From World War II to the present, the U.S.S. Indiana *continues its distinguished service to the United States.*

A Historically Significant Shield for In Vivo Measurements

*Timothy P. Lynch**

Abstract: *Due to the ubiquitous nature of ionizing radiation, in vivo measurement systems designed to measure low levels of radionuclides in people are usually enclosed within a high-density shield. Lead, steel, earth, and water are just some of the materials that have been and are being used to shield the detectors from radiations of cosmic, atmospheric, manmade, and terrestrial origin. At many Department of Energy sites, the counting room shields are constructed of pre-World War II steel to reduce the background levels in order to perform measurements that have low minimum detectable activities. The pre-World War II steel is commonly called low background steel in the in vivo industry vernacular. The low background descriptor comes from the fact the steel was manufactured prior to the beginning of atmospheric testing of nuclear weapons in the 1940's. Consequently, the steel is not likely to be contaminated with fission or activation products from fallout. For high energy photons (600 keV < E < 1500 keV), 30 cm of steel shielding significantly reduces the measured background radiation levels. This is the story of the unique steel that began as the hull of the* U.S.S. Indiana *and now forms a shielded room at the In Vivo Radiobioassay and Research Facility in Richland, Washington. Health Phys. 93(Supplement 2):S119–S123; 2007*

Key words: *operational topic; shielding; historical profiles; radiation protection*

INTRODUCTION

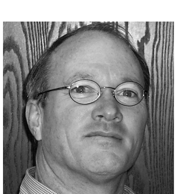
Due to the ubiquitous nature of ionizing radiation, in vivo measurement systems designed to measure low levels of radionuclides in people are usually enclosed within a high-density shield. Lead, steel, earth, and water are just some of the materials that have been and are being used to shield the detectors from radiations of cosmic, atmospheric, and terrestrial origin. At many U.S. Department of Energy sites, the counting room shields are constructed of pre-world War II steel to reduce the background levels to achieve measurements with low minimum detectable activities (MDA). This is one example of what is commonly called low background steel in the in vivo industry vernacular. The low background descriptor comes from the fact the steel was manufactured prior to the beginning of atmospheric testing of nuclear weapons in the 1940's. Consequently, the steel is not likely to be contaminated with fission or activation products from fallout. For high energy photons (600 keV < E < 1500 keV), 30 cm of steel shielding significantly reduces the background levels. This is a brief history about the source of the unique steel that now forms a shielded room at the In Vivo Radiobioassay and Research Facility (IVRRF) in Richland, Washington.

MEASUREMENT SYSTEM

The steel shield surrounds the in vivo measurement system shown in Fig. 1. The walls, ceiling, and floor of the shielded room are 30-cm-thick hardened steel. The interior surface is lined with thin layers of lead, cadmium, and copper and is referred to as a graded atomic numbered (Z) shield. This graded Z shield acts to reduce the intensity and energy of the cascading photons produced from the photoelectric, pair production, and Compton interactions in the steel. The atomic number of each layer of the shield material decreases from the outside layer to the inside layer. Together the shield components significantly reduce the background count rate. Fig. 2 shows a comparison of background measurements inside the shielded room and outside the room. The shield provides a background reduction factor for the Compton continuum of 50 over the energy range of 660 keV to 1,500 keV. The ^{40}K count rate inside the shield is a factor of 200 lower compared to outside the shield.

The detection system is used to monitor workers for intakes of fission and activation products.

* *Pacific Northwest National Laboratory, PO Box 999, Richland, WA 99352.*



Tim Lynch has managed the In Vivo Monitoring Program for the Hanford Site since 1990. He is a certified health physicist. Previously at Hanford, he worked as a radiological engineer and effluent control engineer. Prior to Hanford he worked as an assistant radiation safety officer at George Washington University Medical Center, and as a health physics technician. He is chairperson of the working group that developed and is revising the ANSI/HPS N13.35 standard on the bottle manikin absorption phantom. He especially enjoys fishing and coaching sports. His email address is tim.lynch@pnl.gov.

Figure 1. Coaxial germanium measurement system.

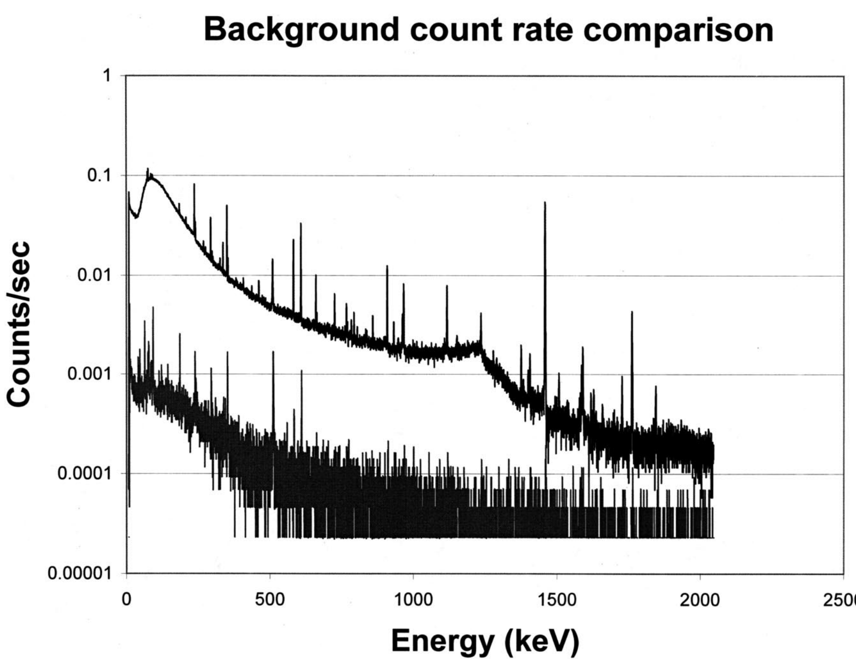


Figure 2. Comparison of background count rate inside and outside shielded room.

The counting system is comprised of five coaxial germanium detectors. The relative efficiency of the detectors ranges from 125% to 130%. Three cryostats share a common dewar and the other two cryostats share a second dewar. Routine counting time is 600 s. The system operates in a scanning mode using a computerized controller and a servo-controlled motion control system. The scan covers the distance from the head to the hips in 540 s and from the hips to knees in 60 s. Total travel length is 173 cm for the routine measurements.

Table 1. MDA values for 10-min whole body scanning measurement.

Nuclide	MDA (Bq)
^{137}Cs	
^{60}Co	50
^{154}Eu	120

MINIMUM DETECTABLE ACTIVITY

The MDA values for routine whole body measurements are shown in Table 1 for the three radionuclides of primary dosimetric interest. The MDA values are calculated using eqn (1):

$$MDA = \frac{(1 + \Delta K) \times [(2 \times \Delta B \times B) + 2L_c + 3]}{K \times T}, \quad (1)$$

where

- L_c = decision level in counts;
- K = calibration factor in count rate per unit activity;
- T = count time;
- ΔK = maximum fractional systematic error bound in the calibration factor K;
- ΔB = maximum expected fractional systematic error bound in the appropriate blank; and
- B = background estimate for the region of interest (ROI).

The L_c value is based on a 5% false positive probability for each measurement using the methodology from ANSI N13.30 (ANSI 1996). The values for the calibration factors are calculated from measurements of bottle manikin absorption (BOMAB) phantoms. The BOMAB phantoms contain radioactive material uniformly distributed within the polyurethane that was used to fill the phantom volume. For routine counting $\Delta K = 0.05$ and is based on replicate measurements of calibration phantoms. The baseline error fraction estimate, ΔB, is currently assigned a value of zero. The MDA values shown in Table 1 are calculated for workers weighing 200 lbs or less. The MDA values are at least 25% higher for workers weighing greater than 200 lbs. The reduction in the measured background radiation levels from the shield is an important reason why these very low MDA values are achievable.

Now, here is the compelling story behind the shield now at IVRRF. The story begins in the late 1930's with the construction of the battleship and ultimately transitions to peaceful uses of the battleship steel after World War II.

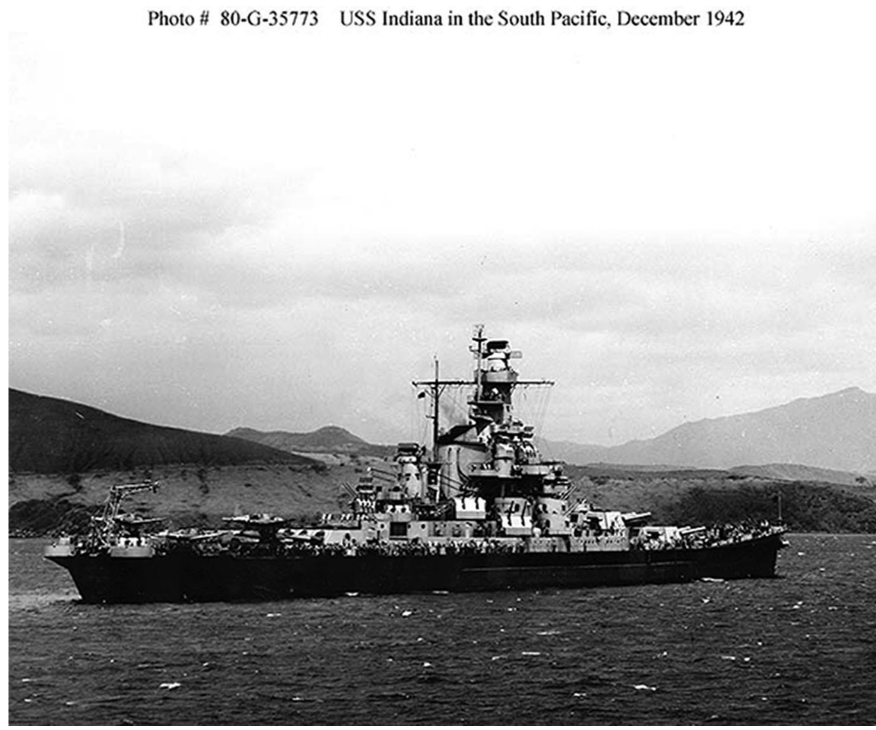


Figure 3. The *U.S.S. Indiana*.

WWII SERVICE

According to the online version of the Dictionary of American Naval Fighting Ships (2001), the *U.S.S. Indiana* was a South Dakota class battleship built at the Newport News Shipbuilding & Dry Dock Co., Newport News, Virginia. The keel was set on 20 November 1939, and two years later she was launched on 21 November 1941. She was commissioned on 30 April 1942 with Captain A. S. Merrill in command. She had an overall length of 680 feet and a beam width of 108 feet. She displaced 35,000 tons with a 29-foot draft and cruised at 27 knots. Her armament included nine 16-inch guns, twenty 5-inch guns, twenty-four 40-mm guns, and sixteen 20-mm guns. Of particular note is the internal armor belt for protection against 41-cm artillery shells and enhanced anti-torpedo protection that was built into the hulls of the *Indiana* and the other three South Dakota class battleships. Fig. 3 shows a picture of the *Indiana* in the South Pacific in 1942. The *Indiana* was assigned a battleship number of BB-58 indicating it was the 58th battleship hull laid as part of the BB series.

Following shakedown cruises in Casco Bay, Maine, the new battleship steamed through the Panama Canal to bolster the U.S. fleet in the Pacific during the critical early months of World War II. She joined Rear Admiral Lee's carrier screening force on 28 November 1942. For the next 11 months, the *Indiana* helped protect the carriers *U.S.S. Enterprise* (CV 6) and *U.S.S. Saratoga* (CV 3). A subsequent mission supported American advances in the Solomon Islands.

The *Indiana* steamed to Pearl Harbor on 21 October 1943, and departed 11 November with the support forces designated for the invasion of the Gilbert Islands. The battleship also protected the carriers that supported the Marines during the bloody fight for Tarawa. Then, late in January 1944, she bombarded Kwajalein for eight days prior to the Marshall Island landings on 1 February. While maneuvering to refuel destroyers that night, *Indiana* collided with the battleship *U.S.S. Washington* (BB 56). Temporary repairs to her starboard side were made at Majuro, and she arrived at Pearl Harbor on 13 February for additional work.

Indiana then joined the famed Task Force 58 for the Truk raid on 29–30 April 1944, and bombarded Ponape Island 1 May. In June, the battlewagon proceeded to the Marianas with a giant American fleet for the invasion of that strategic group of islands. She bombarded Saipan 13–14 June and brought down several enemy aircraft while fighting off concentrated air attacks on 15 June. As the Japanese fleet closed on the Marianas for a decisive naval battle, *Indiana* steamed out to meet them as part of Rear Admiral Lee's battle line. The two great fleets approached each other 19 June 1944 for the biggest carrier engagement of the war, and as four large air raids hit the American formations, the *Indiana*, aided by other ships in the screens and carrier planes, downed hundreds of the attackers. With able assistance from submarines, the U.S. fleet sank two Japanese carriers in addition to inflicting fatal losses on the enemy during "The Great Marianas Turkey Shoot." *Indiana* shot down several planes, and sustained only two near torpedo misses. The issue decided, the battleship resumed her screening duties around the carriers and stayed at sea 64 days in daily support of the Marianas invasion.

In August, the battleship began operations as a unit of Task Group 38.3, bombarding the Palaus, and later the Philippines. She screened strikes on enemy shore installations 12–30 September 1944, helping to prepare for the coming invasion of Leyte. Afterwards, the *Indiana* departed for Bremerton, Washington, and arrived 23 October for a much needed overhaul. She departed Bremerton and reached Pearl Harbor on 12 December. The battleship crew immediately began training preparedness. She sailed 10 January 1945 and with a fleet of battleships and cruisers bombarded Iwo Jima on 24 January. The *Indiana* then joined Task Force 58 at Ulithi and sortied 10 February for the invasion of that strategic island, the next step on the island road to Japan. She supported the carriers during a 17 February raid on Tokyo and again on 25 February, screening strikes on Iwo Jima in the interval. *Indiana* arrived at Ulithi again for replenishment on 5 March 1945, having just supported a strike on Okinawa, the next island targeted for invasion.

Indiana steamed out of Ulithi on 14 March to support the massive Okinawa invasion and until June 1945 supported carrier operations against Japan and Okinawa. These devastating strikes did much to aid the ground campaign and lower Japanese morale at home. During this period she often repelled enemy suicide plane attacks as the Japanese tried desperately but vainly to stem the mounting tide of defeat. In early June she rode out a terrific typhoon, and sailed to San Pedro Bay, Philippines, on 13 June.

As a member of Task Group 38.1, *Indiana* operated from 1 July to 15 August supporting air strikes against Japan and bombarded coastal targets with her big guns. The veteran battleship arrived in Tokyo Bay on 5 September (three days after the signing of the surrender papers on the *U.S.S. Missouri*) and nine days later sailed for San Francisco, where she arrived 29 September 1945.

POST WWII

The *Indiana* was placed in reserve in commission at Bremerton shipyard 11 September 1946. She was decommissioned 11 September 1947, and entered the Pacific Reserve Fleet. *Indiana* received nine battle stars for World War II service. Her missions accomplished, she was stricken from the Navy List 1 June 1962 and sold for scrap.

Parts of the *Indiana* were distributed around the country. In 1962, the governor of Indiana, Matthew Welsh, sent a committee to Bremerton, Washington, to select items to be brought back to the state. Today, the mainmast and a 40-mm gun are displayed on the Indiana University Bloomington campus. One of the huge anchors is displayed in front of the Memorial Coliseum in Fort Wayne. A large anchor at the Columbia River Maritime Museum in Astoria, Oregon, is purported to be from the *Indiana*. Other souvenirs such as the flag silver service, signal flags, search light, chinaware, compasses, steering wheels, voice tubing and sections of the teak deck were given to schools, museums, and other institutions in Indiana state. Some items also made their way to the Naval History Division in Washington, DC. The Veterans Administration hospital in Hines, Illinois, received 65 tons of the Indiana that was used for low background counting work.

In addition to the VA hospital facility, several large sections of the hull weighing a total of 210 tons were also fabricated into a room. These applications were probably never imagined by the original designers of the *Indiana*. These sections of the hull are still being used for the original purpose as a shield; but instead of protecting against artillery shells and torpedoes the new purpose is to shield radiation detectors from the background radiations originating from cosmic, atmospheric, man-made, and terrestrial sources. The larger room was initially constructed at the University of Utah Medical Center in Salt Lake City, Utah. The counting facility was located below grade to take advantage of the

Figure 4. Shielded room construction at the IVRRF.

earth shielding plus the steel. The inside surface was covered with a thin layer of lead. The counting system was used in radiobiology studies including the beagle dog lifespan studies conducted from 1952 to 1980. After the conclusion of the radiobiology studies at the University of Utah, Earl Palmer, the manager of the IVRRF at the time, made arrangements to have the room moved to Richland, Washington, in 1988 (Fig. 4). Here, thin layers of cadmium and copper were added to the lead layer on the inside surface of the room. To this day, the room houses the germanium radiation detection system described previously that is used to monitor workers at the Department of Energy Hanford Site. Thousands of Hanford workers have been counted in the room over the years, as well as a helicopter pilot and workers from Chernobyl, children from Chernobyl, and numerous visitors from the United States and from across the globe.

Acknowledgment: In June 2001, Al Stromquist visited the IVRRF. Stromquist was an ensign who served on the *Indiana* and has compiled a chronology of his time aboard the *Indiana*. Some of the history described above was excerpted from the chronology and served as an inspiration for this article. This manuscript is dedicated to the 5,653 men and women who served our country aboard the *Indiana* from 1942 to 1963. Thanks to their efforts and all those who served in WWII, the staff at the IVRRF can use such a distinguished part of our history for peaceful applications!

REFERENCES

American National Standards Institute. Performance criteria for radiobioassay. McLean, VA: Health Physics Society; HPS N13.30-1996; 1996.

The Dictionary of American Naval Fighting Ships. Available at: http://www.chinfo.navy.mil/navpalib/ships/battleships/indiana/bb58-ind.html. Washington, DC: Naval Historical Center; 2001. Accessed January 2007.