THE CESIUM-137 AGRICULTURAL COMMODITIES IRRADIATOR (CACI)

Harry Farrar IV, G. Subbaraman
C. C. Conners, J. P. Page
Atomics International, Rocketdyne Division
Rockwell International, Canoga Park, California 91304

ABSTRACT

The objective of the U.S. Department of Energy's Byproduct Utilization Program is to develop and encourage widespread commercial use of nuclear byproducts from U.S. defense programs. One of the beneficial uses of the ^{137}Cs isotope is for the low-dose gamma-ray treatment of various food commodities, including destroying insects of quarantine significance, extending food shelf-life, retarding ripening, eliminating mold, reducing bacteria, etc. DOE recently selected Rockwell International to design and build the Cesium-137 Agricultural Commodities Irradiator (CACI) to demonstrate and validate these types of treatment.

CACI will be a panoramic, wet-storage gamma irradiator using ~3 megacuries of ^{137}Cs in the form of ~55 double-walled stainless steel capsules from the Waste Encapsulation and Storage Facility (WESF) at Rockwell Hanford, Richland, Washington. The capsules will be configured in up to four independently operable plaques in a vertical plane, having positioning flexibility within the plaques to optimize the dose distribution in the products. The CACI irradiation chamber will be capable of providing total absorbed doses from 10 Gy to 10 kGy at dose rates of 0.1 to 2 kGy/h. An automated overhead product carrier system will carry bulk and packaged commodities in cartons and will be capable of processing at least 170 carriers (with a volume of 0.34 m^3 per carrier) in an 8-hour shift to a minimum dose of 1 kGy. The irradiation chamber will also accommodate two rotating platforms, each capable of holding a loaded pallet. Additional features will include control and equipment rooms, separate unirradiated and irradiated product storage areas, and laboratory facilities. The CACI facility will be built and operated under a Nuclear Regulatory Commission (NRC) license. Accordingly, safety provisions required by the NRC Regulatory Guide 10.9 and ANSI N43.10 will be fully incorporated into the design, fabrication, and operation.

BACKGROUND AND INTRODUCTION

The scientific and technological feasibility of food preservation by irradiation (destruction of pests and harmful parasites at low doses, and sterilization of micro-organisms at high doses) has been established by several decades of well-documented research, both in the USA and abroad (Refs. 1-3). From a technical standpoint, there is nearly universal agreement that the process is safe, leaves no radioactive residues, and that the food treated by moderate levels of radiation is wholesome and nutritious (Ref. 4). Low doses of radiation, in fact, can kill or sterilize insects without affecting the wholesomeness of the host food products in any detectable way. While not a panacea for the world's hunger problems, radiation processing can help reduce food losses. The recent resurgence of interest in the subject is due, in part, to the U.S. Government's banning of certain chemical treatments, and more favorable Government regulations. These developments have been endorsed by international organizations such as the United Nations and its agencies, and the American Medical Association.

Food irradiation development in the USA was slowed in the 1950s when Congress declared irradiation to be a food "additive." This erroneous action (irradiation is a process, not an additive) resulted in it being extremely difficult to obtain the necessary U.S. Food and Drug Administration (FDA) approval for its application. Nevertheless, research continued in the USA and in other countries. The U.S. Armed Forces have used irradiated rations for years, and irradiated food is regularly given to U.S. astronauts and certain medical patients who must consume only sterilized food. Wide varieties of foodstuffs are routinely irradiated prior to public consumption in a number of countries, most notably The Netherlands (Ref. 5). Gamma radiation and electron beams are being used more and more frequently for sterilizing medical products (Ref. 6), where they have been found to be highly cost-effective and totally free of the contaminants or residues that can accompany some of the alternative treatments.

The original emphasis on applying radiation to food products was to provide complete sterilization, or at least to provide a greatly increased shelf-life. It was later learned that these high dosages led to noticeable changes in many of the foodstuffs, much the same as the effects of overcooking, which for many products (such as oranges) is more or less unacceptable. On dried foods, however, the effects are generally not as noticeable. The current emphasis is on using much smaller doses of radiation to solve or ameliorate a wide variety of food storage and transportation problems. These doses, in turn, produce no detectable change in the foods' chemical compositions, nutritional values, or tastes. An ever-increasing spectrum of valuable uses includes: delaying sprouting (potatoes, onions) (Ref. 7), eliminating mold (strawberries) (Ref. 8), destroying insects (citrus, nuts, wheat) (Refs. 9,10), retarding ripening (avocados) (Ref. 11), eliminating nematodes (trichinosis in pork) (Ref. 12), *reducing bacteria* (salmonella in chicken) (Ref. 13), etc. Although the advanced nations have managed to feed themselves adequately utilizing other traditional preserving technologies, such as pickling, salting, canning, freezing, and most recently fumigating, certain Third World countries are now experiencing mass starvation. Processes such as canning and especially freezing are energy-intensive. It is quite the opposite with gamma irradiation, especially if isotopes separated from nuclear waste are used. The Third World countries produce the largest fraction of their annual food supply during a short growing period. Food must be stored for long periods for distribution and consumption before the next harvest. Radiation processing can extend the shelf-life and significantly reduce major losses due to insects and decay. It is for these reasons that the Third World countries might benefit even more from this technology than could the comparatively energy-rich, developed nations. Acceptance of such preserved food by the hunger-stricken Third World will perhaps be met with less academic debate than will likely occur in the developed countries.

Parallel to this real need for gamma-emitting isotopes is the generally perceived "excess" of nuclear waste from military and commercial reactors. At present, much of the U.S. military's nuclear waste is reprocessed, and the valuable ^{137}Cs is separated, purified, and stored in the form of cesium chloride in double-walled, thick stainless steel capsules at the Waste Encapsulation Storage Facility (WESF) at Rockwell Hanford in Richland, Washington. This isotope is, in fact, a national resource which is ideal for use in food irradiation, and indeed has some advantages over the much more commonly used isotope ^{60}Co, especially because of the much longer half-life of the ^{137}Cs.

The U.S. Department of Energy's byproduct utilization program has been committed since the early 1970s to developing and encouraging the widespread beneficial commercial use of nuclear byproducts such as ^{137}Cs. Recently, the Department of Energy selected Rockwell International to design and construct a demonstration facility, called the Cesium-137 Agricultural Commodities Irradiator (CACI), to be built within about a year either in Florida or California. The two main purposes of CACI (pronounced "Casey") are for research and for demonstration. Research activities include: evaluating the technical feasibility of irradiating specific commodities; defining bounds and optimizing irradiation protocol for currently restricted export commodities; and evaluating irradiation as an alternative to existing methods of quarantine treatment, some of which are under regulatory scrutiny. CACI is also intended to demonstrate the beneficial use of ^{137}Cs and to show to industry, by example, the value and efficiency of radiation for disinfestation or preservation of certain commodities at near-commercial throughputs and load sizes. The demonstration phase of the CACI program is essential and will fully complement the irradiation research on a wide spectrum of commodities. Control variables such as conditioning treatments, commodity temperatures, and modified atmospheres will also be incorporated.

Rockwell International has a long history of involvement in the beneficial use of nuclear radiation, as evidenced by a review article on food irradiation by Beeley in 1958 (Ref. 14), and the design and construction of our own licensed gamma irradiation facility in Canoga Park, California, in the sixties. This facility, which has had up to 120 kCi of ^{60}Co, has been in continuous use for the past 20 years on a wide variety of projects, including recent research on the effects of gamma radiation on citrus (Ref. 15).

PLANT DESCRIPTION

General Layout

CACI will be a fixed installation similar to the preliminary plan shown in Fig. 1. The facility will consist of a shielded irradiation chamber, a food storage warehouse with refrigeration equipment, laboratory space and support facilities. The ^{137}Cs source, comprising approximately 55 WESF capsules, will be stored in the irradiation chamber under water. Operations within these chambers will be performed by a trained operator working in a central control room using various types of automated and remote equipment. Heavy lead-glass windows and closed-circuit TV cameras will provide the irradiation chamber with extensive viewing capabilities. Facilities will be provided to receive, unload, and install the radioactive cesium sources and receive and install truckloads of produce. The plant will be built in accordance with the ANSI N43.10 requirements for a panoramic, wet-storage Category IV irradiator (Ref. 16).

Food Handling Warehouse

The CACI facility will include a temperature-insulated food storage and handling warehouse with a minimum ceiling height of 4.9 m (16 ft) adjoining the irradiation chamber. A continuous barrier will divide the warehouse into two approximately equal and symmetrical halves, to prevent cross-contamination of treated and untreated produce. Each half will have an access ramp, loading dock, and space to store a semitrailer load of commodities. An air curtain or similar provision will allow the conveyor system to pass through the barrier from the treated to the untreated areas to prevent contamination. The concrete floor and walls will be sealed to facilitate cleaning and reduce dust. Separate, walk-in refrigerated storage areas adjustable from 2 to 21°C (35 to 70°F) and maintainable to ± 0.6°C (± 1°F) will be provided for irradiated and unirradiated products. Space will be provided in the appropriate half of the warehouse for possible temporary installation of a palletizer and a depalletizer with their associated conveyor systems.

Control Room

A centrally located control room will be used to monitor and operate the entire irradiation process. Personnel desiring entry into the irradiation chamber may enter the labyrinth leading to the chamber only by passing through this room. Location of the control room immediately adjacent to the irradiation chamber, and the use of lead-glass windows, will allow the operator to see directly the movement of produce in the cell. Windows also face the two warehouse areas where loading and unloading the produce

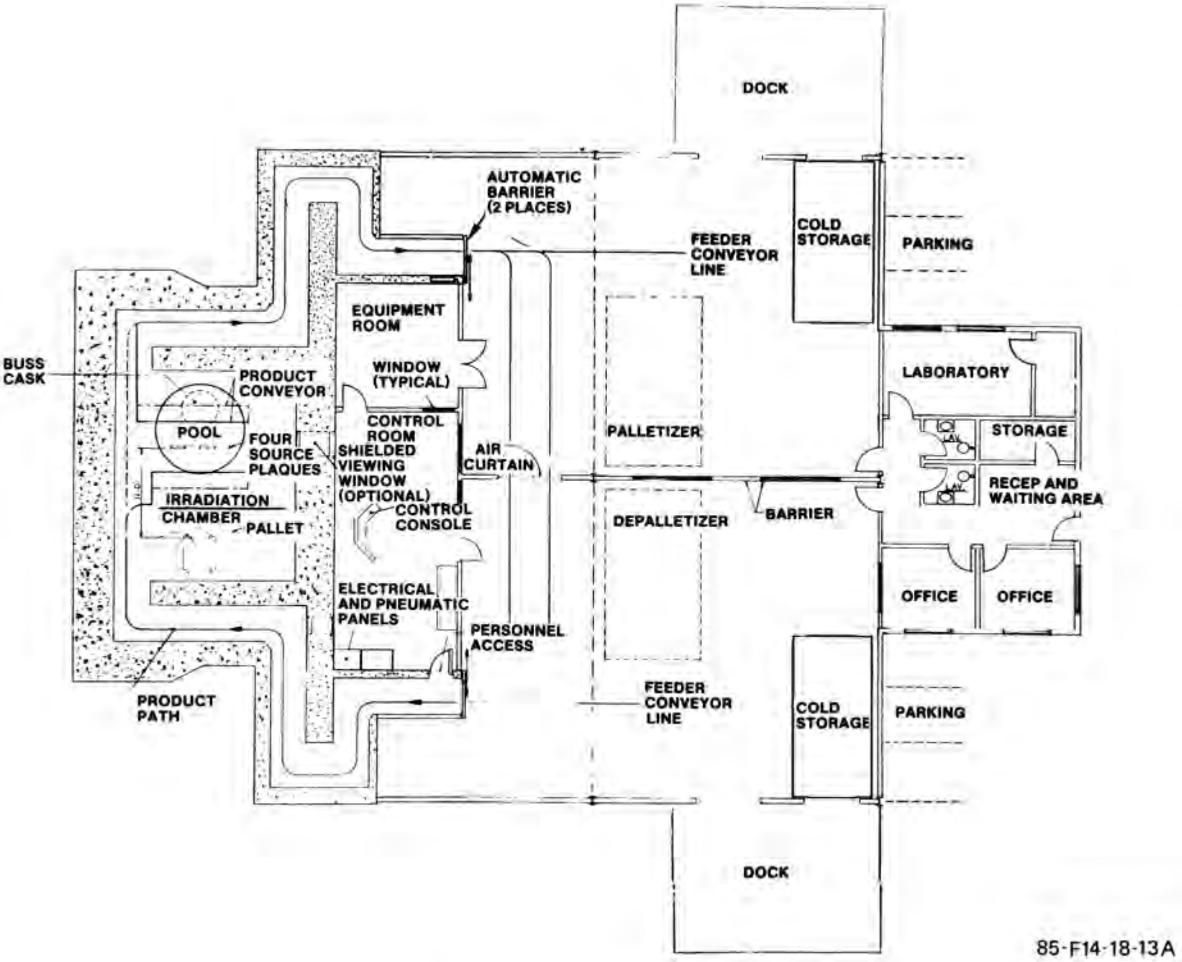

Fig. 1. Plan View of CACI

takes place. Closed-circuit TV monitors, an instrument and control system incorporating radiation safety monitors, source positioning controls, carrier system controls, readouts, interlocks, and other key functions, are all located in the room.

Irradiation Chamber

The irradiation chamber, also shown in Fig. 1, is the location of the ^{137}Cs gamma source and the storage pool. The chamber has thick concrete walls and ceiling, and has enough space for the irradiation of a row of carriers passing at centerline distances of either 61 cm (24 in.) or 119 cm (47 in.) on each side of the source. There is also enough room for the irradiation of two fully loaded pallets with their near faces placed at a distance of 3.3 m (11 ft) from the radiation source. A Heating, Ventilation and Air Conditioning (HVAC) System will maintain the chamber at 21°C (70°F), at a slightly negative pressure with respect to the rest of the building. A removable portion of the chamber roof will permit a Beneficial Use Shipping System (BUSS) cask (Ref. 17), capable of containing 16 WESF ^{137}Cs capsules, to be lowered by external crane through the ceiling and into the pool. All mechanical movements within the chamber will be powered by motors and equipment placed in exterior locations, where they are accessible while the sources are being deployed. Provisions to assist remote cleanup and decontamination, in the unlikely possibility of there being an accidental spill of cesium chloride, will be incorporated into the design. Chamber walls, ceilings, and floors will be sealed for this purpose.

Gamma Source

The irradiation source will consist of approximately 55 WESF ^{137}Cs capsules having a total strength of ~3 MCi. Each individual WESF capsule, as shown in Fig. 2, consists of solid, melt-cast CsCl surrounded by two welded Type 316L stainless steel capsules, each with a wall thickness of 0.35 cm (0.136 in.). These capsules were originally designed for long-term storage in water, but have since undergone rigorous structural and Special Form qualification tests (Ref. 18) A recent review of safety issues pertaining to the use of these capsules as irradiation sources concludes that they meet the requirements for such use in irradiators (Ref. 19).

The capsules will be arranged horizontally in a single vertical plane in up to four source plaques which can be independently raised for product irradiation and lowered into the pool *during maintenance*, repair, or emergency situations. The WESF capsules

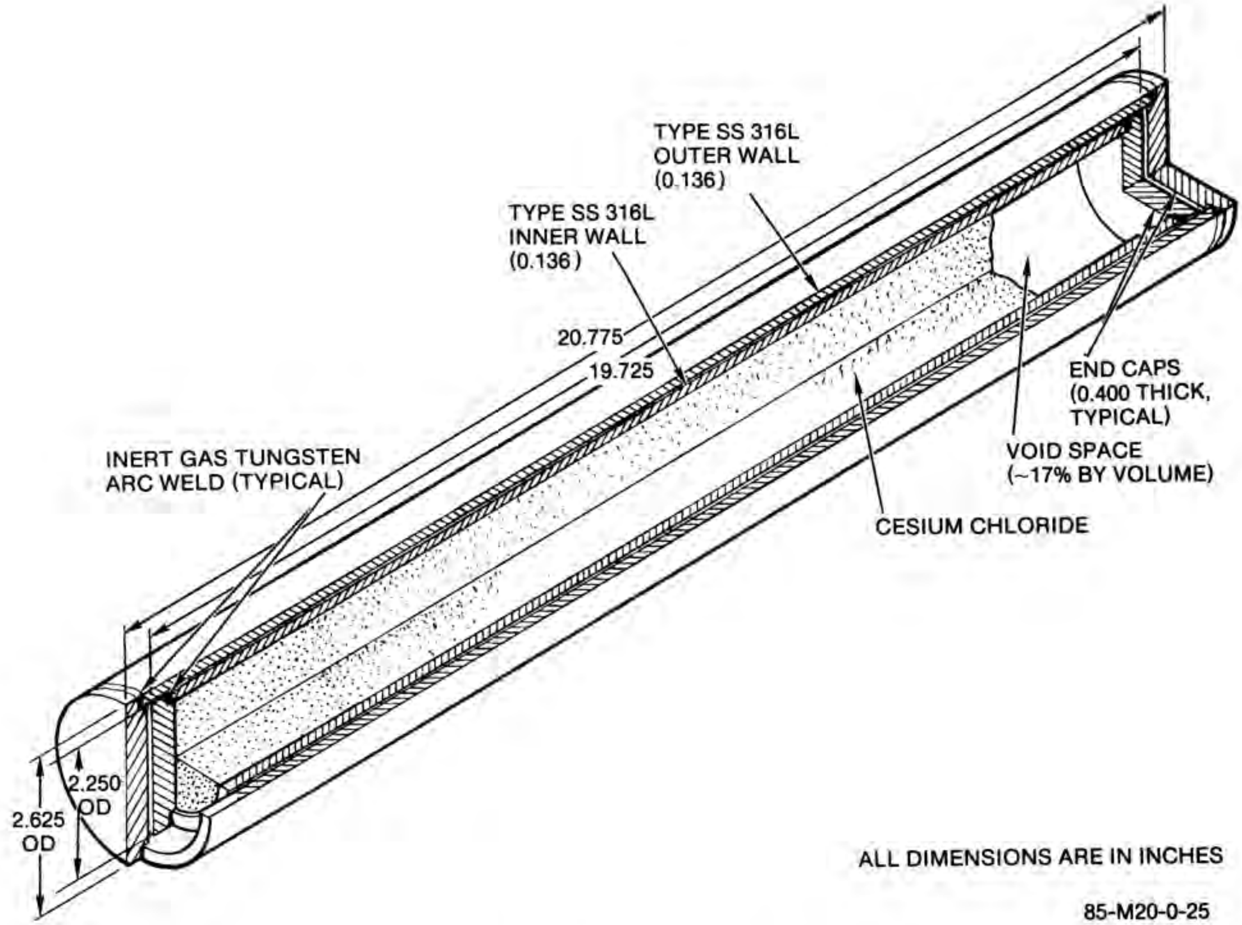

Fig. 2. WESF Cesium Chloride Capsule

will be interspersed with dummy capsules or spacers so that the total source height can be adjusted anywhere between 0.9 m (3 ft) and 1.8 m (6 ft). The flexibility in the vertical arrangement is important for verifying calculations, and for tailoring the sources to give maximum dose uniformities in the product. At the appropriate time, the source plaques will emerge from the water into a protective steel shroud and will be kept cooled to assure that the centerline temperature of the WESF capsules will not exceed 440°C. The sources will automatically return to their storage locations in the pool upon loss of power.

Source Storage Pool

The water pool inside the irradiation chamber will provide adequate shielding when the sources are in the stored position to allow personnel to work in the chamber, and will also be deep enough to shield the WESF ^{137}Cs sources during loading or unloading of the source plaques and the BUSS cask. The walls will be made of thick concrete and lined on the inside with stainless steel. Detailed ANSI N43.10 specifications for pool inlet and outlets with no wall penetrations will be followed. The pool will be located below the ceiling plug, and sufficient clearance will be available for the BUSS cask to be lowered beside the planar array of source plaques. A removable table, and special tools to open and close the BUSS cask and to load and unload the plaques, will be designed for use in the pool. A removable, shielded deionization unit located exterior to the irradiation chamber will maintain water quality and would be used for cleanup in the unlikely event of an accidental capsule leak. Temperature control will include water cooling should the heat transfer calculations so dictate.

Labyrinth

The labyrinth will allow food commodities to pass from the warehouse to the irradiation chamber. The path is designed so that the gamma rays will require at least four scattering events before they can exit the system. The personnel access door, with redundant interlocks, leads to the labyrinth from the control room. Reliable barriers at the entrance and exit of the labyrinth will permit product carriers to pass, but will be inaccessible to personnel.

Carrier System

An overhead commercial carrier system was chosen because it allows maximum flexibility while providing clear floor space for operating personnel and visitor convenience. This arrangement also allows moving the pallets unhindered to any desired distance from the source with no obstruction to the gamma rays. The carriers will be ~0.6 m x 0.6 m x 0.9 m high (2 ft x 2 ft x 3 ft high) and will be capable of holding six citrus cartons. The produce will be loaded into and unloaded from the carriers in the appropriate sections of the food handling warehouse. Provisions will also be made for carrying unpackaged (bulk) commodities. Up to five of the product carriers will provide the capabilities for irradiating the products under reduced pressure (down to 25 mm Hg) and in modified atmospheres such as nitrogen or CO_2.

Pallets

Loaded pallets with dimensions 1.22 m x 1.07 m x 1.52 m high (48 in. x 42 in. x 60 in. high) will be irradiated on two platforms which will be rotated in quarter turns or continuously (up to 1-2 rpm) by remote control. The positioning of the platforms in the chamber, and the loading of the pallets, will be done manually.

Equipment Room

The equipment room, which will be adjacent to the control room and to the irradiation chamber, will have such items as the pneumatic panels, pool chiller, water pumps, air filtration system, air compressor, and fire control systems. The water deionization unit will be located in an accessible, shielded area so that, in the case of a radioactive spill, it could be isolated, removed, and replaced without radiation exposure to personnel.

Laboratory and Office Area

A laboratory for product preparation (e.g., hot dip), temperature conditioning prior to irradiation, gamma dosimetry, quality control testing, and other testing will be provided. Two offices, a storage room, a reception area, etc., will also be included.

PLANT CAPABILITIES

The irradiation system will be designed with sufficient flexibility to provide total absorbed doses in the range 10 Gy to 10 kGy, and dose rates in the range 0.1 to 2 kGy/h. The system will be capable of processing at least 170 product carriers in an 8-h shift to a minimum dose of 1 kGy. For product carriers, a dose uniformity (max/min) of less than 1.3 is expected for a product packaged density of 0.6 g/cm^3.

In the case of products loaded on pallets and mounted on the rotating platforms, a dose uniformity (max/min) of ~2.0 will be achieved at a distance of 3.35 m (11 ft).

The Rockwell design concept allows the option of an extra pass of the product carriers on each side of the source plaque, and the option for modified carriers to be placed one above the other. These features can later be used to increase the volume of product flow, and to maximize source utilization. The validation of the efficacy of such arrangements, with actual measurements of the dose uniformities achieved using the various source and carrier configurations, is the type of information desired for designing future commercial plants.

Preliminary nuclear, shielding, and thermal calculations performed during the conceptual evolution of the CACI design indicate that the above capabilities can be incorporated into the plant. During the detailed design phase of the project, additional calculations will be performed to verify the data. Trade studies performed in conjunction with the design will facilitate optimization of the features. Finally, a development and test program is planned using Rockwell's versatile gamma irradiation facility with 12 WESF ^{137}Cs capsules to validate and benchmark the calculational data.

SAFETY

An uncompromising, design-in-depth and multiple-barrier safety philosophy is a key element of the CACI design. CACI will be built in accordance with the safety requirements of ANSI N43.10. Since CACI will be built and operated under an NRC or an appropriate Agreement State license, the requirements of the NRC Regulatory Guide 10.9 on irradiators will be met. Preliminary and final safety analyses will be performed concurrently with the design, for approval by the appropriate agencies. The analyses will include verification of the adequacy of the shielding, structures, controls and interlocks. Shielding for the irradiation chamber and its roof plug will be sufficient to keep the level of radiation to all accessible areas inside and outside the plant to below 0.25 mR/h.

During the conceptual design of CACI, attention was focused on safety issues pertinent to the use of the WESF capsules. This included a preliminary thermal analysis to determine the cooling requirements for the source plaques so that the centerline temperature of the capsules always remains well below the solid-phase transition temperature of cesium chloride (460°C). In addition, design features to isolate a leaking WESF capsule, to handle its removal, and to decontaminate the storage pool have been incorporated.

A rigorous radiation protection and safety program and a personnel training manual will be developed specifically for the CACI operators and health physics personnel. The program and the manual will comply with the licensing requirements and will be based on the extensive health physics and radiation safety training capabilities available at Rockwell's Training Center.

In conclusion, the CACI will be designed and built to meet all of the goals of the DOE's Byproduct Utilization Program. It is anticipated that the U.S. food processing industry will actively participate in CACI's research and development programs. To this end, it will serve as a flexible tool to transfer the technology toward commercialization of the food irradiation process.

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