Defense Threat Reduction Agency
8725 John J. Kingman Road, MS
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DTRA-TR-10-26

TECHNICAL REPORT

Personnel Radiation Exposure Associated with X-Rays Emanating from U.S. Coast Guard LORAN High Voltage Vacuum Tube Transmitter Units

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July 2011

Paul K. Blake et al.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
31-07-2011

2. REPORT TYPE
Technical report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Personnel Radiation Exposure Associated with X-Rays Emanating from U.S. Coast Guard LORAN High Voltage Vacuum Tube Transmitter Units

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Blake, Paul K; Hall, Jeffery W; Severance, Charles; and Rusiecki, Jennifer.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
DTRA (see block 9),
USCG Logistics, 2401 Hawkins Point Rd, Baltimore, MD 21226
USUHS, 4301 Jones Bridge Road, Bethesda, MD 20814-4799

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Nuclear Technology Directorate
Defense Threat Reduction Agency
8725 John J. Kingman Road, Stop 6201
Fort Belvoir, VA 22060-6201

10. SPONSOR/MONITOR'S ACRONYM(S)
DTRA RD-NTSN

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report analyzes personnel radiation exposure associated with x-rays emanating from U.S. Coast Guard LORAN high voltage vacuum tube transmitter units that operated between1942-2010. Approximately 10,000 U.S. Coast Guard service members operated these units during this period of time and may have been occupationally exposed to this x-ray source. This report provides information concerning the service members' probability of radiogenic disease and culminates with guidance regarding U.S. Coast Guard veterans filing non-presumptive radiogenic disease claims with the Department of Veterans Affairs.

15. SUBJECT TERMS
United States Coast Guard, USCG, Department of Veterans Affairs, VA, LORAN, X-Ray, High Voltage Vacuum Tubes, Radiation Dose, Radiogenic Disease

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU		Dr. Paul K. Blake
U	U	U			19b. TELEPONE NUMBER (*Include area code)* *703 767-3384*

STANDARD FORM 298 (Rev. 8/98)

CONVERSION TABLE

Conversion Factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ⟶ BY ⟶ TO GET
TO GET ⟵ BY ⟵ DIVIDE

angstrom	1.000 000 x E -10	meters (m)
atmosphere (normal)	1.013 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E +2	kilo pascal (kPa)
barn	1.000 000 x E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 x E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E +1	*giga bacquerel (GBq)
degree (angle)	1.745 329 x E -2	radian (rad)
degree Fahrenheit	t_k = (t^of + 459.67)/1.8	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 x E -7	watt (W)
foot	3.048 000 x E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E -3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E +9	joule (J)
joule/kilogram (J/kg) radiation absorbed dose	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E -6	meter (m)
mil	2.540 000 x E -5	meter (m)
mile (international)	1.609 344 x E +3	meter (m)
ounce	2.834 952 x E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E -1	newton-meter (N-m)
pound-force/inch	1.751 268 x E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 x E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 x E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E -2	kilogram-meter^2 (kg-m^2)
pound-mass/foot^3	1.601 846 x E +1	kilogram-meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 x E -2	**Gray (Gy)
roentgen	2.579 760 x E -4	coulomb/kilogram (C/kg)
shake	1.000 000 x E -8	second (s)
slug	1.459 390 x E +1	kilogram (kg)
torr (mm Hg, 0^o C)	1.333 22 x E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The gray (Gy) is the SI unit of absorbed dose.

DTRA-TR-10-26: ***Personnel Radiation Exposure Associated with X-Rays Emanating From U.S. Coast Guard LORAN High Voltage Vacuum Tube Transmitter Units***

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Executive Summary

United States Coast Guard (USCG) veterans stationed at LORAN stations (LORSTA) from 1942-2010 have expressed concern that their duties may have caused them radiogenic disease due to their occupational exposure to x-rays emanating from high voltage vacuum tubes. The time period of concern ranges from 1942 when the USCG began operating LORSTA Battle Harbor, through 2010 when USCG LORSTA operation ceased – removing this ionizing radiation source. In response to this concern, the USCG Commandant, CG-1133 commissioned this technical report of personnel radiation exposure associated with x-rays emanating from LORSTA transmitter units.

Radiation measurements available for analysis included five distinct temporal collections: 1982, 1987-1988, 1993-1999, 2003, and 2008-2011. These measurements provide verification of a valid radiation exposure hazard that could potentially be a source of occupational disease. Radiation measurements in late 1993 resulted in the installation during 1995 of acrylic-lead radiation shields between the high power vacuum tubes and the outer electrical equipment cabinet doors. Subsequent radiation measurements demonstrated that the radiation shields were effective in eliminating occupational exposure from these radiation sources, if the shields were maintained between the USCG maintenance personnel and the energized power amplifier (vacuum tube).

Results from the USCG's limited LORSTA personnel radiation dosimetry monitoring program in 1988 and 1994 demonstrated minimal personnel radiation exposure for monitored personnel, well within federal occupational radiation exposure limits and presumably was the rationale for not establishing a USCG LORSTA personnel radiation dosimeter program. Unfortunately, this limited personnel monitoring program did not address the case of an individual who may have performed exceptional high voltage vacuum tube operational and maintenance activities that may have resulted in significant ionizing radiation exposure.

To assist USCG LORSTA veterans, their dependents, the Department of Veterans Affairs (VA), and the USCG, this report culminates in recommendations for the collection of veteran exposure scenario data and its subsequent use in radiation dose reconstructions. Radiation dose reconstructions are required, in the absence of radiation personnel monitoring data, to perform a probability of radiogenic disease causation calculation, which can lead to a VA radiogenic disease compensation decision.

1. <u>Introduction</u>

a. The Co-Authors' Charge

In March 2010, the U.S. Coast Guard (USCG) Commandant, Division of Environmental Health & Industrial Hygiene, CG-1133 (Rusiecki) contacted the Department of Defense health physicist (Blake) responsible for atomic veteran personnel radiation dose reconstruction and requested assistance in analyzing ionizing radiation exposure data from USCG LORAN Station (LORSTA) operation. This division also requested the support of a USCG active duty member (Hall) and USCG veteran (Severance) experienced with LORSTA operations to collaborate on this technical report. Brief biographies of the four co-authors are provided at the back of this report.

This request for data analysis arose from inquiries from the LORAN veteran community regarding concerns of potential radiogenic disease from occupational exposure to low-energy x-rays arising from high voltage vacuum tubes used in LORAN AN/FPN-39, -42, -44, and -45 transmitting units between 1942-2010. USCG personnel who operated and maintained these systems were not typically monitored for occupational personnel radiation exposure and consequently have become concerned that their unknown personal radiation exposures may have contributed to health risks. The intended audience of this analysis is USCG LORSTA veterans, their dependents, the Secretary of Veterans Affairs, and Commandant, U.S. Coast Guard.

b. A Brief History

LORAN, short for LOng RAnge Navigation, was a terrestrial radionavigation system developed during World War II by the famous Radiation Laboratory at the Massachusetts Institute of Technology. The first version transmitted a single pulse with a carrier frequency in the 1950 Hz range and it was used during the war to guide Allied military ships and aircraft. After the war, this system was renamed Loran-A and, it was made available for public use. In 1958 the U.S. Coast Guard began operation on a new and separate low frequency LORAN-C system that transmitted a pulse train of eight or nine pulses with a carrier frequency of 100 kHz.

Fig. 1: LORAN Support Unit, Wildwood, NJ

In 1974 the Secretary of Transportation adopted LORAN-C as the official radionavigation system for coastal U.S. waters. On December 31, 1980, the Coast Guard terminated Loran-A operation. In the late 1980's, at the request of the Federal Aviation Administration, the Coast Guard began a project to extend LORAN-C coverage from coast to coast in the continental U.S. By 1990, the Coast Guard operated LORAN-C stations in the U.S., its territories, and in "host nations" such as Italy, Japan and Turkey (Bruckner, 1992). Reported accuracy at that time was 0.25 nm (450 meters) at 95% confidence level with 24 hour access (99.7% availability). A historical review of USCG LORSTA operations indicates that over 150 transmission stations existed, and over 10,000 USCG personnel served in them between 1942-2010 (Loran-history.info website, 2010). A typical LORSTA was independently operated by one junior officer or warrant officer or senior enlisted and approximately 8-20 additional enlisted personnel, depending on the era and location of the station. Prior to 1990, it was not uncommon for

LORAN-trained USCG Electronics Technicians (ET) to spend most of their active duty careers (20 plus years) at various LORSTAs. However, at LORSTA Engineering Centers and some overseas facilities (i.e. LORSTA Gesashi, LORSTA Hokkaido, LORSTA Sellia Marina) civilian electronic technicians were employed.

A LORSTA consisted of a single transmission antenna and associated support units where USCG personnel worked and resided. LORAN-C antennas (monopole towers) were typically 625 or 1350 ft in height – see figure 1. A smaller number of LORSTAs were designed with four 695 ft towers arranged in a square, with wire hanging between the towers serving as the radiating antennas. Support quarters for the electronics cabinets and other gear were originally Quonset huts, and in recent years evolved into modern support buildings – see figure 1. Early LORAN-C stations had a separate transmitter building located at the base of the transmitting antenna and located 1,000 yards from the main building.

LORAN-C operation supported both military and civilian users. For the U.S. military, naval ships and weapon systems (e.g. the fleet ballistic missile system) were the critical users along with military aircraft. Likewise, over 1.3 million civilian mariners had LORAN-C receivers and over 80,000 civilian aircraft were similarly equipped.

Since 1994, when the Global Positioning System (GPS) was fully implemented via a network of 24 satellites, Loran-C military and civilian radionavigation users have gradually migrated to this more widespread and increasingly popular system. The major advantage of GPS is increased location accuracy (advertised 7.6 meters) and world-wide coverage in all weather and at all times, when and where there is an unobstructed line of sight to four or more GPS satellites. However, GPS is vulnerable to intentional, unintentional, and natural interference. While the GPS signal is very high frequency, LORAN-C signals are low frequency. LORAN-C signals were also very high-powered, so they penetrated cities, buildings and densely foliaged areas where low level GPS signals could be blocked. From a practical perspective, LORAN was virtually unjammable because of its high power and is significantly more resistant to many forms of interference.

However, in accordance with the 2010 Department of Homeland Security Appropriations Act, the U.S. Coast Guard terminated the transmission of all U.S. LORAN signals in 2010. This ended a system that the Coast Guard had proudly run for more than 67 years. The 2010 closure action reflected the President's pledge to eliminate unnecessary federal programs (USCG, 2010). The last U.S. Coast Guard LORAN station was officially disestablished on 22 Mar 2011 (COGARD LSU Wildwood NJ msg. 221645Z Mar 11).

c. Transmitter Set Evolution

USCG LORAN transmitter technology began with high voltage vacuum tube circuits that generated unwanted incidental x-rays. This problem was exacerbated during transmitter evolution as higher

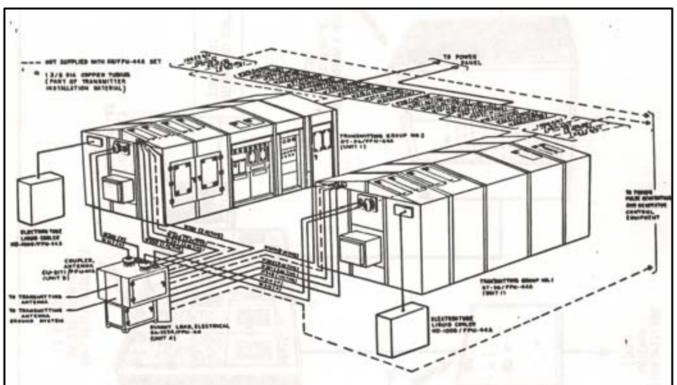

Fig. 2: AN/FPN-44 Transmitter Set

voltages were applied to vacuum tubes in order to increase LORAN signal strength. After several decades of improvements, LORAN transmitters evolved into solid-state technology void of any vacuum tube amplifiers (see Table 1).


Fig. 3: AN/FPN-45 Transmitter Passageway

The AN/FPN-44 (see Fig. 2) was the most advanced vacuum tube type transmitter featuring water-cooled power amplifiers and a walk-in high voltage power amplifier section. All tube type transmitting stations consisted of two transmitters and one antenna coupler/ dummy load. One transmitter was always on air while the other was kept as a ready standby.

The AN/FPN-45 transmitter (see Fig. 3) was the highest powered transmitter in the LORAN inventory. The technicians on the right side of this photograph are trying to locate the source of high voltage arcing in the power amplifier section. Arcing often occurred during tube bake-in procedures, and in conjunction with faults within tuned, power amplifier, and high voltage circuits of all vacuum tube transmitters.

Table 1: USCG LORSTA Transmitter Sets

Nomenclature	System	Designed	Terminated	Peak Power KW
-	Standard Loran	1942	1946	-
CG-52330	Loran-A	1954	1950’s	100
T-137	Loran-A	1954	1980	160
T-137A	Loran-A	1954	1980	160
T-325	Loran-A	1954	1980	160
T-138-A	Loran-A Amp	1954	1980	1,000
AM-701/FPN	Loran-A Amp	1954	1980	1,000
AM-1700/FPN	Loran-A Amp	1956	1980	1,000
AN/FPN-39	Loran-C	1957	1994	100
AN/FPN-42	Loran-C	1962	1994	300
AN/FPN-44	Loran-C	1963	2007	400
AN/FPN-44 ATLS	Loran-C	1963	2007	400
AN/FPN-44B	Loran-C	1980	2007	400
AN/FPN-45	Loran-C	1963	2003	2,000
AN/FPN-45/B	Loran-C	198?	2007	2,000
AN/FPN-64	Loran-C	1975	2010	800

LORAN vacuum tube transmitters amplified their signals through multi-stage class AB or B vacuum tube power amplifier sections. These circuits operated in a parallel push-pull tuned tank circuit configuration and were sensitive to loading and tuning. They were often the source of arcing, and large variations in RF peak voltages that could add energy to the power amplifier plate circuit increasing the RF peak voltage. The antenna coupler at vacuum tube transmitting stations was manually tuned to match the output impedance of the transmitters to the antenna and dummy load. Tuning was usually accomplished during the installation of the transmitter or following changes to the antenna. These transmitters were unable to automatically tune for variations in antenna system characteristics i.e. changes to ground plane due to weather.

The final generation of LORAN transmitters (AN/FPN-64) was significantly different than previous generations since it did not use vacuum tube amplifiers circuits eliminating the source of incidental ionizing radiation. Instead of amplifiers this transmitter used solid-state pulse compression technology consisting of half-cycle generator units which autonomously contributed a portion of the antenna output current. The only possible source of incidental ionizing radiation in this transmitter was a single vacuum tube lightning arrestor in the switch network.

Fig. 4: 1st IPA tube

The AN/FPN-64 transmitter had other significant advantages over earlier generations:

- a cleaner output signal
- a higher ratio of output power to supplied line power, resulting in significant savings in annual electrical power cost
- less maintenance – no vacuum tubes to replace
- an automatic pulse generating and control system, which allowed for unmanned and remote operations at some sites – a significant savings in manpower costs

Fig. 5: 2nd IPA tube

Unfortunately, the conversion cost per LORSTA ranged from $2 million to $4 million. In the late 90's, the Coast Guard began a LORAN-C recapitalization project, which included replacing the remaining high power vacuum tube transmitters with non-radiation emitting, solid state technology. In November 2007, the last west coast older generation tube transmitter was replaced at LORSTA St. Paul Island, Alaska. The more advanced AN/FPN-44 tube type transmitters continue to operate on the west coast until LORAN was shut down at LORSTA Narrow Cape, LORSTA Shoal Cove, LORSTA Tok, and LORSTA Williams Lake.

As shown in Table 1, the first three generations of LORSTA transmitter sets demonstrate the USCG's desire to increase transmitter output power, and hence increase the useful area of signal coverage per LORSTA. The first generation design was based on a three power vacuum tube approach: 1st intermediate power amplifier (IPA) tube, a 2nd IPA, and the final PA tube. The 1st IPA and 2nd IPA tubes typically used smaller applied voltages than the final PA tube. Since LORSTA output signal power is a function of applied voltage and current through a tube, which is defined by the tube manufacturer's operating tube characteristics, the easiest method of increasing LORSTA signal output, is to increase the number of power amplifier units – where one unit consists of a 1st IPA, 2nd IPA, and final PA

Fig. 6: PA tube (EIMAC 6696)

assembly. In fact, the AN/FPN-44 and the AN/FPN-45 sets are essentially the same transmitter with progressively more power amplifier stages and consequently greater output power.

In comparison, AM and FM radio station radiated power output is significantly less. In the U.S., the Federal Communications Commission (FCC) mandates 50 kW or less for AM stations, and 100 kW or less for FM stations (North America broadcast station classes, 2010).

d. Ionizing Radiation Sources-Power Amplifying Vacuum Tubes

Any vacuum tube operating at several thousand volts or more can produce x-rays. X-rays arise when electrons are accelerated by an electric field between the polarized cathode (the emitting surface), through one or more grids controlling the flow of electrons, and are collected by the anode of the vacuum tube. This radiation source is known as bremsstrahlung radiation, or "braking radiation" and is the basis of clinical x-ray tubes. As shown in equation (1), the averaged radiation exposure (X) from a vacuum tube source is a function of the square of the applied voltage (*v*) multiplied by the tube current (*i*). The term (k) is a multiplicative constant and (T) refers to time period of interest.

Fig. 7: Insertion of acrylic-lead radiation shield within PA tube Electrical Equipment Cabinet

(1) $$\mathrm{X} = k\frac{1}{T}\int_0^T v^2(t)i(t)dt$$

However, in the case of most high-power vacuum tubes, x-ray production is an unwanted product, and tubes are designed to minimize its production. USCG LORSTA transmitter units were designed to use a power amplification (PA) tube manufactured by Machlett, Inc. and/or EIMAC, Inc. (named for its two amateur radio operator founders in 1934 - Bill Eitel and Jack McCullough). In 1965, Eimac merged with Varian Associates and became known as the Varian Eimac Division. In 1995, this division was sold and is now known as CPI - Communications & Power Industries. (EIMAC, 2010). PA tubes are often described by the terms "triode," "tetrode," and "pentode." These terms also indicate the number of grids. A triode has one grid, a tetrode has two grids, and a pentode has three grids. USCG LORSTA PA tubes used a triode design.

Fig. 8: LORSTA Transmitter PA Space – with energized tubes

The first and second IPA tubes typically had peak applied voltages of less than 11,000 volts and were not significant sources of personnel x-ray exposure – since much of the

Fig. 9: Close-up of energized PA tube – viewed thru Electrical Equipment Cabinet

bremsstrahlung radiation is attenuated by the tube's glass envelope. However, the PA tube used an applied voltage of 21,500 volts (21.5 kVp), resulting in a peak x-ray energy of a 21.5 keV. This occurs since vacuum tube x-ray production produces a continuous x-ray spectrum with a peak energy based on the applied voltage across the tube. The average energy of the unshielded x-ray spectra is approximately 1/3 – 1/2 of the peak energy. From an x-ray protection viewpoint, a 21.5 kVp source is considered a "soft" x-ray source that is relatively easy to shield. For comparison purposes, clinical diagnostic imaging x-ray units are often operated at 100 kVp, and associated radiation shielding is typically lead sheets of approximately 1.5 mm in thickness. For USCG LORSTA tubes a lighter weight, plastic shield (commercial acrylic-lead) is sufficient. Shields of this nature were inserted in all USCG LORSTA PA electronic cabinets still using vacuum tube based transmitters in 1995.

Fig. 10: Close-up of PA tube deionized water system (red tubing into bottom of anode container)

The other key parameter in PA tube x-ray production is electronic current. The LORSTA AN/FPN-44/45 sets used EIMAC/Machlett 6696 triode tubes continuously operating at 21.5 kV with a peak current of 205 amperes (CPI, 2010). In comparison, clinical diagnostic x-ray tubes use currents of milliamperes for non-continuous operations. LORSTA tubes are considered high power. Clinical x-ray tubes are not.

High power vacuum tubes are not unique to USCG LORSTA operations. The Coast Guard, the Department of Defense, and the commercial sector use a variety of high power vacuum tubes for numerous applications, which are frequently broken into two categories:

- Power grid tubes (e.g. triodes, tetrodes, and pentodes) used in radio, shortwave, TV and LORSTA radiofrequency (RF) transmission
- Microwave power tubes (e.g. klystrons, traveling wave tubes, …) used in radar, linear accelerators

It should be noted, that high power tubes in USCG/DoD radar systems can operate at potentials up to several 100 kilovolts, and USCG and military personnel maintaining and servicing these systems have performed their work without wearing personnel radiation dosimetry.

e. Ionizing Radiation Sources-Vacuum Relays

LORAN transmitters used high voltage vacuum relays (solenoid-actuated, electromechanical switches) to interrupt the flow of current (see Fig. 11). These switches were also a potential source of x-ray exposure (USCG, 1999). These switches were primarily located in the antenna coupler space. However in the AN/FPN-45 configuration, two relay assemblies are located at the far end of the transmitter near the antenna and antenna counterpoise terminals. In figure 12, the antenna coupler cabinet door was modified by cutting out the aluminum center, and installing Plexiglas in its place. This cabinet modification resulted in increased x-ray exposure outside the cabinet, but allowed for visual monitoring of vacuum switch operation. Vacuum switches had neon bulbs attached in order to detect RF to aid troubleshooting emergencies such as an antenna coupler failure.

A separate room housing the antenna coupler was often used as a plenum for air-cooling the transmitters, and dummy load. The area was also used for storage, and the transmitter power amplifier vacuum tube water cooling racks in the AN/FPN-44/B configuration (see Fig. 10). These racks were located at the very back end of the transmitter near the antenna and counterpoise terminals. Unlike the AN/FPN-44/B, the earlier AN/FPN-44 had its cooling rack installed within the transmitter. All AN/FPN-45 transmitters had their six (three for each transmitter) cooling towers located within the transmitters.

Although in later years, the high voltage vacuum relays were labeled with an x-ray warning (see Fig. 13), it is anecdotally reported that due to years of ignoring this concern, many LORAN maintenance personnel did not treat this warning seriously. Investigators have found that x-ray output from these devices is extremely variable and unpredictable (Greenhouse, 1972). Of the 18 relays tested by these investigators, new ones, with notable exceptions were observed to pose less serious x-ray problems than used ones. This was expected, since the surface contacts of the switches usually deteriorate with use.

Fig. 11: Vacuum switches at LORSTA Tok Antenna Coupler Room

Fig. 12: Cooling Rack in AN/FPN-44/B Antenna Coupler Plenum Space

Fig. 13: Vacuum Switch Warning Label

f. Ionizing Radiation Safety Guidance

Both the Department of the Navy and the Food and Drug Administration, which regulates x-ray emissions from television cathode ray tubes with peak operating voltage of approximately 40 kVp use similar control standards:

> Radiation levels shall not exceed 0.5 mrem/hour at five centimeters (two inches) from external surfaces of cabinets or enclosures containing high power vacuum tubes (NAVSEA, 1983 &1991)

USCG policy (USCG, 2006) is to keep x-ray exposures as low as reasonably achievable (ALARA) and to ensure that the authorized limits are not exceeded. The authorized limits for ionizing radiation exposure for USCG LORSTA personnel were promulgated by the Occupational Safety and Health Administration, OSHA (29 CFR 1910.1096):

Table 2: USCG Occupational Radiation Exposure Limits	Rems per calendar quarter
Whole body: Head and trunk; active blood-forming organs; lens of eyes; or gonads	1 ¼
Hands and forearms; feet and ankles	18 ¾
Skin of whole body	7 ½

The USCG does maintain a small radiation personnel dosimeter monitoring program for x-ray technicians at USCG medical clinics (USCG, 2006). This medical clinic dosimeter program reflects a civilian standard of practice, where the x-ray fields are more penetrating (typically 100 kVp or greater) and USCG technicians on occasion must expose themselves to radiation fields, while holding a patient during imaging. On two occasions (1998 and 1994), the USCG performed radiation personnel dosimetry monitoring for LORSTA personnel. Results of this limited monitoring program (summarized in section 3 of this report) demonstrated minimal occupational radiation exposure of LORSTA personnel, well within Table 2's limits and presumably was the rationale for not establishing a USCG LORSTA personnel radiation dosimeter program. Unfortunately, this limited personnel monitoring program did not address the case of an exceptional individual, who may have performed maintenance activities near energized high voltage vacuum tubes that could result in exceptional radiation exposures.

g. Ionizing Radiation Units

There are many ionizing radiation units. However, only a limited number of the units are used within this report. US occupational exposure limits use historical radiation units (e.g. roentgen, rad, rem), while the rest of the world uses an international system (SI) of units (coulomb/kilo-gram, gray, seivert) – see Conversion Table in the beginning of this report. For purposes of radiation protection, the units of R, rad, and rem are often used interchangeably, as evidenced by how measurements were reported in section 3 of this report. However, for purposes of radiation risk assessment and estimation of probability of causation, the biological effectiveness of x-rays is assumed to be substantially higher than the biological effectiveness of higher-energy gamma rays (see section 6.b of this report). Definitions of ionizing radiation units cited in this report follow:

- **roentgen (R):** The roentgen is the term used to describe radiation exposure. This term describes the amount of ionization in air. This is the unit that ion chambers measure. For x-ray exposure, this unit may be converted to rad, via a multiplicative factor of 0.876 (1R = 0.876 rad in air). For performing x-ray dose reconstructions, the conservative assumption is made that R = rad, which is in the veteran's favor for purposes of radiogenic disease compensation. This assumption is also a standard health physics practice. As a consequence, health physicists may also report ion chamber measurements in units of rem or mrem.

- **rad:** Rad is the term used to describe radiation dose. It describes a specific amount of energy absorbed in a medium (human tissue, for example).

- **rem:** Rem is the term used to describe equivalent or effective radiation dose. It is a unit that is the product of energy absorbed in human tissues and the quality of the radiation being absorbed (the ability of the radiation to cause damage). For radiation safety purposes, the quality of the radiation (e.g. the x-ray photon) is nominally defined as 1, and consequently, rad = rem. This is the unit used to report thermoluminescent dosimetry measurements.

Throughout this report, radiation units may be preceded by the prefix milli (m). This prefix divides a unit by a 1,000 and minimizes the use of lengthy decimal nomenclature (e.g. 0.0035 rem vs. 3.5 mrem).

2. Occupational Risk

Ionizing radiation emissions from high power vacuum tubes are but one of the known occupational hazards associated with USCG LORSTA operation. For example, the safety sheet insert for USCG LORSTA PA tubes (Varian, 1980 & 1993) lists the following hazards, if appropriate safety standards are not maintained:

- HIGH VOLTAGE – Normal operating voltages could result in lethal electrocution.
- RF RADIATION – Exposure to radiofrequency (RF) non-ionizing radiation may cause bodily injury (e.g. burns) under exceptional circumstances. Cardiac pace makers may be affected. Note, this was primarily a risk while in close proximity to the antenna and antenna coupler area during active signal transmission (Also see, Gailey, 1987).
- X-RAY RADIATION – High voltage tubes can produce x-rays.
- RADIOACTIVE CONTAMINATION – Small quantities of radioactive material were an internal component of vacuum tubes that became a potential inhalation/ingestion risk if the tube was broken. Note, AN/FPN-44 and AN/FPN-45 transmitters used OA2WA tubes (NSN: 5960-00-03-4880) containing Cobalt 60 or Nickel 63, and JAN4651WA tubes (NSN: 5960-00-262-0286) containing Krypton 85, Radium 226, or Nickel 63.
- BERYLLIUM OXIDE POISONING – Dust or fumes from BeO ceramics used as thermal links with some conduction cooled power tubes are highly toxic.
- GLASS EXPLOSION – Many electron tubes have glass envelopes. Breaking the glass can cause an implosion, which will result in explosive scattering of glass particles.
- HOT WATER – Water used to cool tubes can reach scalding temperatures. Touching or rupture of the cooling system can cause serious burns.
- HOT SURFACES – Surfaces of air-cooled radiators and other parts of tubes can reach temperatures of several hundred degrees centigrade and cause serious burns if touched.

As in most industrial facilities other potential hazards also existed at USCG LORSTAs:

- POLYCHLORINATED BIPHENYLS (PCBs) – a probable human carcinogen. The large electrical capacitors contained PCBs. There are anecdotal reports of personnel contamination events during capacitor fires or capacitor replacement.
- CARBON TETRACHLORIDE – a probable human carcinogen. It was used as a facility solvent and cleaning agent.
- TRICHLORETHYLENE – a probable human carcinogen. It replaced carbon tetrachloride as a solvent and cleaning agent.
- ASBESTOS – a known carcinogen. It was used to insulate steam pipes in facilities, including berthing areas.
- AGENT ORANGE – an experimental carcinogen and teratogen. May be harmful by skin contact. It was used as a defoliate in fields surrounding the transmitting antennas.
- FALLING - A rather unique hazard associated with LORAN stations was the possibility of falling while conducting a climbing inspection tour of the 625 or 1350 ft transmitting antenna towers. To put this in perspective, the Washington Monument in D.C. (550 ft in height) is 70 feet shorter than a typical LORAN-C station tower.

In summary, operating USCG LORSTAs had numerous known personnel hazards, but safe operation was typical, if appropriate training, safe guards, and oversight were exercised.

3. Radiation Measurements

a. Measurement Chronology

Ionizing radiation measurements were made with various thin-window, radiofrequency (RF) shielded ion chambers, radiographic film, and solid-state, integrating thermoluminescent and optically stimulated luminescent dosimeters between 1982 and 2011. A chronological summary of available measurements follows:

- Aug 1982 – USCG Environmental Health Officer (EHO), Pacific Area (J.M. Johnson) and CAPT M. Seales, USPHS health physicist investigate PA tube x-ray exposures at LORSTA Middletown AN/FPN-45 transmitter. LORSTA Middletown was chosen due to its convenient location (California), and since it was representative of other LORSTAs. Measurements were made with CAPT Seales' ion chamber. Reported maximum intensity was 2.5-3.0 mrem/h on contact on the outer glass window of PA electrical equipment cabinet. The intensity dropped off rapidly to an undetectable level at 1 ft. from the cabinet surface.
  - Although these measurements exceeded USCG radiation safety guidance (NAVSEA, 1983), it was concluded that personnel exposure would not meet the threshold for initiating a personnel radiation dosimetry program, since USCG personnel would rarely be in the physical location to receive this exposure, and that USCG LORSTA staff were not at health hazard, with one possible exception. The one possible exception cited was for a staff member to be in close proximity to an energized PA tube with the glass window of the electrical equipment cabinet open. To evaluate this practice, the EHO proposed follow-up measurements. The EHO also noted that due to the low penetrating power of the PA tube x-rays, exposure to lens of eye is a potential concern – if the staff member is not wearing glasses or corrective lenses (EHO, 31 Aug 1982).
- Nov 1982 - USCG EHO, Pacific Area (J.M. Johnson) and CAPT M. Seales, USPHS health physicist performed a follow-up visit to the LORSTA Middletown AN/FPN-45 transmitter. The EHO noted that for staff individuals to receive significant PA tube x-ray exposure they would have to circumvent the electrical equipment cabinet interlock system, which would also engender the possibility of fatal electrical shock or severe skin burns. The EHO received anecdotal information that individuals had in fact circumvented the interlocks to perform emergent transmitter repairs, check for electrical arcing, or to make bias under-voltage adjustments. Other possible justifications proposed for opening the cabinet window were to insert a high voltage probe connected to an external oscilloscope. However, senior staff at LORSTA Middletown also stated that there was no appropriate justification for performing this open window procedure. Repairs on a "cold" transmitter take longer, due to the time required to turn off the unit to enter the cabinet, and then turn it on again, upon exiting the cabinet. The staff related a notch can easily be made in the window frame to allow for insertion of the high voltage probe. CAPT Seale measured 16 mrem/hr (with an open window) at about 1 foot from the surface of the cabinet. The EHO recommended that his chain of command institute a policy of specifically forbidding circumvention of the cabinet interlock system.
- Jun 1987 – USPHS, FDA-CDRH performed a radiological survey using films and thermoluminscent dosimeters (TLDs) on the outside of the electrical equipment cabinet

containing the energized PA tubes at LORSTAs in the Far East section and Dana, IN. TLDs were kept in place for a week, and then processed. Highest readings varied from 3 – 8 mR/h. Based on these results, the USCG leadership determined that a LORSTA personnel dosimetry program be implemented

- Dec 1987 – USCG Commandant (G-KOM-4) requests the Naval Dosimetry Center in Bethesda, MD provide personal dosimeters to six LORSTAs – Dana, George, Gesashi, Hokkaido, Iwo Jima, and Marcus. Dosimeter issue periods run from Feb/Mar – Sep/Nov of 1988. Results are tabulated in Table 3 of this report.
- Dec 1988 – USCG Commandant (G-KOM-4) notes that the LORSTA personnel dosimetry monitoring program reported no significant personnel radiation doses, and consequently, the program was discontinued.
- Jun 1993 – Ion chamber measurements of x-rays emanating from PA tubes at LORSTA George produce health concerns of onsite staff.
- Nov 1993 – Officer in Charge (OIC) LORSTA George requests occupational medical monitoring be instituted. The OIC notes dose rates of 5 mrem/h, which exceed the applicable NAVSEA safety standard of 2.5 mrem/h (NAVSEA, 1983). Based on this request, the USCG leadership restarts a LORAN-C personnel radiation dosimetry program. Results are tabulated in Table 3 of this report.
- Dec 1993 – CAPT Bill Van Pelt, USPHS, Health Physicist, FDA Pacific Region summarized the results of his December 2, 1993 radiation survey of LORSTA George to USCG leadership in a memo (Van Pelt, 1993):
    - The transmitter area consists of two transmitters located on either side of an approximately 30 foot long, 5 foot wide hallway. On either side of the hallway, the first 10 feet or so are taken up by controls and high voltage supplies. The last 20 feet are taken up by the power section containing vacuum tubes… The walls and access doors of the hallway consist of approximately 1/8" aluminum. The power section is accessible from the hallway through 36" x 36" panel doors with 28" x 35" x 1/8" glass panel inserts. There are seven of these doors per side (plus two smaller doors apparently housing non-PA tubes). …The tubes are centered about 2.5' above the deck, partially behind the glass and partially behind the aluminum door.
    - Ion chamber (Victoreen 440 RF/C) readings approximately one inch from the outer door panel ranged from 6 mR/h at the level of the center of the tube to less than 0.2 mR/h at the level of the deck or at the top of the access panel door. CAPT Van Pelt demonstrated that by placing a 7 mm thick piece of acrylic lead shielding (Clear-Pb) in front of his ion chamber at the highest point of radiation exposure that he was able to reduce the measured radiation level to zero. He recommended that radiation shielding be considered for installation at LORSTA PA spaces.
- Mar 1994 – Dennis Swartz, Radiological Health Expert, FDA Midwest Region performed a radiation survey of LORSTA Dana (Kraeger, 1994). He was assisted by ETC Jeffrey W. Hall, USCG, OIC, LORSTA Dana. Measurements were taken by an ion chamber (Victoreen 440 RF/D) – see Table 4. Mr. Swartz noted that it was unlikely personnel would spend more than a few minutes of operation time within inches of the energized PA outer door panel (e.g. reading gauges). At the center of the passageway, maximum radiation exposure (at tube height) was 1.8 mR/h. ETC Hall estimated annual

maintenance man-hours in the PA tube hallway were 865 h – shared by three technicians. Mr. Swartz also recommended shielding installation.

- Oct 1994 – Chief Warrant Officer M. Jones visited LORSTA George. While performing ion chamber measurements, he concluded that the age of the PA tube (new or rebuilt) had no effect on output from the tube. A prototype Clear-Pb shield had been installed around a PA tube, and no detectable radiation was measured outside of the shield. He also notes the prototype shields were remarkably easy to install and remove.
- May 1995 – USCG signs contract with Clear-Pb manufacturer (Nuclear Associates, Carle Place, NY) with a 4 month delivery date (Sep 1995) for 120 shields. Shields are to be shipped directly to affected LORSTAs.
- Apr 1996 – Ms. Lynn Jenkins performs a follow-up ion chamber (Victoreen 440 RF/D) radiation survey of LORSTA Dana (Swartz, 1996). She remeasures the previous locations noted in Table 4 (Kraeger, 1994) and finds no detectable radiation, and concludes that the installed Clear-Pb shielding is effective.
- Oct 1999 – Radiation survey of LORSTA Shoal Cove documents 1.2 rem/h emanating from high voltage vacuum tube switches located in antenna coupler area (USCG, 1999). The report recommends:
    - Rear of coupler unit should be posted as a "High Radiation Area",
    - Restrictions on time on personnel working in this area, and
    - Installation of radiation shielding.
- Mar 2003 – Richard Tell Associates, Inc. performed an RF and x-ray survey of the Canadian Coast Guard LORAN-C station at Williams Lake, British Columbia (Tell, 2003). This station is similar in layout and equipage to U.S. LORSTAs and reported radiation exposures external to equipment cabinets of similar intensities. However, this survey did contain some unique radiation measurements inside the transmitter tube electrical equipment cabinets, in very close proximity to the PA tubes. Reported measurements of this very soft x-ray field varied from approximately 673 – 3,225 mR/h.
- Nov 2008 and Apr 2009 – CDR Luis Benevides, USN, Science Advisor, Naval Dosimetry Center, Bethesda, MD performs a radiation survey of LORAN Support Unit, Wildwood, NJ using Navy DT-702/PD personnel radiation dosimeters and an ion chamber with associated electrometer. Upon removing the Clear-Pb shielding, he verifies previously reported radiation exposure values outside the PA cabinets. However, he also takes measurements inside the Clear-Pb shielding. Maximum radiation dose rates directly in front of the PA tube are:
    - Hs: 3.05 rem/h and Hd: 0.500 rem/h – indicating a soft x-ray source.

  These measurements inside the Clear-Pb shielding are consistent with Landauer, Inc. optically simulated luminescent (OSL) measurements performed at the Canadian operated LORSTA Williams Lake (Tell, 2003).
- Oct 2009 – Rapiscan Systems Inc. performed a follow-on x-ray survey of the Canadian Coast Guard LORSTA at Williams Lake (Gray, 2009). Similar to U.S. LORSTAs, initial PA tube x-ray shielding was installed in 1995. Sometime in 2008, a second layer of shielding was installed, and this extensive survey (external to electrical equipment cabinet, 7 rows by 10 columns of 12" x 12" squares were measured), replicated the three shielding stages (no shielding, one layer, and two layers). A total of 210 consistent measurements.

- Mar 2011 – Paul Blake and LCDR Burke, USN (DTRA), LCDR Hall, USCG (CG Logistics, Baltimore), ETCM Severance, USCG (retired) perform a radiation survey of LORAN Support Unit (LSU), Wildwood, NJ to verify radiation exposure levels emanating from high voltage vacuum relays. A rebuilt power amplifier vacuum tube was examined for evidence of electron etching supporting concerns of concentrated beams or increased radiation levels from older or rebuilt power grid vacuum tubes. Significant electron etching was found on the rebuilt tube anode, while none was found on a newly manufactured tube of similar operational hours. During the visit quiescent voltages of the power amplifiers were measured and meter circuits were calibrated so that accurate anode voltages could be measured using an oscilloscope and high voltage probe. The test indicated that anode voltages exceeded anode power supply voltages at peak half cycles by nearly 2 KV reflecting induced voltages from the power amplifier tuned circuit. Any increases in anode supply voltage not only increase radiation intensity but also increase the parasitic X-ray energy levels. Increases in anode voltages due to transmitter output network tuning or power amplifier balancing are exceptional maintenance scenarios that increase the risk of ionizing radiation exposure. The LSU was disestablished a few days after the survey (COGARD LSU, 2011).

b. Personnel Measurements

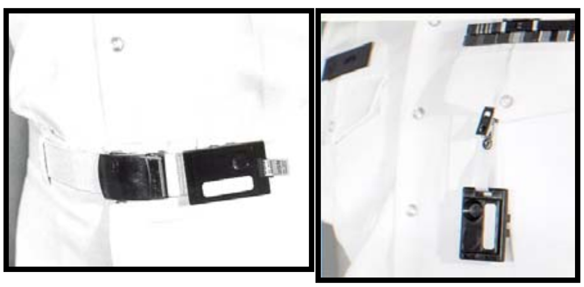

Fig. 14: DT-648/PD worn on belt or attached to pocket

Fig. 15: DT-648/PD open holder with card inside

In December 1987, USCG Chief, Environmental Health and Occupational Medicine (G-KOM-4) initiated a personnel radiation dosimetry program at six LORSTAs: Dana, George, Gesashi, Hokkaido, Iwo Jima, and Marcus. The Naval Dosimetry Center, located at Bethesda, MD provided DT-648/PD personnel radiation dosimeters on a six week issue period to the USCG LORSTAs. This naval dosimeter was capable of monitoring x-ray, gamma, neutron, and beta radiation (Devine, 1990). It was comprised of four LiF:Mg,Ti elements capable of measuring low energy photons and reporting both a shallow dose (the dose at a tissue depth of 0.007 cm (7 mg/cm^2) and deep dose (the dose at a tissue depth of 1cm (1,000 mg/cm^2) – see Figs. 14 and 15. This dosimeter was accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) under the low energy photon category, and consequently was capable of measuring LORSTA x-ray radiation dose to both personnel and fixed point area monitors (NVLAP, 2010).

As shown in table 3, the annual mean dose for monitored USCG LORSTA personnel was 0.005 rem. Reported values for the 1988 exposure period were in shallow dose, and for the 1994 period were in deep dose.

Table 3: USCG Loran Station DT-648/PD Radiation Dosimetry Records								
	Exposure Periods		Unique Individuals		Mean - Rad. Dose (rem)		Weighted Mean Dose (rem)	
Station	**1988**	**1994**	**Personnel**	**Area Monitors**	**Personnel**	**Area Monitors**	**Personnel**	**Area Monitors**
Kodiak	N/A	07-08	5	6	0.000	0.295	0.000	0.066
Dana	03-11	N/A	9	0	0.001	N/A	0.009	N/A
Middletown	N/A	03-07	22	4	0.000	0.525	0.000	2.100
George	03-10	07-09	13	4	0.000	1.059	0.000	4.236
Iwo Jima	08-09	N/A	9	1	0.003	0.200	0.027	0.200
Hokkaido	04-09	N/A	11	2	0.001	0.000	0.011	0.000
Marcus	05-10	N/A	11	0	0.000	N/A	0.000	N/A
Gesashi	02-10	N/A	8	2	0.000	1.722	0.000	3.444
Tok	N/A	07-08	7	4	0.000	0.529	0.000	2.116
Attu	N/A	07-08	10	4	0.001	0.259	0.010	1.036
			105	**27**		**Weighted Mean:**	**0.001**	**0.489**
						Annual Weighted Mean:	**0.005**	**4.236**

Four individuals had detectable radiation exposure (less than 5% of monitored personnel). The highest personnel dose over a six week issue period was 0.038 rem. This was a shallow dose measurement, and presumably the corresponding deep dose would be smaller. This extrapolates to a 0.082 rem/quarter or 0.329 rem/year – and well within the whole body, occupational radiation exposure limit of 1.250 rem/quarter (29 CFR 1910.1096).

The USCG LORSTA DT-648/PD dosimetry results also include area monitor results. In the case of area monitors, personnel dosimeters are mounted in a fixed location during a dosimeter issue period. Area monitor data is more difficult to interpret, since distance and shielding between the radiation source and area monitor are required for interpretation. This information was not available for analysis, and consequently no significant conclusions may be drawn from this DT-648/PD area monitor data.

c. Field Measurements

As noted in section 3.a, measurements of ionizing radiation fields were taken by a number of surveyors, at a number of LORSTAs, with a variety of radiation detectors, from 1982 through 2011. Some of these measurements were made at single points, and others attempted areal measurements. Areal measurements were taken to address:

- radiation field gradients: In relatively “uniform” radiation fields, radiation intensities gradually drop off with distance from some maximum exposure point, and
- hot spots: “Non-uniform” radiation fields may result from “holes” in radiation shielding. In the case of electrical cabinet walls, which serve as radiation shielding for high voltage vacuum tubes, holes may have arisen at LORSTAs to allow for visual observation of a component or to allow an instrument (e.g. high voltage probe) access.

Most early measurements were reported as point measurements around the power amplifying vacuum tubes. (e.g. CAPT Seales’ measurement of 2.5-3.0 mrem/h in August 1982). The only reported measurements of radiation from high voltage vacuum tube relays (switches) occurred in 1999 and 2011.

The first documented areal measurements (by ion chamber) occurred in March 1994 – see table 4. It was typical to identify the four high voltage vacuum tubes in a transmitter unit, as V1, V2, V3, and V4. Based on data reported in table 4 and CAPT Van Pelt’s description of his radiation survey in December 1993, one can generally state that the maximum

Fig. 16: Tube ID’s on exterior of PA electrical equipment cabinet

radiation intensity at 0.5 cm from the outside of the electrical cabinet housing four energized high power amplifying vacuum tubes was at a height of approximately 34" and this radiation intensity gradually decreased to less than 1 mR/h at the level of the deck or the top of the access panel door.

Table 4: LORSTA, Dana Radiation Survey Results (March 1994) **Ion chamber measurements taken <u>outside PA cabinet</u> at heights from floor noted below and 0.5 cm from outer door panel (Clear-Pb shielding not in place)**				
Transmitter 19:				
Tube:	V1	V2	V3	V4
61"	0.1 mR/h	0.2 mR/h	0.5 mR/h	1.2 mR/h
40"	1.4 mR/h	1.0 mR/h	3.0 mR/h	2.1 mR/h
34"	4.4 mR/h	3.2 mR/h	7.9 mR/h	6.4 mR/h
Transmitter 20:				
Tube:	V1	V2	V3	V4
61"	1.8 mR/h	4.5 mR/h	2.1 mR/h	3.4 mR/h
40"	4.0 mR/h	5.6 mR/h	5.1 mR/h	5.5 mR/h
34"	9.0 mR/h	12.5 mR/h	11.5 mR/h	11.5 mR/h

The next set of areal measurements (by a Navy DT-702/PD thermoluminscent dosimeter) was performed by CDR Benevides in November 2008. He obtained measurements, without the Clear-Pb shielding in place, both within the PA electrical equipment cabinet (see Table 5) and also outside the cabinet (see Table 6).

Table 5: LORSTA Wildwood Radiation Survey Results (Nov 2008) **DT-702 measurements taken <u>inside PA cabinet</u> at heights from floor noted below and 0.5 cm from outer door panel (Clear-Pb shielding not in place)**	
Height from Floor	Measurement
45"	248 ± 206 mR/h
35.5"	26.5 ± 4.8 mR/h
28"	18.7 ± 4.3 mR/h
23"	10.4 ± 2.4 mR/h

It is interesting to note that the maximum radiation intensity at LORSTA Wildwood is located at 45" in height above the floor, while at LORSTA Dana the maximum intensity occurred at 34".

Table 6: LORSTA Wildwood Radiation Survey Results (Nov 2008) **DT-702 measurements taken <u>outside PA cabinet</u> at 36" in height from the floor (Clear-Pb shielding not in place)**	
Distance from Cabinet	Measurement
0.5"	3.1 mR/h
15"	1.2 mR/h
24"	0.8 mR/h
32"	0.5 mR/h

The DT-702/PD radiation dosimeter is an upgraded version of the Naval Dosimetry Center's previous radiation dosimeter (the DT-648/PD). The DT-702 was introduced to improve beta particle determinations, as required by the national radiation dosimetry test standard (ANSI N13.11). It was comprised of four LiF:Mg,Cu,P elements capable of measuring low energy photons and reporting both a shallow dose (the dose at a tissue depth of 0.007 cm (7 mg/cm2) and deep dose (the dose at a tissue depth of 1cm (1,000 mg/cm2) – see Fig. 17. This dosimeter was also accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) under the low energy photon category, and consequently was capable of accurately measuring LORSTA x-ray radiation fields (NVLAP, 2010). The Benevides 2008 measurements were verified by Blake et al. in 2011 using a calibrated hand-held survey instrument shown in Fig. 18.

Fig. 17: DT-702/PD card in open holder

Fig. 18: Survey of PA Cabinet

4. <u>Radiation Depth Dose Analysis</u>

a. Introduction

As discussed in the previous sections of this report, the x-ray spectra emanating from LORSTA high voltage vacuum tubes is typically described as a "soft" spectra, where the lower energy photon component may be readily attenuated by a variety of materials before striking a USCG service member. There are also potential LORSTA scenarios where a relatively unfiltered x-ray spectra could strike a service member and a significant part of the radiation field would be absorbed by the veteran's skin and not reach internal bodily organs. For these reasons, it is useful to a mathematically quantify these effects as input to radiation dose reconstructions for USCG LORSTA veterans. The well-know linear attenuation equation for radiation is:

(2) $$I/I_0 = Be^{-ux}$$

where:

I/I_0 is the number of transmitted photons/number of photons without absorber
B is the buildup factor, which accounts for scattered radiations that are rescattered toward location of interest
μ is the linear attenuation coefficient in cm^{-1}
X is the absorber thickness in cm

While μ values are readily derived from tables of mass attenuation coefficients and material density, deriving low energy photon buildup factors is more problematic, since buildup is both a function of the attenuation coefficient μ, itself a function of photon energy, and distance from the source of radiation. In recent years, low energy photon attenuation determinations have been facilitated through widely available probabilistic computational codes.

b. Depth Dose Curves

A variety of radiation transport codes exist that may model the unfiltered or filtered high voltage vacuum tube x-ray spectra transmission through the human body. Graphed data of this type is widely known as "depth dose curves." The most widely used transport code for medical applications is Geant4, a toolkit for the simulation of the passage of particles through matter (Geant4, 2011). Geant4 is an open code developed by over 90 collaborators, distributed via the web for local workstation use, and cited in over 2,000 peer-review publications.

In the three displayed depth dose curves that follow, millions of x-ray spectra photons were simulated to transit various materials (e.g. specified glass window filter and/or human tissue). This "Monte Carlo" simulation is based on the physics of x-ray photon interactions and material cross sections, and appropriately accounts for "buildup." The results of this simulation are graphed at <u>three unique depths (skin at 0.007 cm, lens of the eye at 0.3 cm, and other organs at 1 cm)</u> in the resulting figures:

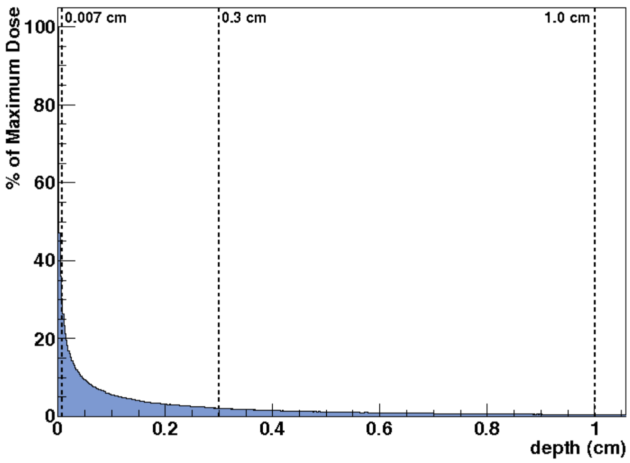

Fig. 19 Depth dose (0-100%) of an unfiltered 21.5 kVp spectra in tissue

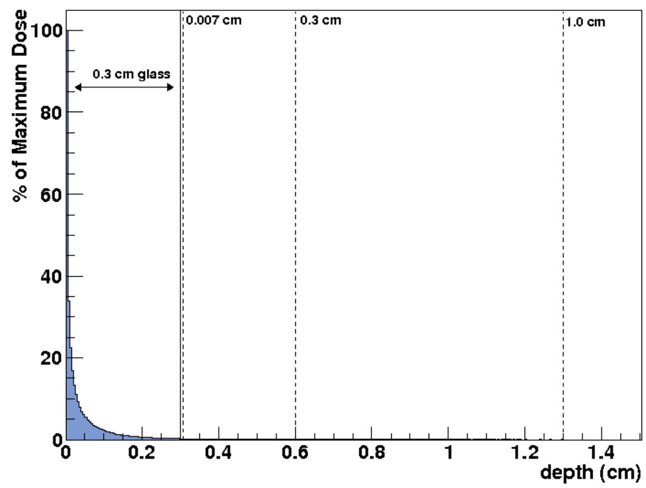

Fig. 20: Depth dose (0-100%) of a 0.3 cm glass window filtered 21.5 kVp spectra in tissue

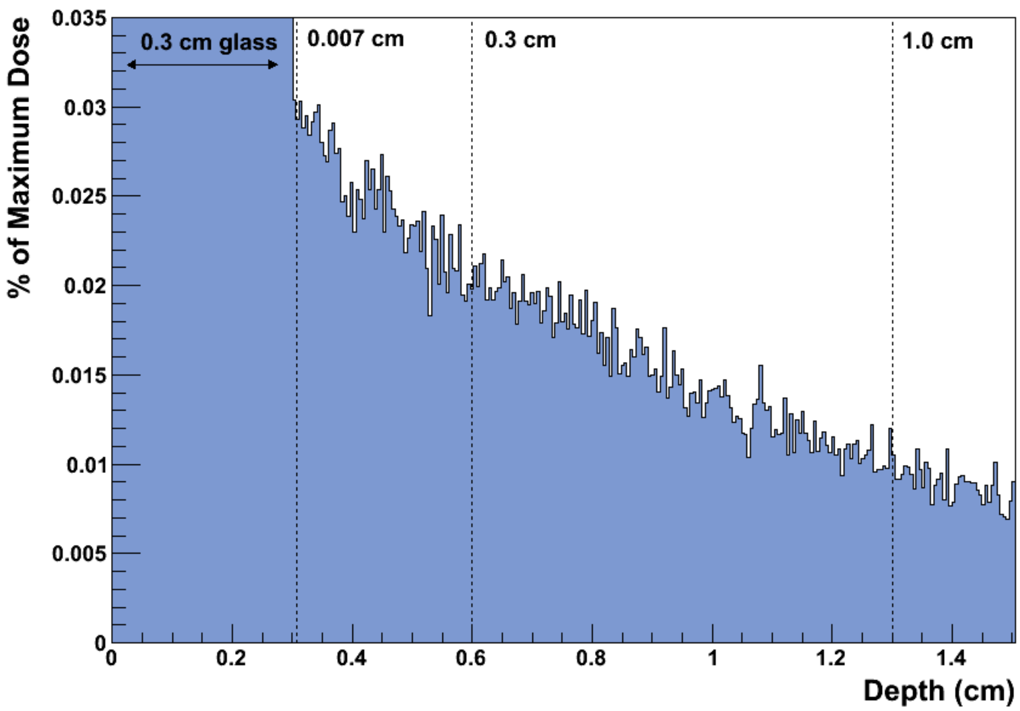

Fig. 21: Depth dose (0 – 0.03%) of a 0.3 cm glass window filtered 21.5 kVp spectra in tissue

Figures 19, 20, and 21 were produced through 10 million photon history histogram simulations (Kramer, 2011). To reproduce the LORSTA PA tube 21.5 kVp x-ray spectrum for a Monte Carlo simulation, a probability distribution was created to translate a random number from a uniform distribution to the relative intensity spectrum desired. The function used for doing this was:

(3) $$E_\gamma = V_p \left(1 - \sqrt{1-\eta}\right)$$

where:

E_γ is the randomly chosen photon energy weighted by the desired photon spectrum
V_p is the peak energy of the photon spectrum in keV
η is a random number chosen in a flat distribution from 0 to 1.

Figures 19-21 demonstrate two significant points in comparing the filtered and unfiltered spectra:

- The glass (or aluminum) cabinet wall will reduce the x-ray spectra radiation intensity by approximately three orders of magnitude (0.03%). This is consistent with ion chamber measurements performed 0.5 cm from the outer door panel of an operating PA cabinet where radiation measurements of a few rem/h (Benevides, 2008) had been attenuated to a few mR/h (Kraeger, 1994).

- There is a significant difference between the depth dose from an unfiltered and filtered spectra. This is expected. For the same source intensity, the skin dose from an unfiltered spectrum would be higher than the skin dose from a filtered spectrum. The filter preferentially removes the lower energy "softer" x-rays, and the resulting "harder" x-ray spectra is more homogeneous. This difference is quantified in Table 7:

Table 7: LORSTA Fractional Transmission Factors

Organ	Fig. 19-Unfiltered Spectra (Open Cabinet Scenario)	Fig. 21-Filtered Spectra (Closed Cabinet Scenario)
Skin	1.00	1.00
Lens of the Eye	0.06	0.72
Other Organs	0.01	0.40

5. <u>Radiation Dose Reconstruction and Associated Uncertainty</u>

a. Exposure Scenarios

Principles and practices of personnel radiation dose reconstruction are well documented (NCRP, 2009). The energized high voltage power amplifying (PA) tubes within their electronic cabinets and the high voltage vacuum tube switches were the USCG LORSTA radiation sources of concern. The next step in performing a personal radiation dose reconstruction (when personnel radiation dosimetry monitoring data is not available) is to develop an individualized radiation exposure scenario. To assist veterans in preparing individualized exposure scenarios, two sample exposure scenarios follow:

<u>Scenario No.1: Standard Operating/Maintenance Duties</u>

LORSTA living and eating quarters were separate from the transmitter PA and vacuum tube switch spaces. Exposure only occurred when staff personnel were in or closely adjacent to these spaces. The mostly likely exposure scenarios occurred between 1995 and 2010, during maintenance activities near the energized PA tubes, before acrylic lead shields were installed. The following historical information (provided by two of the co-authors – Hall and Severance) is available:

Typical maintenance personnel staffing (gender: mostly male; especially in earlier years):

- Two E-4's (avg. age: 22 y)
- One E-5 (avg. age: 26 y)
- One E-6 (avg. age: 29 y)
- One E-7 (avg. age: 33 y)

Annual time in proximity to PA tubes:

- Preventive maintenance: 220 h
- Transmitter meter readings: 5 h Note: 5h ~1 min/d*5 d/wk*50 wk
- Tube seasoning/balancing: 96 h
- Corrective maintenance: 56 h
- Total: 377 h (as compared to a typical work year of: 40h/wk*50wk/y = 2000 h)
- Assume worker's range of distance from active PA tube varied from 1-4 ft

Occupational Radiation Dosimetry Results:

- Maximum annual personnel dose was: 0.329 rem/y (see section 3.b, Table 4)

<u>Scenario No. 2: Exceptional Operating/Maintenance Duties</u>

LORAN transmitter maintenance and engineering experts cite anecdotal reports of LORAN technicians performing exceptional operation/maintenance procedures that entailed significant radiation exposures (EHO, 1982, and Severance, 2011). It is not possible to create a standard scenario for universal application for these personnel. The exceptional scenario must be based on specific inputs from individuals. A few examples include but are not limited to:

- Arc-watches over power amplifier vacuum tubes, or high voltage vacuum tube contactor circuits in order to localize arcing.

- Transmitter interlocks bypassed and electrical cabinets opened allowing service members closer proximity to energized tubes exposing service members to unfiltered radiation.
- Corrective or planned maintenance on the Antenna Coupler or Dummy Load exposing personnel to unshielded radiation from high voltage vacuum tube switches.
- Occupation of the transmitter air plenum potentially exposing personnel to unshielded radiation from the Antenna Coupler/Dummy Load high voltage vacuum tube devices.
- Vacuum tube seasoning procedures especially outside the transmitter in locally fabricated vacuum tube racks potentially exposed service members to radiation from tube arcing and anode current.
- Vacuum tube equalized balancing routines within the transmitter during extended periods of exposure dwell time as vacuum tubes are replaced, swapped, and tested under load.
- Power amplifier vacuum tube rebuild-program, resulting in rebuilt tubes emitting higher levels of radiation.
- Removal of leaded glass due to breakage, equipment panel removal, and equipment panel modifications with acrylic glass in areas near high voltage vacuum tubes devices may have increased personnel exposures.
- Corrective maintenance routines involving detuned tank circuit, transmitter loading, parasitic oscillations, etc. resulted in higher anode peak voltages and subsequent higher radiation energy levels.
- Setting water leak, water vane, leakage current, high voltage contactor watch, or any other watches and activities in close proximity to the high voltage vacuum device.
- Maintenance routines in the vicinity of high voltage vacuum tube amplifiers and high voltage vacuum switches when both transmitters are operating at full anode voltage, or drive increased exposures to service members. It was common for both transmitters to be running when working on RF amplification or balancing problems.
- LORAN maintenance, repair, and certification teams from Far East Section Office (FESEC), Activities Europe (ACTEUR), South East Section Office (SEASEC), Philippines Section Office, and other Headquarters, District and Area offices.
- Installation crews and installation teams of LORAN transmitters.
- LORAN transmitter maintenance instructors at USCG Training Centers.
- Engineers and electronic technicians at USCG Engineering Centers (EECEN), Loran Support Unit (LSU).
- LORAN maintenance and repair teams on LORAN US Coast Guard support vessels such as USCGC Kukui (WAK-180) and USCGC Nettle (WAK-169).
- LORAN transmitters that operated during the Cold War, Vietnam War, Korean War, World War II or during special evolutions i.e. nuclear tests, missile launches or NASA space launches demanded extremely high levels of equipment readiness and tolerances. Many LORAN chains operated for military service interests, i.e. Hawaiian Chain for the Pacific Missile Test Range and North West Pacific Chain for the Trident Missile Submarine Fleet, etc. These and other (often classified) operations requiring LORAN timing or navigation dictated extremely high levels of readiness and tolerances that often resulted in extreme maintenance routines.

b. Sources of Uncertainty

The major source of uncertainty in LORSTA veteran radiation dose reconstructions arises from scenario no. 2. We have limited data associated with radiation exposures emanating from the LORSTA high voltage PA tubes and even less exposure data associated with LORSTA vacuum tube switches, and other high voltage vacuum tube devices such as arc suppressors. As described in sections 3.a and 3.c, these measurements varied over time and between individual tubes, and LORSTAs. In particular, as procedures changed, field changes were made, and radiation shielding was installed, radiation exposure scenarios evolved. Sources of uncertainty in terms of radiation exposure include:

- The 3 rem/h dose rate measurement from an unfiltered PA tube reported by CDR Benevides in 2008 resulting from no glass window between the USCG service member and energized PA tube may have differed over time and at different facilities. This is the hypothesized dose rate associated with some of the anecdotal exceptional operation/ maintenance procedures. It is not unreasonable to assume an uncertainty of 2X (or an upper bound of 6 rem/h) for this measurement.
- Duration of individual service member exposures while performing exceptional operation/maintenance procedures is a large source of uncertainty. It is not unreasonable to assume a conservative value while developing a service members' exposure scenario.
- Vacuum tube amplifier arcing - generating a short pulse of intense x-ray exposure. One unique source of arcing was unbalanced parallel amplifiers in push-pull circuits. There are reports in the literature of unanticipated high voltage transients exceeding the standard operating voltage (21.5 kVp) of PA tubes (Hunter, 1990). As noted in eqn. 1, since radiation exposure is a function of voltage squared, this could result in higher radiation exposures than previously measured.
- Vacuum switch and other vacuum tube device arcing - generating a short pulse of intense x-ray exposure.
- Detuned transmitter output circuits going unnoticed and generating increased anode voltages and arcing in power amplifier section.
- Antenna coupler tuning mismatched to antenna causing large variance in radiation exposures between the standby transmitter in dummy load and operate transmitter into antenna.
- Unreliable electromechanical voltage regulators with possibly higher than expected anode and bias voltages. These regulators were replaced by comparably more reliable solid-state regulators in the later years of LORSTA operation.
- Evolving changes in vacuum tube manufactures, vacuum tube types, and vacuum tube rebuild programs, evidenced by the Mean Time Between Failure (MTBF) of older transmitters, and operational commitments of transmitters operated before 1995 requiring considerably more maintenance time resulting in increased exposure time.
- High cost vacuum tubes such as the power amplifiers were often operated using unconventional methods to extend their life in order to save operating expenses. Older tubes inherently generating non-uniform and potentially increased radiation exposure, as do many rebuilt tubes. The power amplifier rebuild program was so successful that the manufacturer could no longer build new tubes at a reasonable price so the cost increased from $1,600 to nearly $8,000. This effect reinforced the use of rebuilt vacuum tubes that could be purchased for $3,000.

In summary, unanticipated high voltage transients would most likely have occurred as high voltage vacuum tubes were nearing their end of their lifetimes. This is also when electrical arcing problems may have surfaced, and therefore was also when the service members may have performed exceptional operating/maintenance duties. Arc watch procedures in particular could last for hours, with the technician's face against the glass window watching for arcs, or in rare cases, observing with an open window.

6. Radiogenic Disease Compensation

a. Radiogenic Disease

Disease arising from exposure to ionizing radiation (radiogenic disease) is typically described by one of two exposure scenarios:

1. Deterministic: characterized by acute exposures of 200 rad or greater, and typically manifesting acute radiation syndrome (ARS) symptoms from whole body irradiations of nausea, vomiting, headache, erythema, fatigue, epilation, and conjunctival reddening. During the history of USCG LORSTA operation, there have been no known reports of ARS. This fact establishes an upper bound on USCG LORSTA personnel radiation doses. There is at least one case where U.S. military members received high voltage, vacuum tube exposures that resulted in ARS. This occurred in March 1960 at a military installation in Lockport, New York from an unshielded klystron tube (UNSCEAR, 2008).
2. Stochastic: characterized by non-acute exposures that may result in disease (e.g. cancer). Radiogenic disease latency periods (time between radiation exposure and diagnosis of disease) can vary between a few years for disease such as leukemia to decades for solid tumors.

USCG veterans are eligible for Department of Veterans Affairs (VA) medical care and compensation due to health impairment resulting from their active duty. VA active duty determinations for reservists performing ADT (active duty training) versus IDT (inactive duty training) are beyond the scope of this report. Radiogenic disease resulting from active duty occupational radiation exposure is a recognized health impairment that can arise in veterans' post-active duty service, due to radiogenic disease latency periods.

Unfortunately, there are no unique biological markers that can distinguish between occupational radiation exposure and background radiation exposure (e.g. from natural sources or medical procedures). However, it is possible to calculate the risk or odds (probability) of developing radiogenic disease. The Health Physics Society provides a useful introductory table (HPS, 2011):

Table 8: Radiogenic Disease Summary		
	No. of Cancers that occur over a lifetime in a population of 1 million people	**Odds of cancer (natural occurrence)**
Cancer Baseline	420,000*	1 in 2.4
Possible increase in cancer incidence caused by exposure to radiation above the naturally occurring background		
Dose	**No. of Cancers if 1 million people receive that dose over a lifetime**	**Combined odds of cancers (natural occurrence + additional risk from radiation dose****
1 rem	421,700	1 in 2.4
10 rem	437,000	1 in 2.3
100 rem	590,000	1 in 1.7
1,000 rem	A person would die before cancer could occur	

*: Average male + female lifetime incidence (http://srab.cancer.gov/devcan) **: Adapted from ICRP 2007, Appendix A, Table A14

Since it is often possible to estimate tissue-specific radiation doses with reasonable precision, the relationship between dose and subsequent cancer risk is probably better quantified than for any other common environmental carcinogen. The VA (38 CFR 3.3.11b) recognizes 24 nonpre-sumptive radiogenic diseases – see Appendix 3. An unlisted disease may be considered provided the claimant has cited competent scientific or medical evidence that the claimed condition is a radiogenic disease.

b. Illustrative Examples

For the VA to connect the veteran's radiogenic disease to active duty occupational radiation exposure, a number of inputs are required, including: clinical documentation of the disease, date of the disease diagnosis, veteran's sex (male or female), date of birth, radiation dose to the tissue of disease origin and associated periods of exposure during active service. These inputs are required for input into the Interactive Radioepidemiological Program (IREP) of the National Institute for Occupational Safety and Health (NIOSH), which is used by VA in adjudicating radiogenic disease claims (IREP, 2010). The VA uses IREP software, and in some cases, a review of the medical literature to develop a medical opinion, as to whether it is likely, unlikely, or as likely as not that the claimed disease is the result of exposure to ionizing radiation.

Typically, VA requests the military service to provide the veterans' radiation dosimetry records. These records are maintained in two locations, in the veterans health record, on the DD Form 1141, "Record of Occupational Exposure to Ionizing Radiation" and in centralized military service repositories. However, since few of the USCG LORSTA service members were monitored for radiation exposure, a radiation dose reconstruction must, instead, be submitted. This reconstruction will be an estimate of the veteran's radiation exposure, based on estimates of time, distance, and shielding of the veteran's proximity to operating LORSTA high voltage vacuum tubes. Although these dose reconstructions should be conservative, providing the veteran benefit of the doubt in undocumented conditions, they should also take into account the known USCG personnel dosimetry results documented in table 3 of this report.

As was discussed in section 4, LORSTA high voltage vacuum tubes produced low energy x-ray fields (e.g. photons E<30 keV). IREP incorporates an assumption that low energy x-rays are about twice as effective as high energy gamma rays (e.g. photons E>250 keV) in inducing cancer under the same conditions of exposure (Kocher, 2008). Specifically, IREP probability distributions for low energy x-rays at the 95% credibility level result in a radiation effectiveness factor, which represents their biological effectiveness, ranging from 1.1 to 6.1, with a median value of 2.4. This is reflected in the following examples:

Example 1 (Ref: Sect. 5.a, Scenario 1): An ET2 (E-5), male service member (born: 1939) performed engineering support at a USCG LORSTA from 1965-1968. He separated from the U.S. Coast Guard in 1968. In 2009, he was diagnosed with prostate cancer. In 2010, he filed a VA claim for service connection. Upon review of his historical duties, it was determined that no "exceptional" maintenance activities occurred during his LORSTA service. Therefore, the exposure scenario discussed in section 5.a of this report was assumed: 377 h in proximity to PA tubes. Assumed prostate exposure rate was 1 mrem/h. This results in 377 mrad/y (which exceeds the radiation exposures of any of the 105 LORSTA service members who were monitored for radiation exposure – see Table 3). The veteran's NIOSH- IREP, ver. 5.6 manual entry calculation, based on Veterans Health Administration (VHA) guidance (Otchin, 2007) is shown below. Associated website screen shots are captured in Appendix 2:

https://www.niosh-irep.com/irep_niosh/

NIOSH-IREP input (ver. 5.6) manual entry:

- Claimant Name: John Q. Doe
- Gender: Male
- Birth year: 1939
- Year of Diagnosis: 2009
- Cancer Diagnoses: Prostate Cancer
- Cancer ICD-9 code: All Male Genitalia (185-187)
  Note: Malignant neoplasm of prostate is ICD-9 code: 185
- Alternate cancer model run? No
- No. of exposures: 4
- Dose input:
  1: 1965, Constant (0.377 rad), acute exp. rate, photons E<30keV
  2: 1966, Constant (0.377 rad), acute exp. rate, photons E<30keV
  3: 1967, Constant (0.377 rad), acute exp. rate, photons E<30keV
  4: 1968, Constant (0.377 rad), acute exp. rate, photons E<30keV

NIOSH-IREP output:

Probability of Causation (PC) 99th percentile: **4.08%**.

Note: This result is much less than 50%, and the VA medical opinion would probably state it is unlikely that the prostate cancer can be attributed to exposure to ionizing radiation in service. The acute exp. rate option is veteran friendly, and its use is indicated in VHA guidance. Similarly, it is VHA guidance to enter conservative dose estimates, using the "Constant" option.

If this veteran had been diagnosed with acute myeloid leukemia (AML), keeping all other factors the same, the resulting PC 99th percentile: **10.89%**.

If this veteran had been diagnosed with a basal cell carcinoma (BCC) skin cancer, assuming an ethnic origin of white, non-hispanic, and keeping all other factors the same, the resulting PC 99th percentile: **15.94%**.

If this veteran had been diagnosed with posterior subcapsular cataract of the eye, an IREP calculation could not be performed, since IREP does not currently calculate a PC for this potential radiogenic disease. Instead, a medical opinion would be drafted, based on a review of the peer-review literature.

Example 2 (Ref: Sect. 5.a, Scenario 2): An ETC (E-7), male service member (born: 1932) performed supervisory engineering support at a USCG LORSTA from 1965-1968. He retired from the U.S. Coast Guard in 1972. In 2010, he was diagnosed with acute myeloid leukemia. In 2011, he filed a VA radiogenic disease claim. Upon review of his historical duties, it was determined that he had performed "exceptional" maintenance activities during his LORSTA service. During two of these years he had received up to 50 h of unfiltered exposure to the energized high voltage vacuum tube, and otherwise typical maintenance exposures (0.377 rem/y). As indicated by CDR Benevides' 2008 survey results, the unfiltered exposure rate was 3 rem/h. However, to determine the bone marrow dose (the organ of interest for leukemia), we must take into account depth dose. From Table 7, we obtain a fractional transmission factor of 0.01, which results in 1.5 rad to the bone marrow during the 50 h of unfiltered radiation exposure. However, there is significant uncertainty associated with this value, which is difficult to quantitate. Providing the veteran the benefit of the doubt, it is not unreasonable to assign an uncertainty of 2X this estimated dose value, resulting in an upper bound value of 3 rad to the bone marrow during the 50 h of unfiltered radiation exposure.

NIOSH-IREP (ver. 5.6) input (manual entry):

- Claimant Name: John Q. Doe
- Gender: Male
- Birth year: 1932
- Year of Diagnosis: 2010
- Cancer Diagnoses: AML
- Cancer ICD-9 code: Acute Myeloid Leukemia (205.0)
- Alternate cancer model run? No
- No. of exposures: 4
- Dose input:
  1: 1965, Constant (3.0 rad), acute exp. rate, photons E<30keV
  2: 1966, Constant (0.377 rad), acute exp. rate, photons E<30keV
  3: 1967, Constant (3.0 rad), acute exp. rate, photons E<30keV
  4: 1968, Constant (0.377 rad), acute exp. rate, photons E<30keV

NIOSH-IREP output:

Probability of Causation (PC) 99^{th} percentile: **37.01%**.

Note: This result is less than 50%, and the VA medical opinion would state it is unlikely that the veteran's acute myeloid leukemia can be attributed to his exposure to ionizing radiation in service.

If this veteran had been diagnosed with prostate cancer, keeping all other factors the same, the resulting PC 99^{th} percentile: **15.60%**.

If this veteran had been diagnosed with a basal cell carcinoma (BCC) skin cancer, assuming an ethnic origin of white, non-hispanic, no smoking or non-ordinary radon history, and also assuming no depth dose drop-off (since target of interest is skin versus an internal organ), the applicable dose input becomes:

NIOSH-IREP (ver. 5.6) input (manual entry):

- Claimant Name: John Q. Doe
- Gender: Male
- Birth year: 1932
- Year of Diagnosis: 2010
- Cancer Diagnoses: BCC skin cancer
- Cancer ICD-9 code: Lung (162)
- Alternate cancer model run? No
- Ethnic Origin: White-Non-Hispanic
- Exposure Sources: Other Sources
- Smoking History: Never smoked
- No. of exposures: 4
- Dose input:
    1: 1965, Constant (150 rad), acute exp. rate, photons E<30keV
    2: 1966, Constant (0.377 rad), acute exp. rate, photons E<30keV
    3: 1967, Constant (150 rad), acute exp. rate, photons E<30keV
    4: 1968, Constant (0.377 rad), acute exp. rate, photons E<30keV

NIOSH-IREP output:

Probability of Causation (PC) 99th percentile: **95.96%**.

If this veteran had been diagnosed with posterior subcapsular cataract (PSC) of the eye, an IREP calculation could not be performed, since IREP does not calculate a PC for this potential radiogenic disease. Instead, a VA medical opinion would be drafted, based on a review of the peer-review literature. To determine the PSC dose, we must take into account depth dose. From Table 7, we obtain a fractional transmission factor of 0.06, which results in 9 rem to the PSC during the 50 h of unfiltered radiation exposure. Similar to the other organ calculation, providing the veteran the benefit of the doubt, it is not unreasonable to assign an uncertainty of 2X this estimated dose value, resulting in an upper bound value 18 rem to the PSC during the 50 h of unfiltered radiation exposure. Total dose sums to: 18 + 0.38 + 18 + 0.38 = **37 rad**. Recent studies of Chernobyl clean-up workers found that the maximum likelihood dose threshold for Stage I PSC was **35 rad with a 95% confidence interval of 19-66 rad** (Worgul, 2007). Consequently, a medical opinion in this case would probably note that it is likely that the claimed disease is the result of exposure to ionizing radiation.

These results suggest that most USCG LORSTA veterans who performed standard operating/maintenance duties (see section 5.a, scenario 1) will probably not receive VA compensation for radiogenic disease, since their PC at the 99th percentile is less than 50%. However, some USCG LORSTA veterans who performed exceptional operating/ maintenance duties (see section 5.a, scenario 2) may qualify for VA compensation, depending on the specific disease. However, this will strongly depend on the type of disease. For the LORSTA radiation scenarios, diseases such as skin cancer or PSC are more likely to be service-connected by the VA, while a disease such as prostate cancer is comparatively less likely to be service-connected.

c. Recommendations

- For USCG LORAN service members concerned about their potential occupational personnel radiation exposure:
    - Contact their local USCG healthcare provider for further information.
- For USCG LORAN veterans (first time filers) claiming entitlement to VA disability compensation due to radiogenic disease arising from active duty service:
    - Complete a VA Form 21-526, Veterans Application for Compensation and/or Pension, and attach (if available):
        - Discharge or separation papers (DD214 or equivalent)
        - Dependency records (marriage & children's birth certificates)
        - Medical evidence (doctor & hospital reports)
    - This documentation can be submitted online or via a local VA Regional Office (VARO)
    - For assistance, call toll-free: (800) 827-1000
- For USCG LORAN veterans (previously denied VA service connection) for disability compensation due to radiogenic disease arising from active duty service:
    - May refile based on new information presented in this technical report. The veteran should contact the VA Regional Office and request that the claim for service connection be reopened. The veteran should cite this technical report as the basis for the reopened claim, i.e., new and material evidence.
- For the surviving spouse of a deceased USCG LORAN veteran wishing to submit a dependency and indemnity compensation (DIC) claim,:
    - The surviving spouse should complete a VA Form 21-534 for an original claim. If an original claim has been filed in the past, and denied, then the surviving spouse can reopen the previously denied claim by submitting new evidence (i.e., this technical report) DTRA-TR-10-26.
- For the Veterans Benefits Administration (VBA) which has centralized processing of radiogenic disease claims at VARO, Jackson, MS (VBA, 2006).
    - Upon receipt of a USCG LORAN veteran claim for radiogenic disease, VARO Jackson should request the veteran complete a LORAN Occupational Radiation Exposure Questionnaire (see Appendix 1),
    - Upon receipt of this completed questionnaire, forward a request to Commandant, U.S. Coast Guard (Attn: CG-1133) for the veteran's occupational radiation exposure records,
    - Upon receipt of CG-1133 response, VARO Jackson should submit the records to the Under Secretary for Benefits (Director, Compensation Service), for review. The Under Secretary for Benefits may request an advisory medical opinion from the Under Secretary for Health (Director, Environmental Agents Service).

Fig. 22: VA Regional Office, Jackson, MS

- For the Veterans Health Administration (Director, Environmental Agents Service) who is located in Washington, DC:
  - Use the scenarios cited in sections 4 and 6 of this technical report as guidance in performing their medical opinion. Chief, Nuclear Test Personnel Review, Defense Threat Reduction Agency is available for technical consultation.
- For Commandant, U.S. Coast Guard, Division of Environmental Health & Industrial Hygiene (CG-1133):
  - Upon receipt of VARO Jackson's request for a USCG LORAN veteran's radiation exposure records, first verify if the veteran is one of the 105 LORAN veterans for which occupational radiation exposure records exist. Then forward the VA provided LORAN Occupational Radiation Exposure Questionnaire to Chief, Electronic Navigation Division, Commandant (CG-5532) for a technical/historical consult. Upon receipt of CG-5532's review, forward results to VARO Jackson.
- For Commandant, U.S. Coast Guard, Division of Electronic Navigation (CG-5532):
  - Upon receipt of CG-1133's consult request, initiate a technical/historical review. The goal of this review is to determine whether the information provided in the veteran's radiation exposure questionnaire is valid and representative of standard operating/maintenance duties or exceptional operating/maintenance duties. Title 38 of the Code of Federal Regulations, section 3.102, "Reasonable doubt" provides the following guidance, "It is the defined and consistently applied policy of the Department of Veterans Affairs to administer the law under a broad interpretation, consistent, however, with the facts shown in every case. When after careful consideration of all procurable and assembled data, a reasonable doubt arises regarding service origin, the degree of disability, or any other point, such doubt will be resolved in favor of the claimant." Results of the review should be returned to CG-1133.

7. Conclusions

Approximately 10,000 USCG service members stationed at LORAN stations from 1942-2010 could potentially have been exposed to occupational ionizing radiation exposure. Numerous radiation surveys during this period of time document x-ray fields emanating from high voltage vacuum tubes. Twice during this time period, USCG personnel stationed at LORAN stations were monitored for personnel radiation exposure. Results of this monitoring indicated that radiation exposure received by these personnel was within required safety exposure guidelines. However, there are numerous anecdotal reports of LORAN veterans performing exceptional operation/maintenance procedures which potentially entailed significant radiation exposures. As a consequence, there are two discrete scenarios of service member radiation exposure:

- the majority of the LORAN service members who received minimal occupational ionizing radiation exposure, and
- a smaller group of LORAN personnel who performed "exceptional" maintenance activities (and were not monitored with personnel radiation dosimeters). This group potentially received significant ionizing radiation doses. There is also significant uncertainty associated with this scenario.

Recommendations, guidance and documentation are provided to assist USCG LORAN veterans and their dependents, the Secretary of Veterans Affairs and the Commandant, United States Coast Guard in responding to USCG LORAN veteran VA radiogenic disease claims.

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9. Acknowledgements

- CDR Dana Thomas, USPHS – former Chief, Occupational Medicine (CG-1133). She initiated this review at Coast Guard Headquarters, and remained heavily involved despite transferring to a follow-on duty assignment.
- CDR Gary M. Thomas, USCG – former Commanding Officer, USCG LORAN Support Unit, Wildwood, NJ, who currently serves as Chief, Electronic Navigation Division, COMMANDANT (CG-5532). His historical knowledge and dedicated support were invaluable in compiling this report.
- MCPO Bill Dietz, USCG, Retired and ETC Joe Jester USCG, Retired who maintain the LORAN history website.
- The LORANIMAL community of the United States Coast Guard, who proudly stood the watch for over 67 years.

Fig. 23: LSU Wildwood – 17 Mar 2011

10. Co-Authors' Biographies

Paul K. Blake

Paul Blake is the program manager of the Nuclear Test Personnel Review (NTPR) Program, Research and Development Directorate, Defense Threat Reduction Agency, Fort Belvoir, Va. DTRA safeguards America's interests from weapons of mass destruction by controlling and reducing the threat to the United States and its allies, and providing quality tools and services for the warfighter. In this capacity, he leads the Department of Defense's efforts to confirm participation and reconstruct radiation doses for veterans involved in U.S. atmospheric nuclear weapons testing (1945 to 1962), and the post-World War II occupation forces of Hiroshima and Nagasaki, Japan. He also serves as DTRA's representative on the Veterans' Advisory Board on Dose Reconstruction – a federal advisory board that provides recommendations to the Department of Defense and the Department of Veterans Affairs.

Dr. Blake is a retired United States Navy captain, having served 26 years active duty. During his time in the Navy, he initially served aboard the USS Fulton (AS 11) and the USS Samuel Gompers (AD 37). In his first shore assignment, he served as head, Radiation Dosimetry Division, Armed Forces Radiobiology Research Institute. Upon completing his doctoral studies in 1986, he reported to the Naval Dosimetry Center as science advisor. He co-designed and implemented the Navy's personnel radiation dosimeter – the DT-648/PD. In 1989, he transferred to Naval Hospital Portsmouth as staff physicist and radiation safety officer and later served as head of his Radiology Department.

In later duty assignments he served as head, Radiological Controls Branch, on the staff of Chief of Naval Operations and as the Surgeon General's specialty leader for radiation health while assigned to the Bureau of Medicine & Surgery. In 2002, he returned to the Naval Dosimetry Center as officer in charge and supervised the implementation of the Navy's next generation radiation dosimeter – the DT-702/PD that monitors over 50,000 workers. In 2004, he briefly served on the faculty of the Uniformed Services University of Health Sciences before retiring from active duty.

Dr. Blake is a diplomate of the American Board of Health Physics and is a member of the U.S. Naval Institute and Health Physics Society. He earned a bachelor's degree in chemistry and a master's degree in health physics from Rutgers, the State University of New Jersey. During his graduate studies at Rutgers University he served as a Health Physics Fellow at Brookhaven National Laboratory in Long Island, N.Y. He later earned a doctorate degree in medical physics from the University of Wisconsin-Madison.

Jeffrey W. Hall

Lieutenant Commander Hall is serving as the Logistics Department Head at Coast Guard Sector Baltimore, MD. As Logistics Department Head, LCDR Hall manages supply & finance, naval & civil engineering, and personnel management as well as serving as the Commanding Officer of Military Personnel for more than 300 active duty and reserve members.

LCDR Hall has more than 29 years of active duty in the Coast Guard. In addition to tours aboard Coast Guard Cutters ALERT and SPENCER, CG ACADEMY, TISCOM, and two tours at Coast

Guard Headquarters, he served 15 years in the LORAN community. Beginning in 1982, he served at LORSTAs Port Clarence, AK; Dana, IN; OMEGA Station Kaneohe, HI; and on LANTAREA Coordinator of Chain Operations staff located at LORSTA Seneca, NY. In his capacity as an electronics technician, he has over nine years of experience maintaining the AN/FPN-42, AN/FPN-44B, and AN/FRT-88 vacuum tube-type transmitters. He attended the LORAN-C Engineering Course in New London, CT in 1989.

During his tour as Officer in Charge of LORSTA Dana, IN, he documented x-ray emissions from the AN/FPN-44B transmitters with the assistance of the Food and Drug Administration office in Chicago, IL. These findings, along with those at LORAN Station George, WA led to the design and installation of clear lead-embedded acrylic shielding in the transmitters to mitigate the exposure to operating and technical personnel.

LCDR Hall was selected for the Advanced Computers and Engineering Training (ACET) program from 1996-1998 where he received his Associates of Applied Science in Computer Engineering. He received his B.S. in Information Resource Management from University of Maryland University College in 2005 and is currently taking graduate courses in Information Assurance at Wilmington University.

Charles Severance

Master Chief Severance served twenty-years in the US Coast Guard. He is retired and resides with his wife Andrea, and five children in Wasilla, AK. He is a member of IEEE, and was a member of the Loran Wild Goose Association. He graduated from Loran Engineering School and taught Loran Engineering focusing on transmitters for three years. He retired as the School Chief for Electronic C-Schools that include LORAN, Radar, and communications. He was also the Subject Matter Expert for the ET rate and wrote the service wide exams and end of course tests. ETCM Severance also served at COMMSTA Kodiak, Far East Section Japan (LORSTA Gesashi, LORSTA Iwo Jima, LORSTA Yap, LORSTA Hokkaido, LORSTA Marcus, and Commando Lion). ETCM Severance also served two tours at TRACEN Governors Island NY, one as Section Chief for Loran-C, and one tour as LORAN-A instructor. His first two tours of duty were Loran-A stations LORSTA Cape Christian Baffin Island and LORSTA Pt Grenville.

During the past seven years he has been working as an advocate for LORAN parasitic x-ray exposure awareness. Prior to his arrival in Alaska he worked as Washington State Electrical Administrator, Chief Engineer, and Operations Manager. As Electrical Administrator he was responsible for ensuring compliance with the National Electrical Code, OSHA safety regulations, and Washington State laws and safety guidelines pertaining to electrical contracting. While working as Chief Engineer he was responsible for the design, and compliance of all electrical projects, and bids. Responsibility for Operations Manager included managing, training and safety of staff of IBEW electricians and independent contractors. The job included bidding on new contracts, and management of a just in time inventory supporting all operations in the state of Washington.

Jennifer Rusiecki

Jennifer Rusiecki completed a Ph.D. in epidemiology from Yale University, School of Medicine and a post-doctoral fellowship in epidemiology at the National Cancer Institute, Division of Cancer Epidemiology and Genetics, in the Occupational and Environmental Epidemiology Branch. Currently an Associate Professor of Epidemiology at the Uniformed Services University (USU), she has worked in the Department of Preventive Medicine since 2005. She teaches the Occupational and Environmental Epidemiology course at USU and is involved in teaching Epidemiology Methods and Chronic Disease Epidemiology.

Her research focus includes studies of occupational and environmental exposures and risk for various cancers; epigenetic influences of environmental exposures, particularly pesticides and heavy metals; and health of emergency responders. She has analyzed health effects data from the Coast Guard responder population who were involved in the Hurricane Katrina disaster response, and she is currently focusing on the Deepwater Horizon responder cohort from the Coast Guard.

A graduate of the Coast Guard Academy, she served on active duty from 1989 to 2005. Currently, a Commander in the Coast Guard Reserve, she supports the Directorate of Health, Safety and Work Life at U.S. Coast Guard Headquarters.

U. S. Coast Guard

LORAN Occupational Radiation Exposure Questionnaire

SECTION I: PARTICIPANT CONTACT INFORMATION

Name:	Service Number/Social Security Number:
Mailing Address:	
Telephone/Email:	
If this questionnaire is completed by someone other than the participant, please provide:	
Name:	
Mailing Address:	
Telephone/Email:	
Relationship to veteran:	

SECTION II: ASSIGNMENT SUMMARY (LORAN-A and/or LORAN-C)

Duty Station	Dates Assigned	Rate (ET1, SK2, etc)	Names of other personnel (up to four) assigned

During these dates, were there any times you were not involved in transmitter operations?
☐ Yes (explain) ☐ No

Which of the following best describes your assignment(s)? More than one answer is possible.
___ Administrative Support (FS, SK, HS)
___ Command Cadre (CO/OIC, XO/XPO)
___ Engineering (EM, MK, DC)
___ Maintenance Technician (ET3 - ET1)
___ Technical Management (ETC or above)
___ Engineering, Development, or Project Staff (EECEN/LSU, Installation Teams, etc).

SECTION III: DUTIES, RADIOLOGICAL MONITORING, & PROTECTIVE EQUIPMENT (LORAN-A or LORAN-C)

The following questions are intended to assess your potential for occupational radiation exposure. Please provide details for answers to the best of your recollection (qualify as "approximate" as necessary). Use back or a separate page with reference to question number if more space is needed. If you are unable to answer a question or provide details, state "Unknown."

MAINTENANCE DUTIES

- Did you perform/observe preventive and/or corrective maintenance to the transmitter (to include arc watches) or antenna coupler?
  - If so, how many days each year did you work in or near the transmitter or antenna coupler?
  - For each day you performed maintenance, how many hours were spent working on the equipment, in general?
  - For each day you performed maintenance, how many hours were spent near the final power amplifier section?
  - For how many years did you carry out this type of work?
- Did your duties require you to work beyond interlocked sections of the transmitter?
  - If so, how many days each year did you work within the restricted area?
  - For each day you worked within the restricted area, how many hours were spent working on the equipment, in general?
- Did you perform "tube seasoning/tube bake-ins"?
  - How many tube seasoning events did you ever perform?
  - During a typical tube seasoning event, how many hours were spent near the equipment?
- Did you perform engineering testing (EECEN/LSU, Wildwood, NJ)?
  - If so, how many times per year did you take transmitter readings?
  - How many total transmitter readings did you take during all your assignments?
  - How many days each year did you work in or near the transmitter?
  - For each day you performed maintenance, how many hours were spent working on the equipment, in general?
  - For each day you performed maintenance, how many hours were spent near the final power amplifier section?
  - How many total years did you work in or near the transmitter?

SECTION III - (CONTINUED)

OPERATIONS DUTIES

- Did you observe and record transmitter meter readings ("daily readings")?
  - If so, how many times per year did you take transmitter readings?
  - How many total readings did you take during your all your assignments?

RADIOLOGICAL MONITORING

Were you issued a radiation dosimeter during your tour?

PROTECTIVE EQUIPMENT

- During your tour(s) of duty at a LORAN Station (to include EECEN/LSU), did the transmitters have clear, lead-embedded acrylic shields installed in the final Power Amplifier section?
  - If yes, were the shields installed during your entire tour?
  - If not, how many months during your tour(s) were the shields installed?

ADDITIONAL COMMENTS

SECTION IV: SIGNATURE

I certify under penalty of perjury under the laws of the United States of America that the information provided on this form is true and correct.

Signature: ____ Date: ____________________________

SECTION V: PRIVACY ACT STATEMENT

AUTHORITY: 38 U.S.C. 1154 (Veterans' Benefits) delineates United States Coast Guard (USCG) and Department of Veterans Affairs (VA) responsibilities for collection of information in the adjudication of non-presumptive radiogenic disease compensation.

PRINCIPAL PURPOSES: The information on this form is necessary to facilitate location of record(s) or information, provide participation and dose information, support scientific studies or medical follow-up programs, and provide data or documentation relevant to the processing of administrative claims or litigation. For use by Agency officials, employees, and authorized contractors.

ROUTINE USES: Disclosures are permitted under 5 U.S.C. 552a(b) of the Privacy Act, to USCG, VA, Department of Homeland Security, Department of Defense, Department of Labor, Veterans' Advisory Board on Dose Reconstruction and under the 'Blanket Routine Uses' published at the beginning of USCG's compilation of systems of records notices.

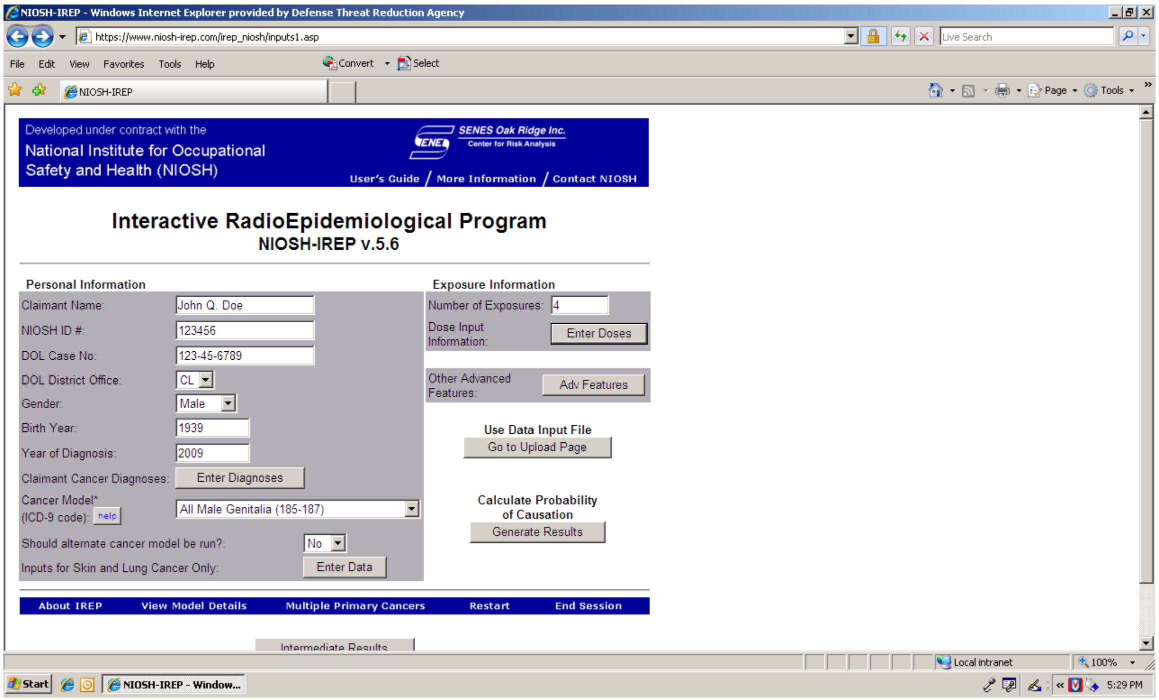
DISCLOSURE: Voluntary. However, failure to provide the requested information may delay or preclude the USCG/VA from producing your radiation dose assessment.

SECTION VI: AGENCY DISCLOSURE NOTICE

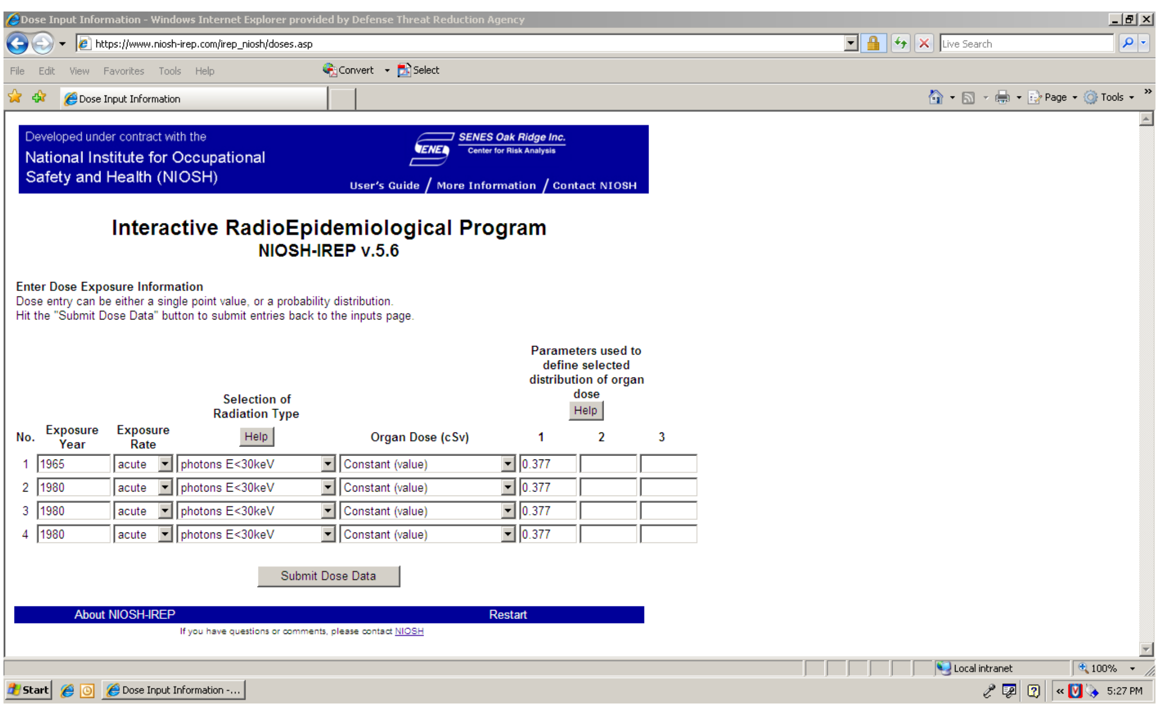
The public reporting burden for this collection of information is estimated to be less than one hour. If you have any questions regarding this form, please write to: HQ USCG, CG-1133, 2100 Second Street SW, Mail Stop 7902, Washington, DC 20593-7902.

Appendix 2: NIOSH-IREP Website Screen Shots

1st Shot:



2nd Shot:



3rd Shot:

NIOSH-Interactive RadioEpidemiological Program
Probability of Causation Results

Date of Run: 1/14/2011 NIOSH-IREP version: 5.6
Time of Run: 6:31:11 PM Analytica/ADE version: 3.0
Claimant Name: John Q. Doe

Claimant Cancer Diagnoses:

Primary Cancer #1: Prostate Cancer Date of Diagnosis: 2009

Claimant Information Used In Probability of Causation Calculation:

Gender: Male Race (skin cancer only): N/A
Birth Year: 1939 Year of Diagnosis: 2009
Cancer Model: All Male Genitalia (185-187) Should alternate cancer model be run?: No
Smoking history (trachea, bronchus, or lung cancer only): N/A

NIOSH-IREP Assumptions and Settings:

User Defined Uncertainty Distribution: Lognormal(1,1)
Number of Iterations: 2000 Random Number Seed: 99

General Exposure Information:

#	Exp. Year	Organ Dose (cSv)	Exp. Rate	Radiation Type
1	1965	Constant (0.377)	acute	photons E<30keV
2	1966	Constant (0.377)	acute	photons E<30keV
3	1967	Constant (0.377)	acute	photons E<30keV
4	1968	Constant (0.377)	acute	photons E<30keV

Probability of Causation (PC)

1st percentile	0.00 %
5th percentile	0.00 %
50th percentile	0.27 %
95th percentile	2.10 %
99th percentile	4.08 %

Appendix 3: 38 CFR 3.311b – VA Nonpresumptive Radiogenic Diseases

1. All Leukemias (except CLL)
2. Thyroid cancer
3. Breast cancer
4. Lung cancer
5. Bone cancer
6. Liver cancer
7. Skin cancer
8. Esophageal cancer
9. Stomach cancer
10. Colon cancer
11. Pancreatic cancer
12. Kidney cancer
13. Urinary bladder cancer
14. Salivary gland cancer
15. Multiple myeloma
16. Posterior subcapsular cataracts
17. Non-malignant thyroid nodular disease
18. Ovarian cancer
19. Parathyroid adenoma
20. Tumors of the brain and CNS
21. Cancer of the rectum
22. Lymphomas other than Hodgkin's disease
23. Prostate cancer
24. Any other cancer

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UNITED STATES COAST GUARD

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Division of Environmental Health & Industrial Hygiene
U.S. Coast Guard Headquarters
1900 Half Street, SW, Jamal Bldg.
Washington, DC 20593-0001

COMMANDANT (CG-5532)
Division of Electronic Navigation
US Coast Guard Headquarters
2100 2nd Street SW, Mailstop 7683
Washington, DC 20593-7683

Commander, USCG Personnel Service Center
Attn: CDR Dana Thomas PHS/USCG
4200 Wilson Boulevard, Suite No. 950
Arlington, VA 22203

Commanding Officer
USCG SECTOR Baltimore Logistics
Attn: LCDR Jeffrey Hall, USCG
2401 Hawkins Point Rd
Baltimore, MD 21226

DEPARTMENT OF DEFENSE

Defense Technical Information Center
Attn: DTIC/OCA
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6201

Defense Threat Reduction Agency
Attn: Dr. Blake, RD-NTSN
8725 John J. Kingman Road,
Fort Belvoir, VA 22060-6201

Defense Threat Reduction Information Analysis Center
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8725 John J. Kingman Road
Fort Belvoir, VA 22060-6201

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Naval Dosimetry Center
8901 Wisconsin Ave
Bethesda, MD 20889-5614

DEPARTMENT OF VETERANS AFFAIRS

Department of Veterans Affairs
Veterans Health Administration
Director, Environmental Agents Service (10P3A)
810 Vermont Ave., NW
Washington, DC 20420

Department of Veterans Affairs
Veterans Benefits Administration
Director, Compensation Service (211B)
810 Vermont Ave., NW
Washington, DC 20420

Department of Veterans Affairs
VA Regional Office
Attn: Director (21 - Radiation)
1600 East Woodrow Wilson Ave.
Jackson, MS 39216

FEDERAL AGENCY ADVISORY BOARDS

Veterans' Advisory Board on Dose Reconstruction
801 North Quincy Street, Suite 600
Arlington, VA 22203

Veterans' Advisory Committee on Environmental Hazards
Department of Veterans Affairs
Compensation Service (211)
810 Vermont Ave., NW
Washington, DC 20420

INTERESTED INDIVIDUALS

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