-1). This rail serves as a barrier to prevent personnel from accidentally falling into the pool. The pool extends to a depth of 5.4 m [18 ft], and the source assemblies are held in place at the bottom of the pool using a source plenum. The depth of the water table is 2 m [6.6 ft] below the facility floor; thus, the source assemblies normally reside below the water table (NRC, 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 and other structures within the pool. Thus, any forces that impact the plenum and other structures will not be 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.

1.2 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 as part of this report.

The scope of this report is to compile available 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 risk of other nuclear facilities. However, this report provides a statement of the likelihood that an aircraft crash or natural phenomena may lead to the loss of control of radioactive material.

1.3 Methodology

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. A recent history of the frequency and magnitude of each of these events is compiled, and a determination is made of the potential hazard to the proposed facility.

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. 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.

For natural phenomena, historical data on the frequency and severity of previous earthquakes, tsunamis, and hurricanes are collected, and conclusions about the hazards associated with these events are drawn based on these data. The likelihood of each of these hazards is then provided. The likelihood of these hazards resulting in a loss of control of radioactive material is also provided.

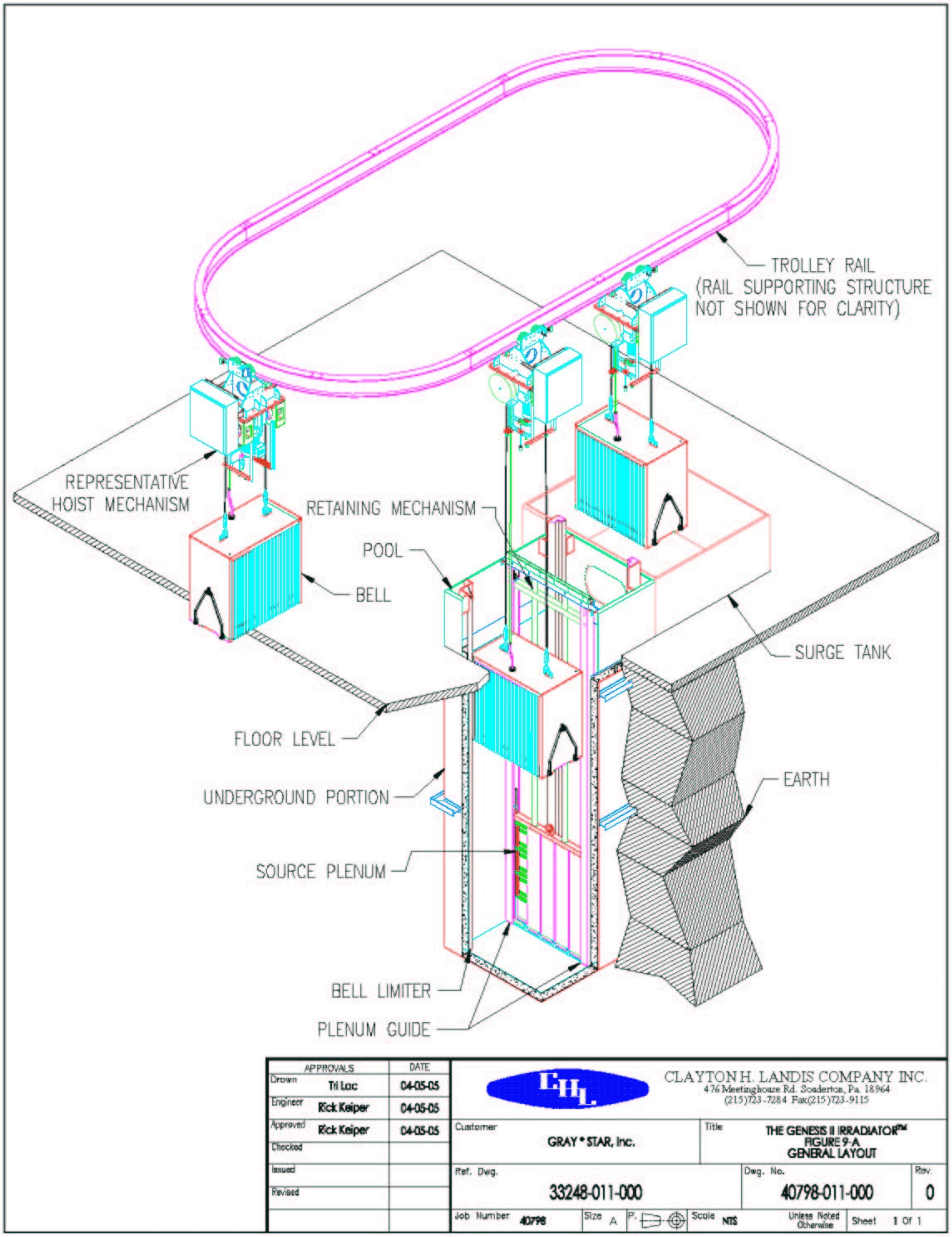

Figure 1-1. Architectural Drawing of the Proposed Irradiator Showing the Source Plenum, Pool, and Hoist and Rail System (GRAY*STAR, Inc., 2005)

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 described, followed by the 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 on 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 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, additional information that is needed to complete the probability estimation follows.

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 at the airport. This airport is the principal hub of Aloha Airlines and Hawaiian Airlines. These airlines fly to other islands in addition to several domestic and international airports. Many domestic and international airlines also fly to this airport.

Nearby Hickam Air Force Base shares operations 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 airlifting operations. The 15th Airlift Wing of the Air Force currently uses C-17 Globemaster III aircraft for worldwide missions in support of the Pacific Air Forces.

There are four primary runways at Honolulu International Airport: Runway 8L/26R, Runway 8R/26L, Runway 4R/22L, and Runway 4L/22R (AirNav, LLC, 2006). The lengths of each of these runways is provided in Table 2-1. The dual designation for a single runway indicates that a single runway serves two different directions. For instance, Runway 8L/26R is designated 8L when aircraft are landing from the west and 26R when aircraft are landing from the east. For the remainder of this report, Runway 8L will be considered as 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	mi
8R/26L	3,749	12,300	2.33
8L/26R	3,658	12,000	2.27
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 8R/26L is known as the Reef Runway, and the traffic pattern is on the left side. The Reef Runway is also a designated back-up landing site for the National Aeronautics and Space Administration space shuttle program. The Reef Runway is used for instrument landing and usually handles takeoffs by wide-body jet aircraft to reduce the effects of noise on the city (Barnes, et al., 2001). Runway 4R/22L has a left traffic pattern, and Runway 4R is used for instrument landings. Runway 4L/22R has a left traffic pattern, and no instrument landings are conducted on this runway. In addition, there are two designated offshore (water surface) runways, 8W/26W {length 1,524 m [5,000 ft]} and 4W/22W {length 914 m [3,000 ft]} for seaplanes. The location of each runway is shown in Figure 2-1.

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 provides radar sequencing, aircraft separations, and air traffic safety advisories to aircraft flying under instrument flight rules 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 landing on runways 8L and 8R will climb and then turn right to the holding pattern over the ocean. Similarly, aircraft with missed approaches to landing on runways 4L and 4R will climb and then turn right into the 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 the left turn to the assigned headings within 3.7 km [2.3 mi] of the departure end of the runway.

2.1.2 Aircraft Operations at Honolulu International Airport

Statistics are compiled on the number of aircraft flights at Honolulu International Airport and are classified into five general categories: commercial, transient general aviation, air taxis, military aircraft, and local general aviation. Commercial aircraft include large passenger aircraft that typically arrive from overseas. Transient general aviation aircraft include small, usually private airplanes that arrive in Hawaii from overseas. 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 it is in general commercial services carrying less than 70 passengers (Kimura, et al., 1996). Military aircraft are not distinguished by size and include any aircraft owned and operated by the military. Local general aviation aircraft are the same as transient general aviation aircraft but are licensed in Hawaii.

Statistics on the number of aircraft operations at Honolulu International Airport were obtained from three independent sources: AirNav, LLC (2006), the FAA (2006a), and information obtained from B. Schlapak,[1] 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.

The direction of the flights is an important component of estimating the risk of an aircraft crash. Information provided by B. Schlapak[2] stated that approximately 45 percent of the traffic at Honolulu International Airport is handled by runway 8L/26R. Runway 4R/22L handles roughly 28 percent of the traffic. The remaining traffic is handled by runway 8R/26L (17 percent) and runway 4L/22R (10 percent). Tropical trade winds blow from the northeast at an angle 40° to 90° from the north for a major portion of the year.[3] The warm ocean temperature in the central Pacific Ocean reverses the trade wind pattern, and wind blows from the southwest. This is

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	323,400	100%	323,726	100%	330,506	100%
Commercial	177,870	55%	176,755	55%	181,780	55%
Transient General Aviation	77,620	24%	78,743	24%	66,100	20%
Air Taxis	48,510	15%	47,057	15%	66,100	20%
Military	16,170	5%	15,815	5%	16,525	5%
Local General Aviation	6470	2%	5356	2%	N/A	0%

*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. Oahu, Hawaii: Hawaii State Department of Transportation. 2006

[1]Schlapak, B. "Aircraft-Specific Information Related to Pa'ina Irradiator." Email communication (October 31) to M. Blevins, NRC. Oahu, Hawaii: Hawaii State Department of Transportation. 2006.

[2]Ibid.

[3]Ibid.

called the Kona wind and lasts from a few days to a few weeks. 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 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 (i.e., approximately 25 percent of the year). Since the direction of the Kona wind varies from 150° to 270° from the north, 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 only preserved for two weeks and are not summarized.[4] Based on information about operations 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 are given in Table 2-4. The values are normalized so that the combined number adds up to 100 percent.

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) in size. Space 011 108, adjacent to this space,

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

Runway	Estimated Number of Annual Operations
8L	109,256
26R	36,416
8R	41,272
26L	13,754
4R	67,980
22L	22,660
4L	24,280
22R	8,090

[4] Ibid.

Table 2-4. Annual Operations for Each Type of Aircraft (Land or Takeoff) at Honolulu International Airport								
	Runway							
Aircraft Type	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

is available for expansion. The approximate location of the facility is shown in Figure 2-2, and the dimensions of the proposed facility are given in Table 2-5.

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 located at some distance from an airport, P_A, 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 j^{th} aircraft
N_{ij} = number of aircraft movements per year by the j^{th} aircraft along the i^{th} flight path
A_j = effective area of the facility for the j^{th} aircraft

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

Table 2-5. Dimensions of the Proposed Facility*		
Length, m [ft]	**Width, m [ft]**	**Maximum Roof Height, m [ft]**
19.5 [64]	35.3 [116]	9.0 [29.6]
*Kohn, M. "Draft Request for Additional Information Related to Environmental Review." Email communication October 23) to M. Blevins, U.S. Nuclear Regulatory Commission. Honolulu, Hawaii: Pa'ina Hawaii, LLC. 2006.		

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) and by combining transient general aviation and local general aviation in Table 2-2 to make the general aviation category in NUREG–0800 (NRC, 1981).

The location of the proposed facility with respect to the four runways is shown in Figures 2-3 through 2-5. For the runways at Honolulu International Airport, the ends of the runways 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 at or taking off from a runway. Values for C_j applicable to the proposed facility are given in Table 2-6 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: 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 area, A_S (DOE, 1996). This is written mathematically as

$$A_{eff} = A_f + A_S \quad (2\text{-}2)$$

where

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

and

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

Table 2-6. 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.				

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(ϕ) = mean cotangent of the aircraft impact angle

Characteristics of different aircraft, namely, wingspan, skid distance, and mean cotangent of the impact angle, obtained from DOE (1996), are presented in Table 2-7. Using Eqs. (2-1) through (2-4) and the information presented in Tables 2-5 and 2-7, the effective area of the proposed facility estimated for each aircraft type is given in Table 2-8.

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 strikes the facility. Landing phase crashes historically occur short of the runway (Glaser, 1996). There is no recorded evidence of a commercial aircraft, while attempting to land, crashing beyond the departure end of the runway. Additionally, there are no records in the commercial database of a mishap where the aircraft would crash behind the point where it started its run for takeoff (Glaser, 1996). Based on analysis of data, Kimura, et al. (1996) concluded that a crash during takeoff typically occurs about 1 km [0.6 mi] beyond the departure end of the runway. Similarly, a crash during landing typically occurs about 2.3 km [1.4 mi] short of the threshold 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; results follow.

<u>Runway 8L</u>

The proposed facility is located closer to the departure end 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. Informal Land and Hold

Table 2-7. Characteristics of the Aircraft*			
Aircraft Type	**Wingspan *WS*, m [ft]**	**Mean Cotangent of Impact Angle cot Φ**	**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 2-8. Estimated Effective Area of the Facility for Each Type of Aircraft		
Aircraft Type	**Effective Facility Area**	
	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

Short procedures were observed 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} to expedite arriving at the interisland terminal of the airport. This practice effectively shortens the 3,658-m [12,000-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 somehow leaving the runway while decelerating toward the proposed facility must pass through a wooded area and the control tower facility 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 end of the runway and the proposed facility. There are no documented cases of such an accident (Glaser, 1996; Kimura, et al., 1996).

An aircraft taking off from this runway may reach the proposed facility; however, as the aircraft comes closer to the facility, a steeper turn in a direction perpendicular to the runway centerline is necessary. Additionally, there is a small probability of a crash onto the proposed facility after takeoff, especially if the required right turn to reach the assigned route is made too early.

Runway 26R

The proposed facility is close to the runway threshold in a direction perpendicular to the runway centerline. An aircraft landing at this runway needs to make a very sharp turn to reach the proposed facility, crossing two runways on the way. An aircraft directly approaching the facility needs to be precisely aimed at the facility due to the presence of several other structures and Keehi lagoon. This scenario means only a small fraction of the aircraft landing at this runway have the potential to crash into the proposed site.

An aircraft taking off from this runway will have to travel in a direction perpendicular to the runway centerline to reach the facility, crossing two runways on the way. The 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. An aircraft will make a right turn after takeoff to reach the assigned route, which would bring the aircraft in a direction opposite the facility. During takeoff an aircraft must pass through a taxiway and several other structures to reach the proposed facility. Again, as the aircraft gathers speed while running toward the departure end of the runway, it becomes increasingly difficult to reach the facility because the angle of travel with the runway becomes increasingly steeper.

An aircraft landing at this runway will have little probability to reach the facility because it is almost 3.2 km [2 mi] from the runway threshold. An aircraft again needs to travel through a taxiway and several other structures to reach the facility. The probability of a direct landing on the facility is negligible because there are no documented cases supporting such a possibility (Glaser, 1996; Kimura, et al., 1996).

Runway 26L

An aircraft taking off from this runway is unlikely to travel to the proposed facility because it has to travel through a taxiway and several other structures to reach the proposed facility. A portion 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.

An aircraft landing on this runway has some probability of crashing into the proposed facility. However, the accident must involve landing on the effective area of the building, thus missing the runway, which is a low probability event because of the presence of the lagoon and other structures nearby that would block the aircraft.

<u>Runway 4R</u>

The proposed facility is close to the point where the aircraft would start a run for takeoff. An aircraft doing this would have a small probability for crashing into the facility because the facility is located beyond the threshold and perpendicular to the runway, making it extremely difficult for an aircraft to hit it. Therefore, the potential for crashes into the proposed facility is negligible when the aircraft is taking off from this runway. However, an aircraft landing at this runway has a probability of crashing into the proposed facility because it is close to the end of this runway.

<u>Runway 22L</u>

The proposed facility is almost beyond the departure end of this runway. If an aircraft somehow leaves the runway when decelerating after landing, it must pass through other existing structures before it reaches the proposed facility. Once an aircraft is airborne, there is little probability that the aircraft could navigate toward the proposed facility. Therefore, the probability of an aircraft crashing into the proposed facility while landing at this runway is negligible. There is a probability of an aircraft crashing into this facility while taking off from this runway and making the required left turn to reach the assigned route.

<u>Runway 4L</u>

The proposed facility is behind the point where the aircraft would start the run for taking off. Therefore, the probability of an aircraft crash into the proposed facility during takeoff is negligible. However, there is a probability that an aircraft could crash into the proposed facility while attempting to land on this runway.

<u>Runway 22R</u>

The proposed facility is beyond the departure end of this runway during landings. Therefore, the probability of an aircraft crash into the proposed facility during landing is negligible. However, there is a probability that an aircraft from this runway could crash into the proposed facility during takeoff. There is an additional, although small, probability that an aircraft could crash into the proposed facility during takeoff from this runway after making a left turn to reach the assigned route. 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 corresponding to the relative location of the facility with respect to the runway end (Table 2-6), and the estimated effective area (Table 2-8). The estimated aircraft crash frequencies are shown in Table 2-9. 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 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 Conservatism in the Estimated Annual Frequency

A significant amount of conservatism is inherent in the analysis methodology and data used to estimate the annual frequency of aircraft crashes involving the proposed facility. This section discusses the main conservative assumptions.

(1) 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 (DOE, 1996) suggests that the locations of aircraft crashes at different airports 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 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.

Table 2-9. 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}

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

(3) 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 same in the negative x-direction (i.e., toward the center 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 center introduces conservatism in the estimated frequency.

(4) 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 at this airport would bring the aircraft away from the proposed facility toward the ocean. Similarly, any missed approach while landing would take the aircraft toward the ocean 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.

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. As described above, the source plenum is located at the bottom of a 5.4-m [18-ft] pool that is filled with water to act as shielding and coolant for the source assemblies. The source assemblies in the source plenum are not mechanically coupled to the plenum structure and the plenum structure is not coupled to the rest of the building. If the plenum structure is damaged, the irradiator is designed to disassemble, leaving the source assemblies intact at the bottom of the pool. As discussed in Section 1.1, the source assemblies are doubly encapsulated and have been tested to withstand very strong forces. A significantly larger force must be generated by an aircraft crash because much of the force will result in damage to the building and the structures in the pool. Transferring the force to the bottom of the pool will also result in significant absorption of the force. It is highly unlikely that a source assembly would be breached if an aircraft crashes into the proposed facility.

Based on the FAA forecasts, nationwide commercial aircraft operations are projected to increase from 28.6 million in 1998, to 36.6 million in 2010, and to 47.6 million in 2025. This represents a 66-percent increase in U.S. commercial aviation operations by 2025. The annual number of general aviation operations (takeoffs and landings) at all towered and nontowered airports in the United States is projected to increase from 87.4 million in 1998 to 92.8 million in 2010 and to 99.2 million in 2025 (FAA, 1999). This is a projected increase of general aviation traffic of 14 percent by 2025. The FAA also estimates that the growth in operations at Honolulu International Airport (FAA, 2006b) will be approximately 33.3 percent in fiscal year 2012 (510,000 operations) from 382,466 operations in fiscal year 1997. Based on these estimates, for the 10-year period of the license application, the increase in flight operations at Honolulu International Airport is likely to increase by about 20 percent. This will increase the probability of an aircraft crash into the proposed facility, but the likelihood that the source assemblies will be breached and the radioactive material released is 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 determined to be about 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. It is believed that the actual crash frequency is much less than the 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. It has further been shown that the source assemblies have been designed and tested to be able to withstand very strong forces and will not be breached in the event of an aircraft crash. An aircraft crash will not be able to impart enough force to the source assembly to eject it from the bottom of the irradiator pool. In addition, the depth of the pool extends below sea level, making it unlikely that the water would be removed from the pool and cause the sources to become unshielded. Therefore, the probability of the loss of control of radioactive material as a result of an aircraft crash is negligible.

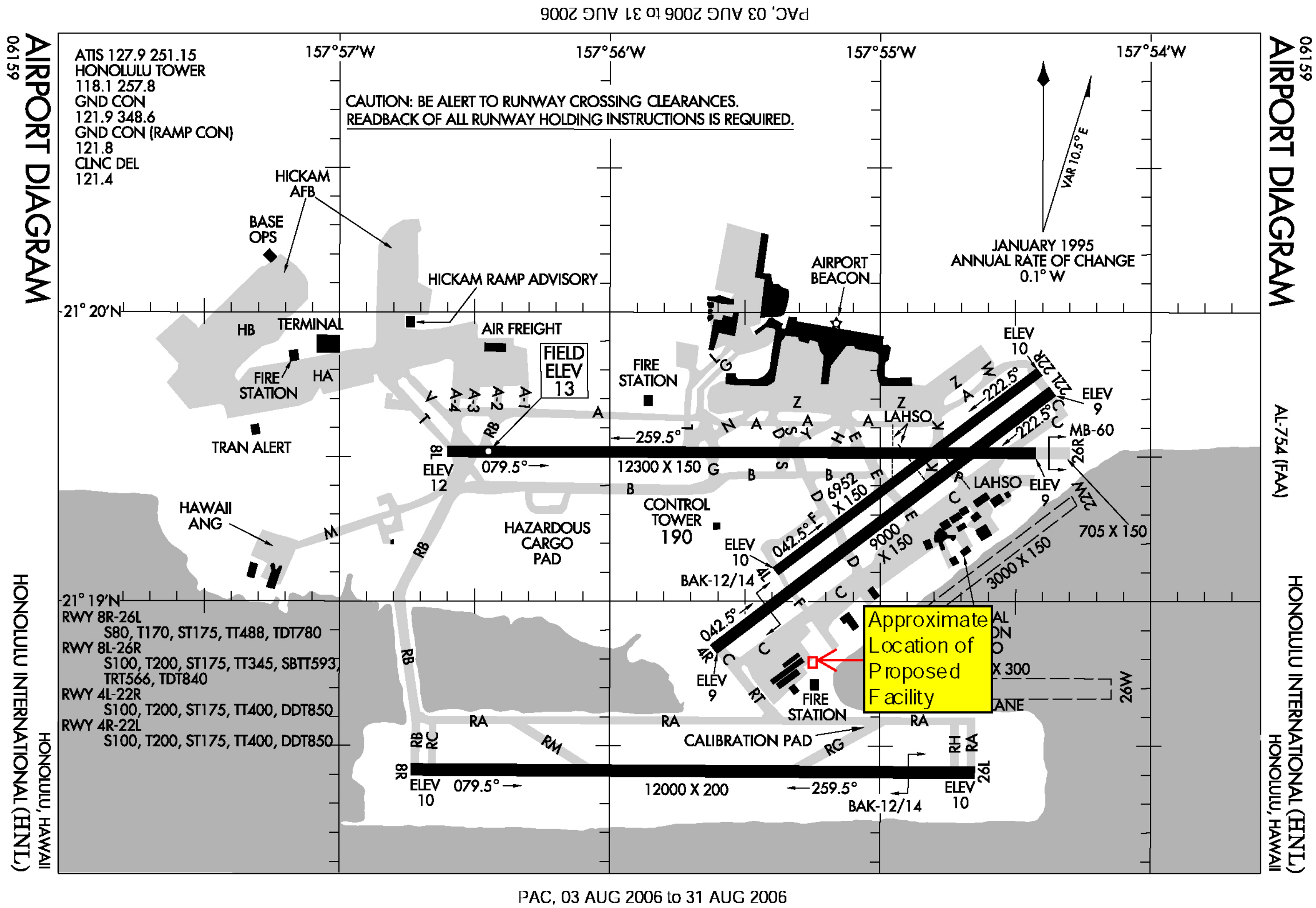

Figure 2-1. Layout of the Pa'ina Airport Showing the Location of the Proposed Facility (FAA, 2006b)

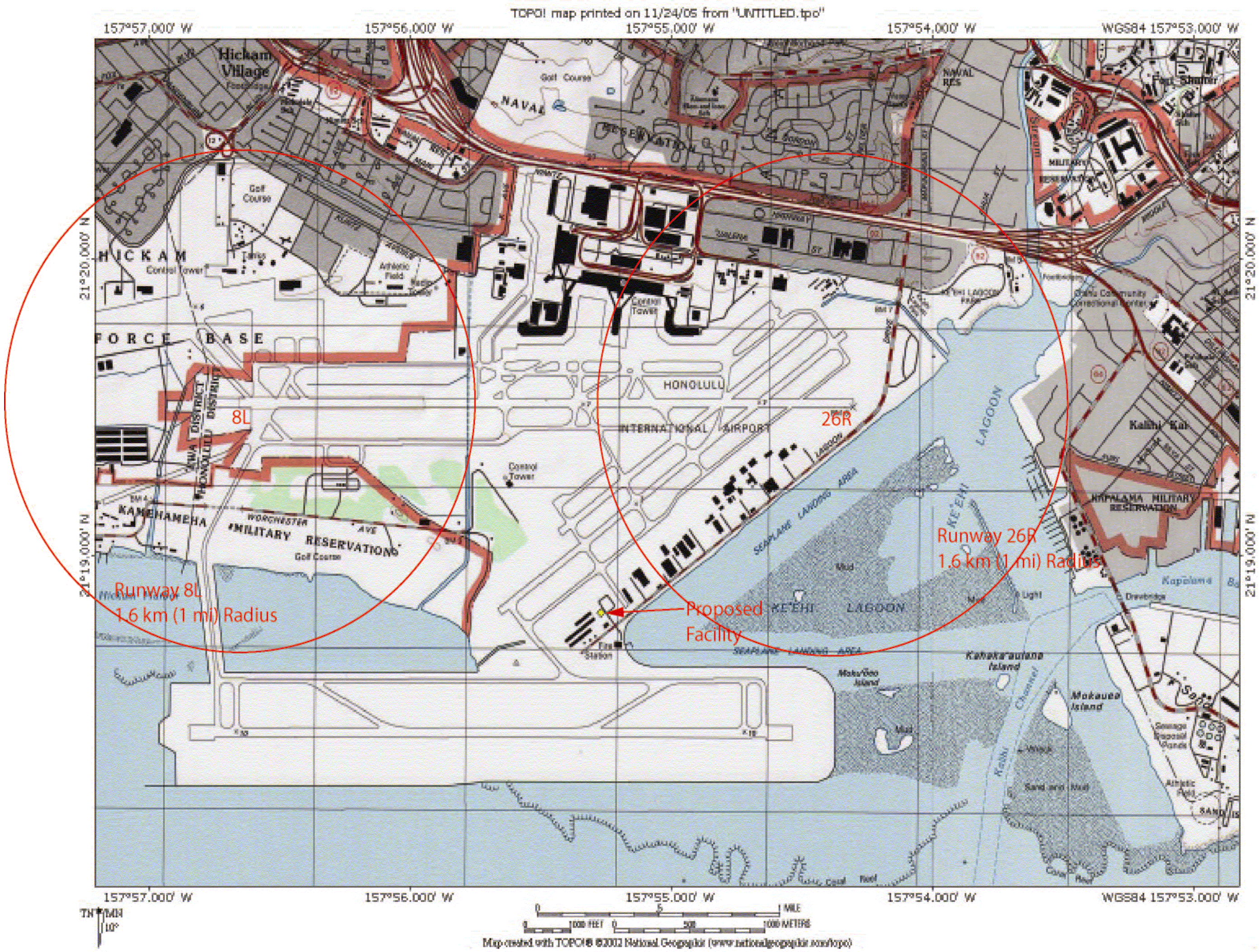

Figure 2-2. Runway 8L/26R With Respect to the Proposed Facility (Modified From FAA, 2006b)

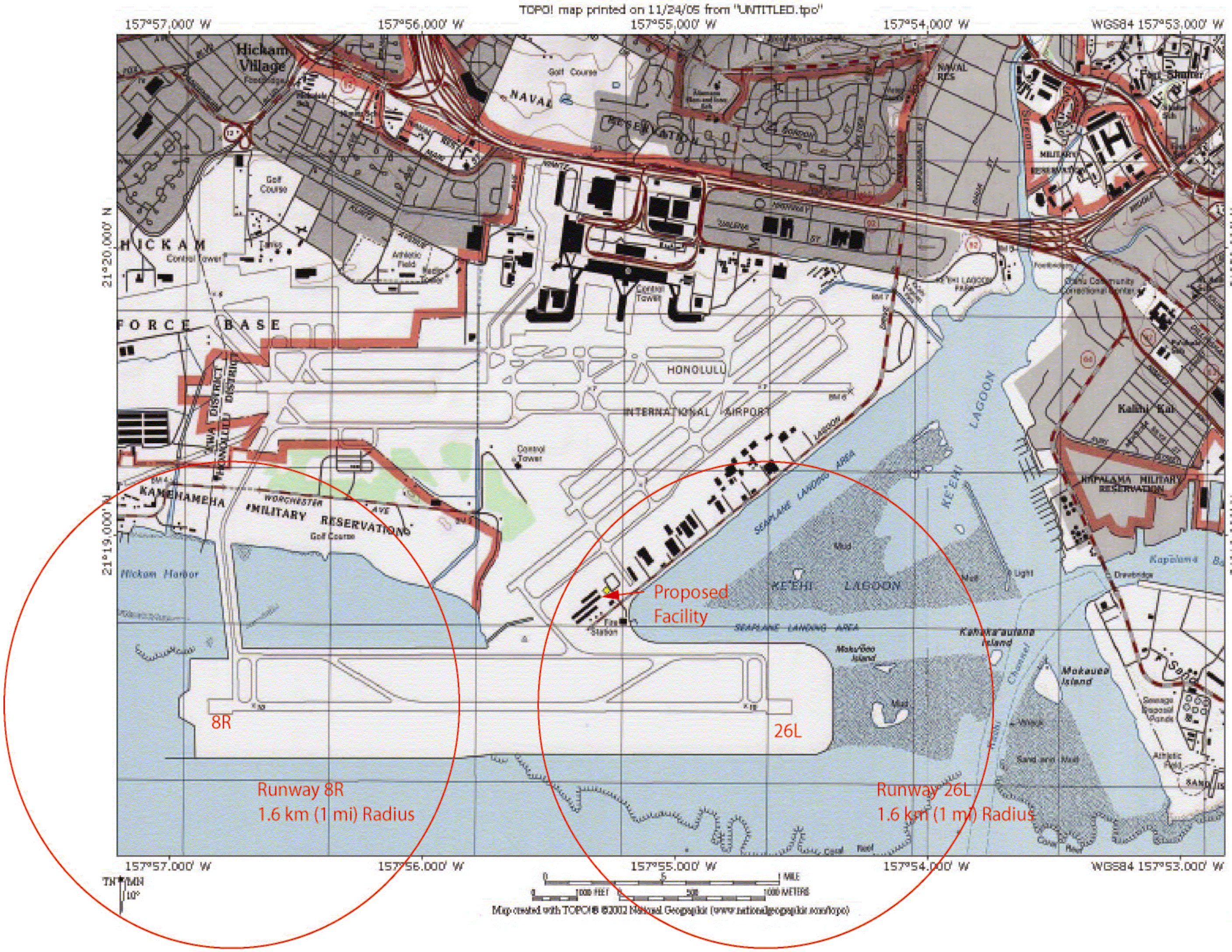

Figure 2-3. Runway 8R/26L With Respect to the Proposed Facility (Modified From FAA, 2006b)

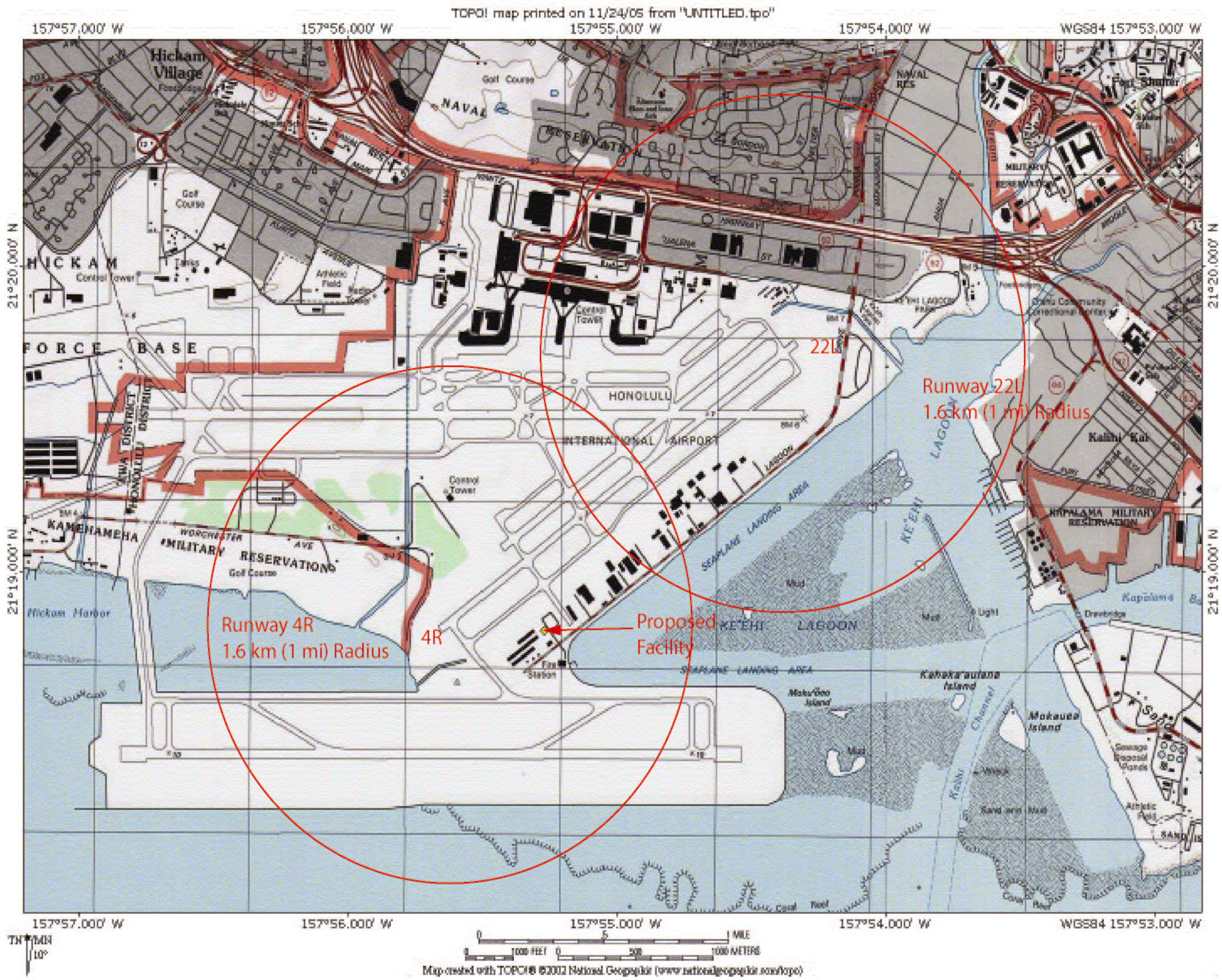

Figure 2-4. Runway 4R/22L With Respect to the Proposed Facility (Modified From FAA, 2006b)

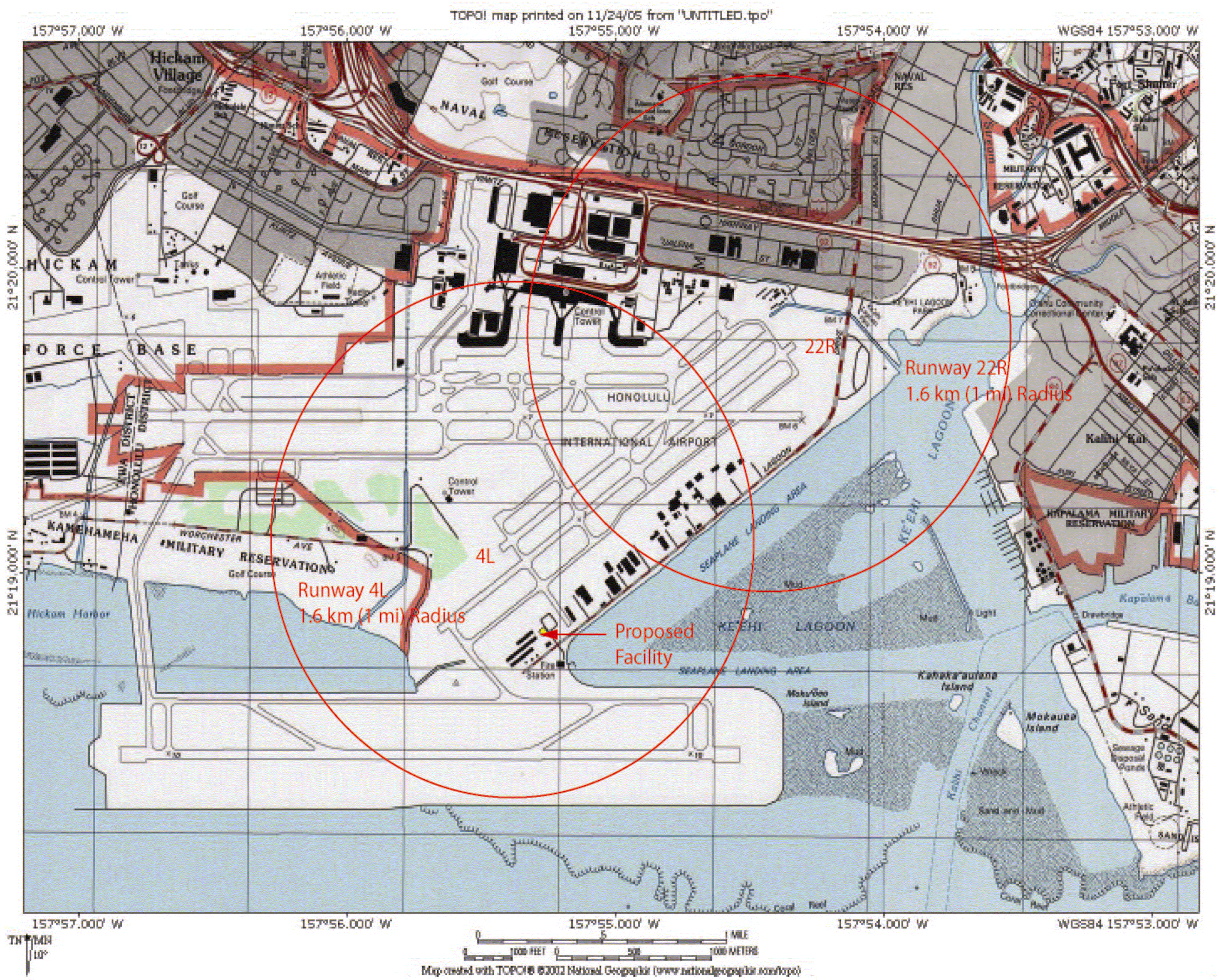

Figure 2-5. Runway 4L/22R With Respect to the Proposed Facility (Modified From FAA, 2006b)

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 are 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 six principal islands of the Hawaiian chain (Hawaii, Maui, Oahu, Kauai, Molokai, and Lanai) 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 comprised of 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 been 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 kyr (Lanphere and Dalrymple, 1980). According to the United States Geologic Survey (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). Kelin, 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 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, M = 7.0 earthquake near Lania (Figure 3-1). 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 Hawaii Island (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 U.S. Geological Survey (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 Hawaii.

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). A small earthquake in 1948, 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.

After reviewing the available data on earthquakes that could affect Honolulu International Airport and vicinity, it is concluded that damage to the proposed irradiator facility is highly unlikely. 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 excavation phase. Although the irradiator pool will be installed to mitigate the consequences of a seismic event, including liquefaction, the proposed facility is not

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

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. Because of the strength of the source assemblies, the potential for breaching the sources during an earthquake is negligible. In addition, 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 sea level 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

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 M_W = 8.6 Unimak, Alaska earthquake. The most extensive damage was at Hilo and Pololu Valley on the island of Hawaii, which incurred $26 million in damage and 159 fatalities. Runup heights 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, 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 up to 4.8 m [16 ft], but the Honolulu tide gauge only measured a 0.5-m [1.6-ft] change in sea level. At Kahului, Maui, maximum runup was up to 3.7 m [12 ft]. On the 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, 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. 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 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."[2] The letter goes on to state that tsunami hazards are not considered a significant threat to the safe operation of Honolulu International Airport.

To further constrain the potential for tsunami-generated runups to lead to a loss of control of radioactive material, a stylized fluid dynamic calculation was conducted. 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 lower limits on velocity because they assumed a shallow pool in which the accident 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 cavity with a 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 released 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. To simplify the model, calculations were performed on an equivalent sphere oriented randomly in the fluid. The equivalent sphere had the same volume, mass, and weight of the source assembly.

The calculations showed that for a sphere equivalent to a regular sized source assembly, a vertical velocity of 35 m/s [79 mph] is required to induce a drag force sufficient to lift the source assembly. This vertical velocity would be generated by a shear velocity of at least 118 m/s [265 mph]. The drag coefficient for the sphere 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 (Erturk, et al., 2005; Ghia, et al., 1982).

At the shore, tsunami waves up to 10 m [32.8 ft] can reach velocities of 13 m/s [42.6 ft/s] (Chen, et al., 2003; National Aeronautics and Space Administration, 2006). This velocity is significantly less than 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 would likely not even reach the southern shore of the facility. The Oahu Civil Defense Agency flood maps (2006) for evacuation zones in the event of a tsunami show that Honolulu International Airport is above the evacuation zone. These calculations show that there is a negligible potential for tsunami waves could have sufficient velocities to remove the Co-60 source assemblies from the irradiator pool.

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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.

In summary, tsunamis are known to affect the Hawaiian Islands. However, the wave velocities of even the largest tsunamis are not 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 have been 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 scattered 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 Hawaii from southeast to the 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. 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]

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)

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 1.852.
‡Storm category is based on the Saffir-Simpson hurricane scale. TD = tropical depression; TS = tropical storm; HS1 = 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 3.28.

on the evening of November 30. Oahu experienced moderate rains along with a 72 km/h [45 mph] wind. The highest wind speed of 147 km/h [92 mph] was on Kauai at Kilauea Light on December 1. A very high surf with a 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]. In some places, 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 was 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 of property damage. On the morning of September 10, a top wind 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] of 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 all cyclones (tropical depressions, tropical storms, and hurricanes) was used in developing 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 the locations where the depression, storm, or hurricane first developed the maximum sustained wind speed recorded by the National Weather Service. The data include only those storms that occurred between 1980 and 2005—a total of 26 years. Figure 3-2 shows that the first occurrence of maximum wind speeds were generally recorded quite far from Honolulu International Airport and the rest of the Hawaiian Islands. Information presented in the web publication of the Central Pacific Hurricane

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

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.

Information presented for major hurricanes affecting the Hawaiian Islands and information on all tropical cyclones since 1980 suggest that the island of Oahu, especially Honolulu International Airport, 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 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, it is appropriate to consider that the proposed facility is located in a site 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 of this report is considered to appropriately capture any possible 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 significant hazards, and the potential effects of storm surges associated with these storms appear to be bounded by the more significant wave heights that could be generated by tsunamis. The wave velocity associated with a wind-generated storm surge of this size is significantly less than that associated with a tsunami. As shown in Section 3.2, a tsunami is not capable of removing a Co-60 source assembly from the bottom of the proposed irradiator pool. Therefore, the likelihood of a storm surge associated with a hurricane resulting in the loss of control of a Co-60 source assembly is negligible.

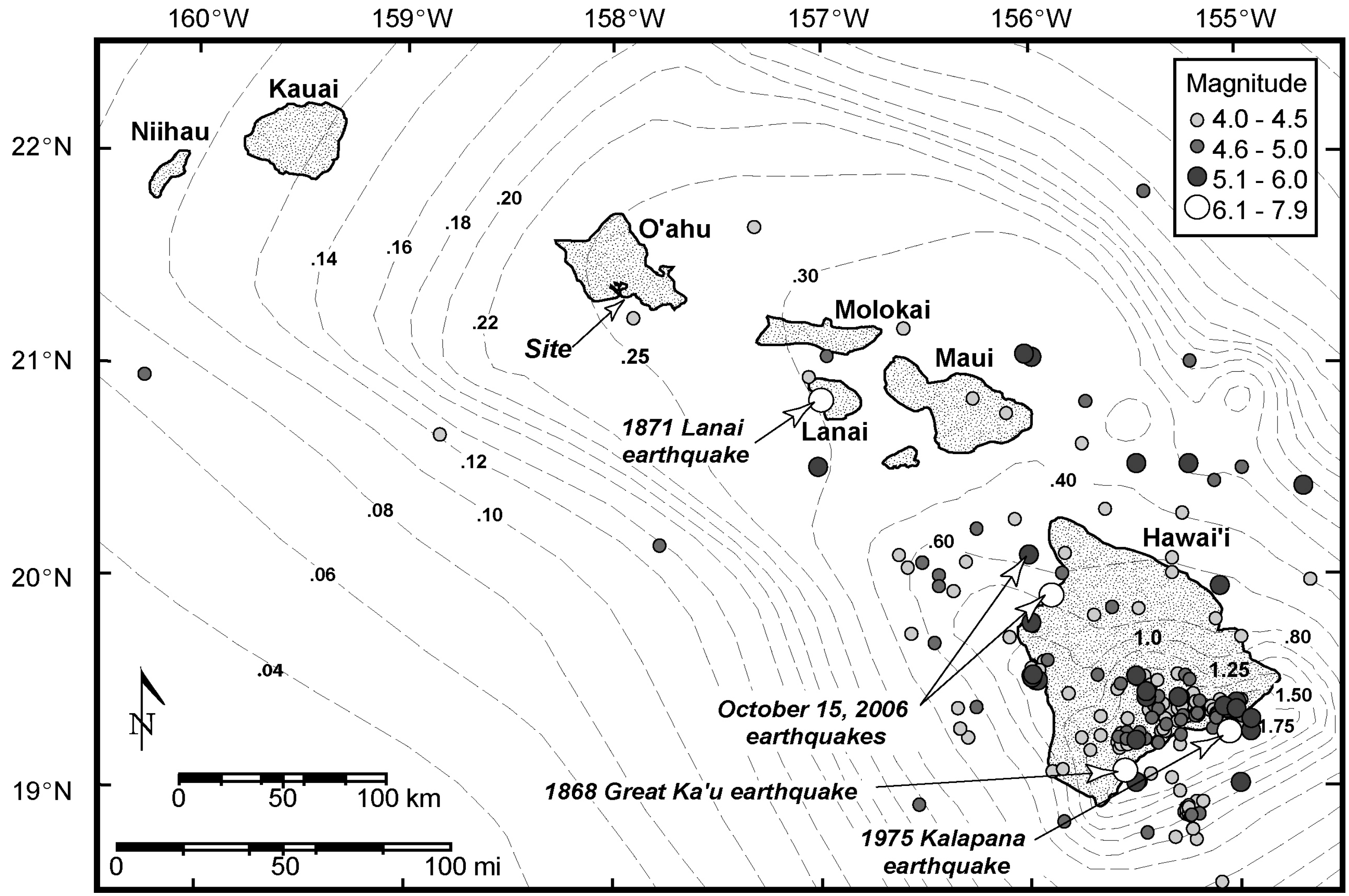

Figure 3-1. Map of the Hawaiian Islands Showing the Location of Earthquakes With Magnitudes Greater Than M = 4.0. Earthquake Data Between 1868 and October 30, 2006 Was Obtained from the USGS Catalog and from Munson and Thurber (1997). Dashed Contours Show the Horizontal Peak Ground Acceleration (% g)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

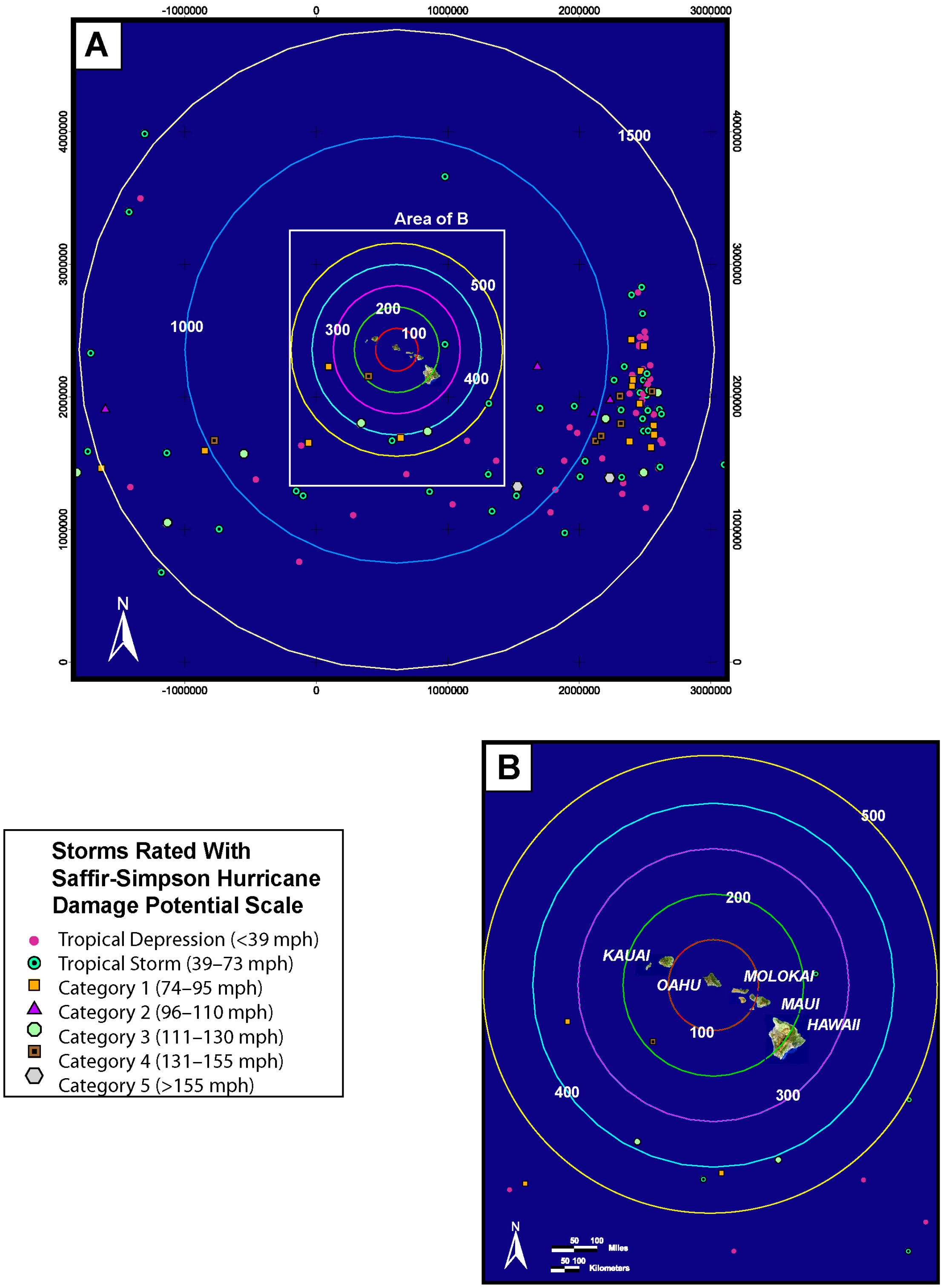

Figure 3-2. Locations Where Hawaiian Cyclones (Depressions, Storms, or Hurricanes) First Developed Maximum Sustained Wind Speeds Recorded by the National Weather Service (National Oceanic and Atmospheric Administration, 2006b)

4 CONCLUSIONS

This report has discussed information on the hazards associated with aircraft accidents and natural phenomena on a proposed irradiator facility to be located near Honolulu International Airport. The aircraft crash analysis discussed the number and types of aircraft that routinely land and takeoff from 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 conclusions drawn in this report are based on the robustness of the source assembly. The source material is doubly encapsulated and, in accordance with 10 CFR 36.21, prototype assemblies have been shown to withstand, at a minimum, a pressure test, an impact test, a drop test, a puncture test, and a bend test. The source assembly can withstand very strong forces without breaching.

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 likely to be lower for a number of reasons discussed previously. Given the 10-year license, 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 significantly 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. In addition, the source assemblies are doubly encapsulated in a package that is tested to be able to withstand very strong forces without breaching. Thus, the probability is negligible that a loss of control of radioactive material will occur as the result of an aircraft crash into the facility.

This report also discussed 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 at Honolulu International Airport large enough to cause a source assembly to be removed from the irradiator pool by ground motion. 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 to an extent sufficient to have an adverse impact on public health and safety.

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