Reprinted from ADVANCES IN CHEMISTRY SERIES, Number 65, Page 156, 1967

U. S. Army Radiation Laboratory

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The world's largest irradiation laboratory for preserving foods by ionizing energy is operated by the U. S. Army at Natick, Mass. It has two radiation sources, a food development-preparation laboratory, and an experimental development kitchen. The sources are cobalt-60 and an electron accelerator with a maximum energy of 24 m.e.v. They are supported by three laboratories: health physics, radiochemistry, and dosimetry. Other facilities include a section which develops suitable containers for use in irradiation experiments. By housing all these facilities in one location, one has complete control over each phase of the experimental procedure. The Army is concentrating its efforts on meat sterilization to provide the armed services with food which needs no refrigeration and yet resembles fresh food when prepared.

In 1962 the U. S. Army opened at its Natick Laboratories in Natick, Mass., the world's largest irradiation laboratory (*2*) for preserving foods by ionizing energy (Figure 1). This laboratory is unique in that, in addition to having two radiation sources, a 24-m.e.v., 18-kw. electron linear accelerator and a 1,250,000-curie cobalt-60 isotope source, it includes a food development–preparation laboratory and an experimental development kitchen (Figure 2).

Before construction of this laboratory the Army depended upon industrial and national laboratories to provide irradiation services on a contractual basis. This procedure lacked the complete control over experiments that is obtained if all functions are housed in one facility, where scientists of the various disciplines can freely discuss experimental designs and results.

The food irradiation program in the United States is broad in scope and divided principally between the U. S. Atomic Energy Commission (AEC) and the U. S. Army, with the Army's concentrating on meat sterilization and the AEC's concentrating on fruits, vegetables, and fish pasteurization. Sterilization and pasteurization are differentiated by both the level of the radiation dose employed and the shelf storage life of the products. The sterilization program of the Army has as its goal to supply the armed services with foods which do not require refrigeration during storage yet resemble fresh foods when prepared.

Radiation Sources

The radiation field was surveyed for all possible types of sources that could be used for food sterilization. Since cobalt-60 and electron accelerators with energies greater than 5 m.e.v. showed the most promise, they were chosen.

Electron Accelerator Facility. The linear accelerator facility consists of an electron accelerator with a maximum energy of 24 m.e.v. and peak power of 19.2 kw. at this energy (Table I). This machine is located in an irradiation cell 48 feet long by 30 feet wide (Figure 3). Other components of the accelerator facility are the power supply in the modulator room and the control console and electronic shop in the control room. The irradiation cell is entered by passing over a man-trap and through a labyrinth (5 feet 6 inches wide), constructed of solid concrete blocks stabilized with grout to facilitate modifications of the labyrinth or to enable larger pieces of the machine to be removed or modified if necessary. The electron machine is located near the east wall to permit various conveyor configurations and to provide experimental setup room. The electron machine is currently

Table I. Beam Parameters of NLABS S Band Linac

Microwave frequency, mc.	2856
No. of accelerator sections	4
Klystrons (1 per section)	4
Maximum peak r-f power, Mw.	5
Maximum average r-f power, kw.	10
Energy range, m.e.v.	3 to 30
Beam energy at maximum efficiency, m.e.v.	22
Peak beam current at maximum efficiency, ma.	375
Rated average power, kw.	
At 2 m.e.v.	0.68
At 6 m.e.v.	1.38
At 12 m.e.v.	6.48
At 18 m.e.v.	12.6
At 24 m.e.v.	19.2
Maximum peak beam power, kw.	19.8
Maximum peak beam current, ma.	375
Normal operation duty factor	0.002
Beam pulse lengths, μsec.	0.5 to 5.5
Pulse repetition rates per second at 0.5 to 5 μsec. (Single pulses available)	15, 30, 60, 90, 180, 360
Energy spectrum	2.5% at half current for 20 m.e.v.
Spot size	0.5 cm. diameter min.

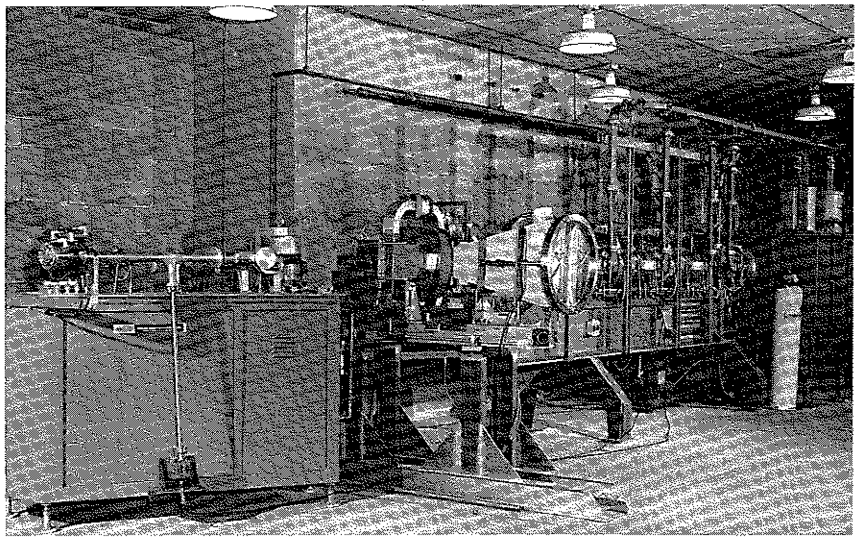

Figure 3. The electron linear accelerator with energy analyzing and scanning systems

equipped with a beam-handling system that includes three windows—straight ahead, 30° right, and 30° left—as well as a 90° window with a scanning bucket (16 x 3 inches) to permit irradiation of larger samples than the nominal electron beam spot size of 1 cm. For most food irradiations, samples are conveyed past the 90° window at a controlled rate. The conveyor used is an overhead monorail type with each carrier self-propelled through the labyrinth by a small low voltage d.c. motor. At approximately 3 feet from the center line of the scanner the carrier is coupled to a servochain drive that controls speed through the beam. This drive system has a range from 0.0004 to 0.8 foot per second and is controlled by a servosystem with less than 1% variation.

In addition to the present energy-analyzing system, the accelerator is being equipped with a beam-handling system consisting of two pairs of quadrapole magnets, a servoslit system, and two 45° bending magnets which will allow control of the spot size and shape. This modification will improve the machine's usefulness for basic research in the radiation chemistry of foods, dosimetry systems, and chemical systems at various dose rates. To provide adequate biological shielding when converting the electron beam to x-rays, the cell wall directly in front of the straight-ahead port and the 90° left port are 11½ feet of standard concrete with 2 feet of solid concrete blocks stacked within the cell. This wall tapers to a minimum of 8 feet in the corners of the cell. This design was chosen for maximum safety and economy.

Owing to the possible production of radioactive isotopes, ozone, and oxides of nitrogen, the accelerator cell is equipped with an independent ventilation system which normally removes approximately 3000 standard cu. feet per minute of air, corresponding to 10 air changes per hour when the machine is not in operation. This air is drawn into the cell, through the labyrinth, by the air-exhaust fan located on the roof of the building. This fan has a capacity of 9000 scfm and is used at capacity when the machine is operating. For this higher rate, 6000 scfm of fresh air is supplied at the entrance of the labyrinth by a make-up fan. The air exhaust is filtered through a roughing filter and an absolute filter to remove any radioactive particles before the air is exhausted up a 20 foot stack to the atmosphere. The top of this stack is approximately 38 feet above the ground.

MODULATOR ROOM. The power supplies, pulse-forming network, and r.f. drivers for the accelerator are all located in a steel vault in the modulator room. This room is provided with access ports and a 1-foot square sand-filled trough to permit cables to be installed between the Linac cell and the modulator room and between the cobalt cell and the modulator room. In addition, ports are provided, through which an Omniscope may be inserted to observe operations within the cells during operation.

CONTROL ROOM. The accelerator control room was designed to enable the operator to view the entrance to the cell directly from the control console as a safety precaution (Figure 4). From this console an operator can

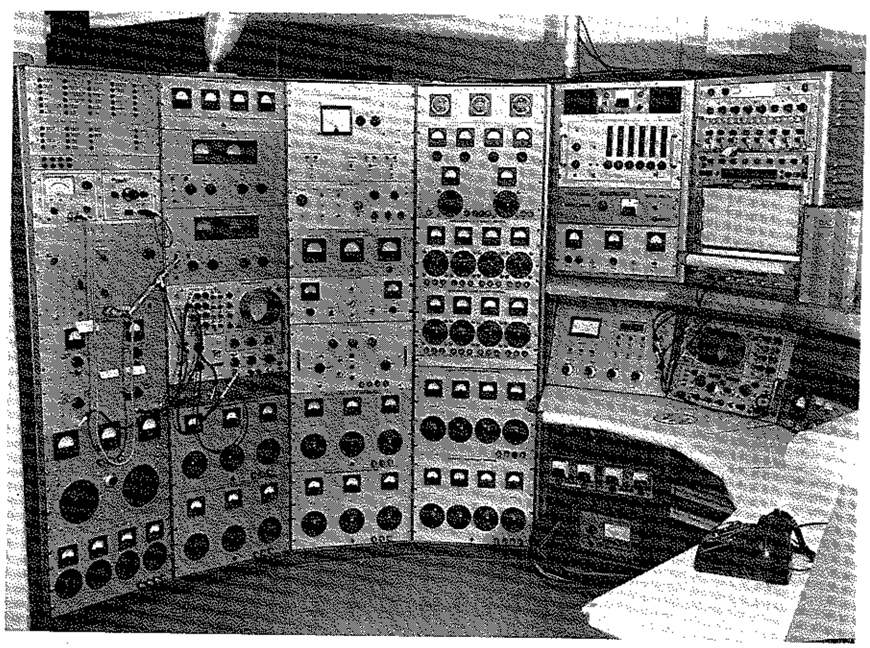

Figure 4. The accelerator control console

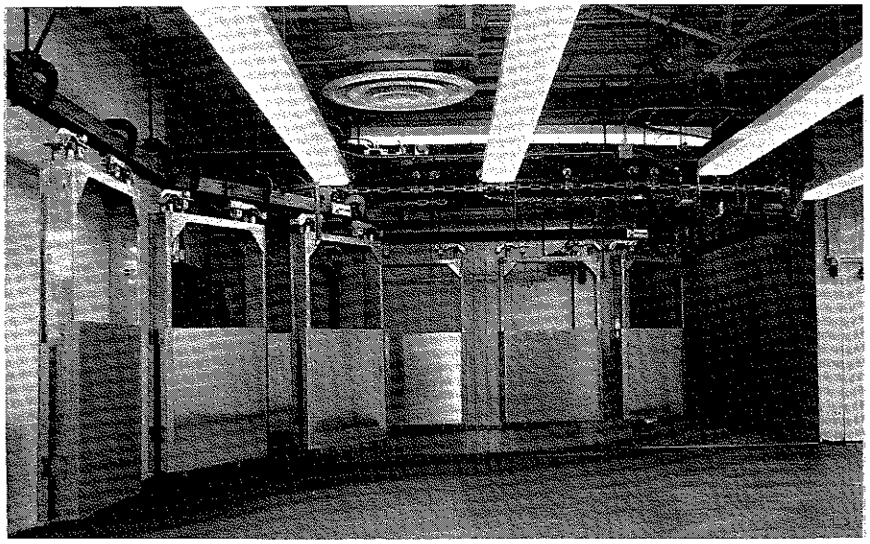

Figure 5. The cobalt cell entrance and carrier loading area. The carriers shown are of bulk type with internal dimensions of 41 inches wide × 33½ inches high and 7½ inches deep

control all the operations, including tuning the machine, advancing the carriers, regulating the conveyor speed, and controlling the cell lockup.

This control room also houses work benches and test equipment used to maintain and modify the machine.

The electrical cables between the control room, the modulator room, and the irradiation cell are in pipes below the floor. A cable trough is being installed in the labyrinth to increase the cable capacity between the cell and the control room.

Cobalt Facility. The cobalt facility consists of the cobalt-60 source located in the irradiation cell; source loading pool, outside the building; source elevator pool, in the irradiation cell; and control console, in the cobalt control room.

IRRADIATION CELL. The irradiation cell is entered by passing over a man-trap and through a labyrinth (7.0 feet wide) constructed of standard concrete (Figure 5). The cell walls provide a minimum of 6-foot shielding in all directions to provide adequate biological shielding for 3 megacuries of cobalt-60. The initial loading of the cell was approximately 1.25 megacuries.

The cobalt-60 source consists of 392 individually encapsulated rods (*1*). Each cobalt rod, which is 0.725 inch in diameter, is covered by a stainless steel jacket with welded end closures. This, in turn, is covered with an aluminum jacket (Figure 6). The doubly sealed slugs are 0.943 inch in diameter and approximately 10.7 inches long. The cobalt rods were encapsulated before activation in 1245 aluminum alloy to minimize activation of impurities in the aluminum. The rods may be arranged in various geometries by modifying the elevator source jig plates. For all work to date the rods have been arranged in two parallel plaques (Figure 7), each consisting of 49 vertical source holder tubes mounted on a mandrel, at-

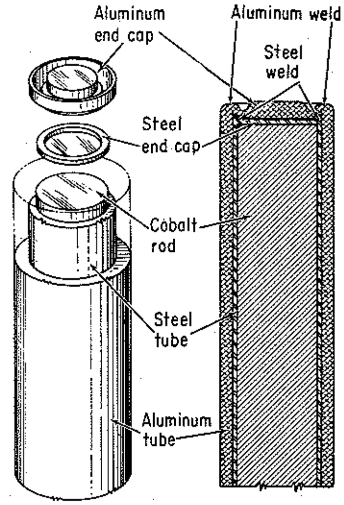

Figure 6. Exploded and cross-section view of an encapsulated cobalt rod

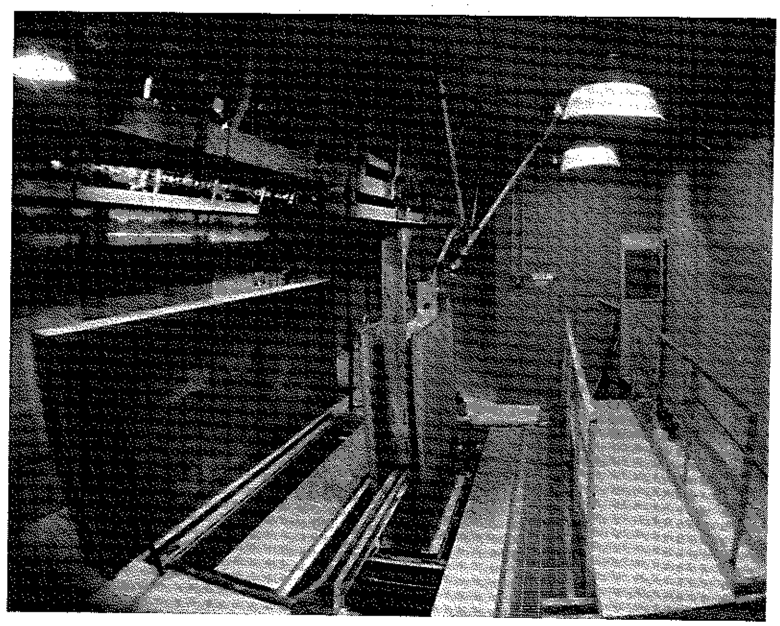

Figure 7. Interior of cobalt cell as seen through the omniscope. A carrier is in the dwell position with the source raised

tached to the jig plate. Each source holder tube contains four cobalt-60 rods positioned on top of one another.

The over-all dimensions of the active portion of the plaques are 42.2 inches high by 56.2 inches wide and the center line distance between the two plaques is 16 inches. The original center line distance between the two plaques of 11 inches was changed to 16 inches to improve the over-all dose uniformity in the carriers.

CARRIERS. Samples to be irradiated are arranged in a carrier and transported into the irradiation cell through the labyrinth and in turn between the source plaques by an overhead monorail conveyor, which has a variable-speed drive capable of conveyor speeds from 0.6 to 60 feet per minute. The carrier selected depends upon the temperature requirements and size of the samples to be irradiated. For samples larger than a No. 3 (can) cylinder (4¼ x 7 inches) a bulk-type carrier is used, 41 inches wide, 33½ inches high, and 7½ inches deep (inside dimensions) (Figure 5). For microbiological samples a special carrier has been constructed which can handle up to 44 10-mm. test tubes with temperature control between —190° and +100° ± 20°C. (Figure 8). For samples up to a No. 3 cylinder a special low temperature carrier has been constructed of four stainless steel Dewars (inside diameter 4½ inches) which can accommodate 20 No. 3 cylinders (Figure 9). It can be used to control the sample temperature between room temperature and —190° ± 15°C.

For temperature control runs it is necessary to run the conveyor in the dwell mode of operation—i.e., the carrier is transported to a fixed location, centered between the plaques in the cell, at which point a liquid nitrogen line is remotely attached to the carrier (Figure 10). The rate of nitrogen flow, hence the cooling rate, is controlled by copper-constantan thermocouples in the carriers which are connected to temperature controllers outside the irradiation cell.

For normal operation the conveyor is operated in a batch-type operation. In this mode the carriers are transported at 60 feet per minute, to minimize the transport time, to a fixed position between the source plaques. The carrier is disconnected from the power chain and remains in this position for a predetermined period of time to obtain the desired radiation dose. It is possible to perform this operation with the source either raised from the water or in the lowered position.

In a second mode, the carriers are transported to a fixed position at one end of the source at the maximum speed. The conveyor drive shifts to a selected speed and continues to convey the carrier past the source. When the carrier is completely past the source, the conveyor shifts back to the maximum speed and transports the carrier from the cell.

In a third mode, the carriers are attached to the conveyor drive chain at fixed intervals and are conveyed through the labyrinth and between source plaques at a fixed speed. This mode is the most time-con-

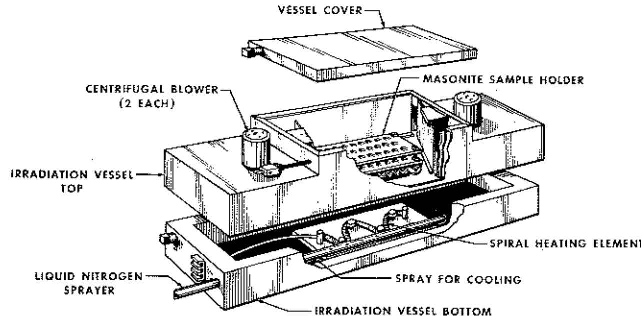

Figure 8. The cryogenic biological radiation box used for irradiating samples in test tubes at controlled temperature between 80° and −196°C.

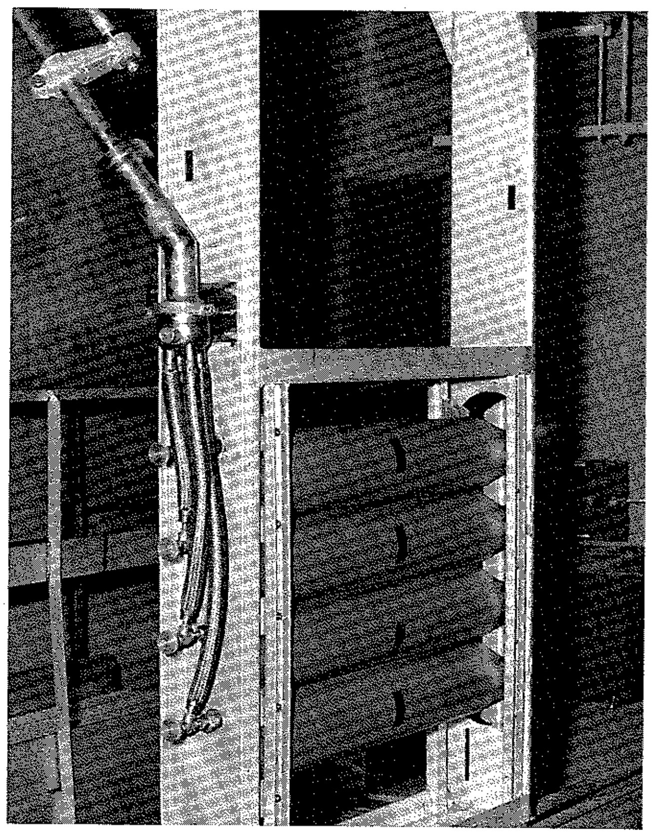

Figure 9. Low temperature carrier designed to accommodate 20 No. 3 cylinders. For irradiations at controlled temperatures between room temperature and −190°C.

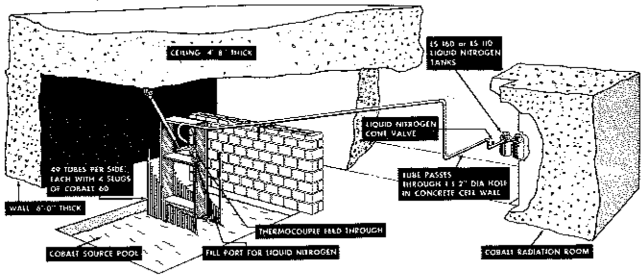

Figure 10. Perspective view of cobalt cell with liquid nitrogen cooling system

suming and has been used only for irradiating large volumes of fruits at low total doses.

The conveyor used with the cobalt source was originally designed to be used with no lubrication. However, because of rust buildup on the wearing surfaces it was found to function better if lubricated (Atomic Energy of Canada, Ltd., SKF-M-3 ball grease base).

The cobalt source is raised into the irradiation cell from the bottom of its storage pool for irradiation by the source elevator. The drive for the elevator is located in the modulator room. The motor for lifting the source is mounted on the main drive shaft by a torque-sensitive drive mechanism. This mechanism provides a safety feature by which, if the source jams, the elevator motor will hit limit switches and stop.

The cobalt-60 is received in stainless steel lead-lined casks (approximately 18 tons) which are lowered into the receiving pool by portable

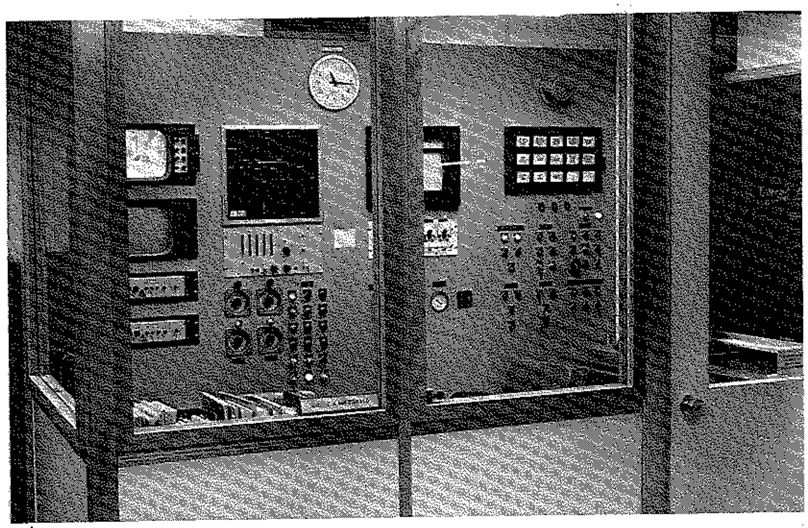

Figure 11. The cobalt-60 source control room

cranes. The cobalt is removed from the casks remotely under 23 feet of water by using long-handled tools, and it is then transferred into the source storage pool in the cell, where it is arranged in source tubes and loaded on the source elevator for use.

CONTROL ROOM. The cobalt control room was designed to enable the operator to observe directly the carrier loading area and the entrance to the cobalt cell and to view remotely the interior of the cell by use of television cameras (Figure 11). From the control room the operator can control the conveyor functions and the source elevator in addition to monitoring air flow, water activity, and pool water level.

Laboratory Support

The radiation sources are supported directly by three laboratories: a health physics laboratory, a radiochemistry-low level counting laboratory, and a dosimetry laboratory.

Health Physics Laboratory. The health physics laboratory is located at the entrance to the radiation sources controlled area (Figure 2). From this laboratory the access to the radiation sources area is monitored and controlled. The health physics laboratory is equipped with portable beta, gamma, and neutron survey meters of various designs and ranges to facilitate the area monitoring, air monitors for airborne contamination, and anticontamination equipment. It is equipped with monitors and alarms for the area radiation detectors, pool water level indicators, and access doors. It also has ready access to the counting equipment of the radiochemistry laboratory.

Low Level Counting Radiochemistry Laboratory. The low level counting-radiochemistry laboratory consists of an area of approximately 200 sq. feet. This laboratory is used for measuring the level of radioactivity in foods. This activity can originate from naturally occurring radioisotopes, fallout from nuclear devices, or induced activity resulting from the radiation sterilization process. It has been demonstrated that no measurable activity occurs as a result of irradiating food with gamma-rays from cobalt-60 and cesium-137, with x-rays of energies less than 5 m.e.v., or with electrons with energies less than 10 m.e.v. To perform these measurements, the laboratory is equipped with RIDL-400 and 1600 channel analyzers with accessories, a Beckman Wide Beta II counter, a Packard Tricarb counter, a Tracerlab Low Beta counter, two 5 x 5-inch and two 3 x 3-inch NaI detectors, and conventional end-window Geiger counters. The shield for the 5 x 5-inch NaI crystals was fabricated from the mid-section of a 16-inch 1918 naval gun barrel (Figure 12). This shield was selected because it was cast before detonation of nuclear devices and is, therefore, free of fallout.

Dosimetry Laboratory. The radiation dosimetry laboratory is adjacent to the health physics laboratory and measures approximately 190 sq. feet, with an additional 300 sq. feet in the controlled area. All source

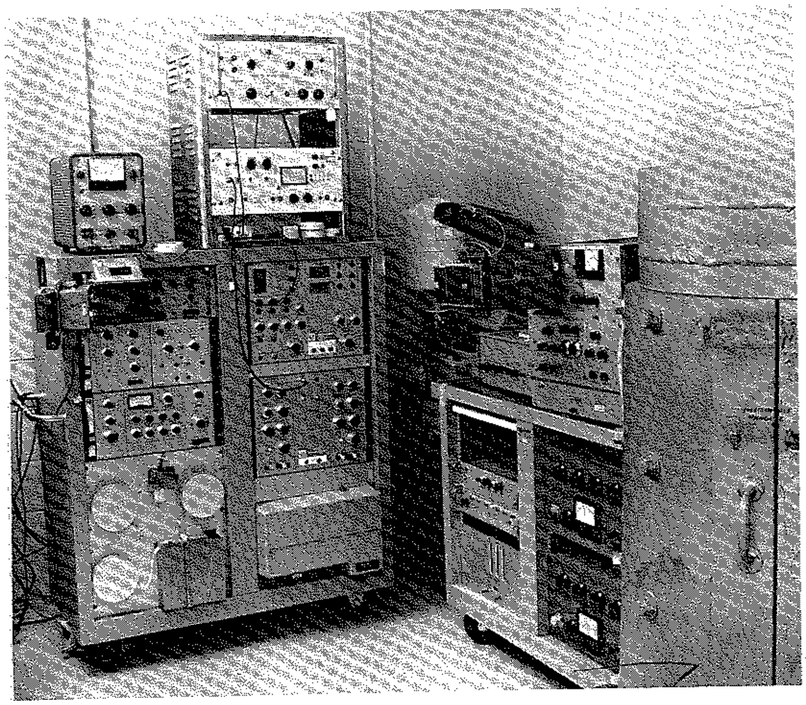

Figure 12. Low level counting equipment consisting of two RIDL multi-channel analyzers with accessories and a modified gun barrel shield

calibration is performed in these areas. This dosimetry consists of measuring the transmittance change in solutions, films, and glasses, measuring the e.m.f. or pH change in solutions, and measuring the electrical properties of materials and gas production as a function of the radiation dose. This laboratory is equipped with three spectrophotometers, a gas chromotograph, an automatic titrator, and standard analytical instruments.

To calibrate the cobalt source, three systems are most often used: ferrous sulfate, ferrous sulfate–cupric sulfate, and ceric sulfate. Dosimeters of these solutions are prepared by filling 5-ml. chemical-resistant glass ampoules with approximately 5 ml. of solution and flame-sealing the ampoules. The ampoules are then arranged in "phantoms" of Masonite or similar materials (Figure 13) to simulate the food items. These phantoms are placed in containers similar to those used for food products, and arranged in the conveyor carrier in which they are transported into the irradiation cell. Because of the upper dose limit of the ferrous sulfate and ferrous sulfate–cupric sulfate dosimeters (40,000 and 800,000 rads, respectively), these systems can be used only to establish the dose rate in the facility and not to monitor the total dose during food irradiation. The ceric dosimeter which is suitable for measuring megarad doses is used for quality control during processing.

For calibrating the accelerator, poly(vinyl chloride) films and a simple water calorimeter are used in addition to monitoring and controlling the electrical parameters of the accelerator which affect the dose output and, in turn, the absorbed dose. The poly(vinyl chloride) is used primarily for establishing the depth dose in samples irradiated with the scanned electron beam. This film is relatively thin when compared with the range of 10

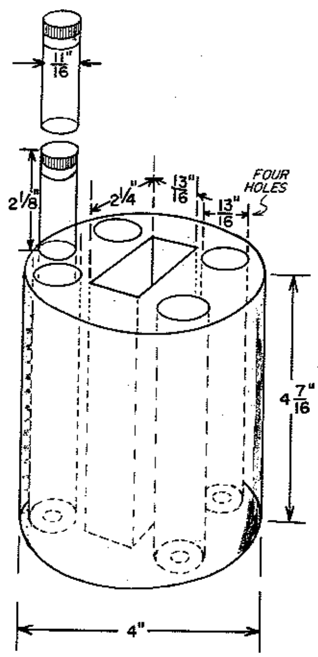

Figure 13. Phantom constructed of 1/8-inch masonite disks to simulate foods canned in a No. 2½ can. Dosimeters shown are made of polystyrene ampules

m.e.v. electrons and is suitable for measuring the dose in the range of 0.5 to 3.5×10^6 rads. The film changes color when irradiated, and this color change is stabilized by annealing the irradiated film for 15 minutes at 64°C. The dose received is determined by measuring this color change at a fixed wavelength (3950 A.) in a spectrophotometer. This film is also used to establish the beam spot size and location and to indicate that the samples have been irradiated.

The water calorimeter is used as a production monitor. It consists of a water-filled plastic Petri dish, containing a temperature-sensing device (normally a copper-constantan thermocouple). The Petri dish is thermally insulated with approximately 2 inches of Styrofoam insulation. The dose received by the calorimeter is determined by measuring the temperature change in the calorimeter caused by irradiation. This calorimeter is reproducible within ±2% and has a calculated accuracy of ±2%. It is used for production monitoring by irradiating a calorimeter before and after the sample carriers containing the product to confirm that no changes occurred during the processing.

Product Development

The food preparation area of approximately 6000 sq. feet is fully equipped with steam kettles, rotisserie, grills, deep fat fryers, retort, ovens, smoke house, blast freezer, and storage boxes (Figure 14).

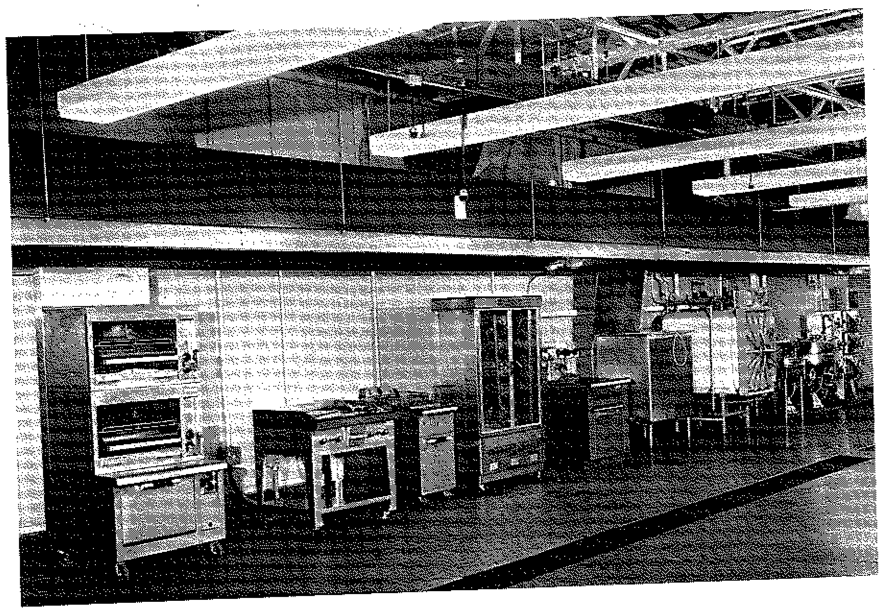

Figure 14. Food preparation area

Container Development

The Container Division at NLABS provides technical assistance in developing containers suitable for use in irradiation processing. The use of the electron accelerator has placed the most stringent requirements upon packaging. These requirements are dictated by the range limitation of 10 m.e.v. electrons, which is 3.3. cm. for a single-side irradiation. This range can be increased by modifying the accelerator's method of irradiating and the product conveyor system. Because of this range limitation it has been necessary to develop a flexible package which is impermeable to gases, light, easy to seal, inert to the foods which it contacts, and not appreciably affected by radiation. A series of films has been explored in detail for use.

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RECEIVED November 26, 1966.