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HANDBOOK FOR THE EXPERIMENTAL OPEN–POOL IRRADIATION FACILITY OF THE LETABA CO-OPERATIVE LIMITED, AT TZANEEN

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ATOMIC ENERGY BOARD

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'n Volledige tegniese uiteensetting van die eksperimentele voedselbestraler wat gesamentlik deur die Raad op Atoomkrag en die Letaba Koöperasie Beperk op Tzaneen opgerig is, word gegee. Die ingebruikstelling van die bestraler, dosismeting en bedryfsprosedures word bespreek. Aandag word gegee aan die regulatoriese beheer van 'n sodanige bestraler en 'n uiteensetting van moontlike ongelukke en die gepaste optrede daarna, word voorsien.

ABSTRACT

A detailed technical description of the experimental food irradiator which was jointly established by the Atomic Energy Board and the Letaba Co-operative Limited at Tzaneen, is presented. The commissioning of the irradiator, the dosimetry and the plant operating procedures are discussed. Attention is paid to the regulatory control of such an irradiator, and a hazards evaluation and the appropriate action to be taken is provided.

CONTENTS

1. INTRODUCTION

The potential role of gamma irradiation in the treatment of subtropical fruit was investigated intensively over several years by the Atomic Energy Board in collaboration with the Letaba Co-operative Limited at Tzaneen [1–5]. The stage was eventually reached at which a closer comparison between laboratory-scale experiments and normal commercial production practice became necessary. To meet this requirement and to investigate the marketing and consumer acceptance of such irradiated subtropical fruit, it was jointly decided by the two principals to establish a large-scale experimental gamma irradiator at Tzaneen.

Because of the capital-intensive nature of a fully automated commercial irradiation plant, it was decided to erect a simple and inexpensive batch-type pool irradiator capable of irradiating relatively large quantities of fruit. Although this type of irradiator can contribute little additional information to the radiation-technological and economic aspects of a true commercial irradiator, it enables large volumes of fruit to be irradiated for a relatively small capital investment. Furthermore, the versatility of this design lends itself to a wide range of applications.

This report details the technical aspects, regulatory requirements and safety hazards associated with running the Letaba plant. In drawing up this report the recommendations of the Codex Alimentarius Food Additives Committee on food irradiation were followed. This was done in order to bring the operation of the plant in line with anticipated international practice.

2. PLANT DESCRIPTION AND SPECIFICATIONS

2.1 Source Storage Pool

The pool is 2,286 m long by 1,830 m wide and has a depth of 5,850 m (Fig. 1). The pool wall is of a double-wall concrete construction, separated by a glass-fibre membrane.

The pool walls and floor are tiled and the grouting between the tiles is coated with three coats of an epoxy resin to prevent leaching away of the cement by the demineralised pool water. The pool is filled with municipal water which is continuously circulated through a 5 μm filter with a part flow through a double-bed resin ion-exchange column.

A water-level monitor, connected to an audible alarm, is positioned at the poolside and is designed to be activated in the event of the pool-water level falling more than 25 cm below the proper level. The monitor operates on the principle of measuring the conductivity between two probes.

A movable bridge spans the pool to facilitate handling operations. The pool is normally partially covered with wooden boards, strong enough to take foot traffic, which are only removed during source loading or source augmentation.

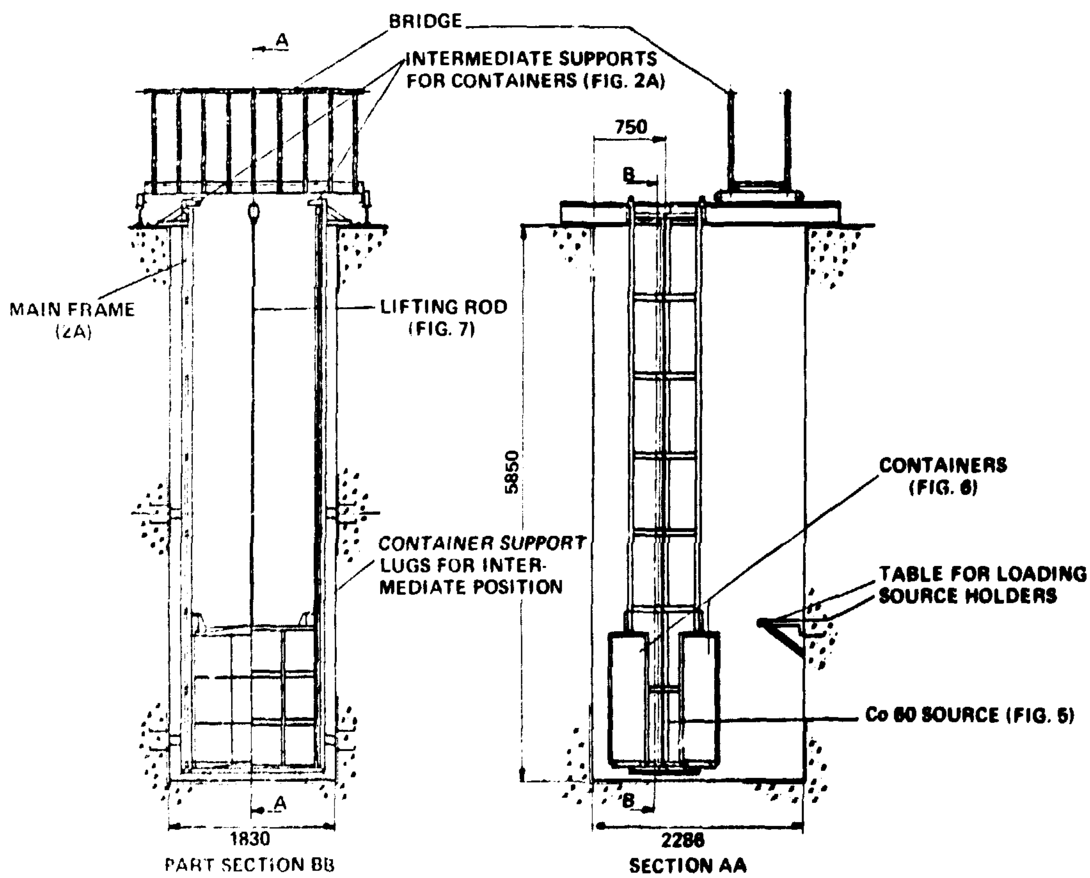


FIGURE 1
SOURCE STORAGE POOL

2.2 Main-Frame Construction

The main frame is constructed of austenitic stainless steel (M 316) and is located in the pool on brackets cast into the pool walls (Figs. 2A and 2B). This frame has guides to position both the irradiation containers and the source frame. It incorporates a locking device to ensure that the source frame cannot be inadvertently raised.

The container guides can be positioned such that the distance from the source centreline to the nearest face of each irradiation container can be varied between 23 and 197 mm.

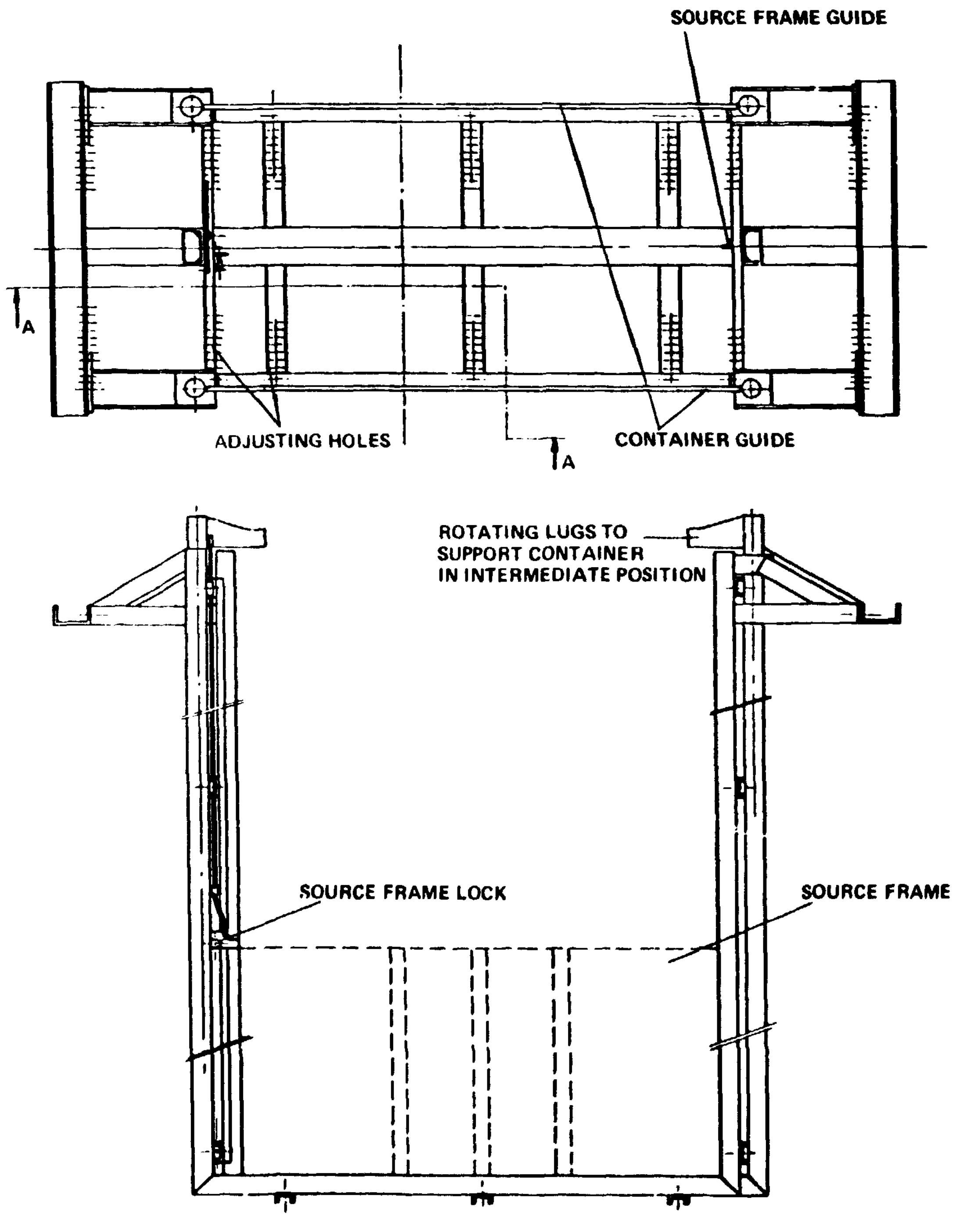


FIGURE 2A
MAIN-FRAME CONSTRUCTION

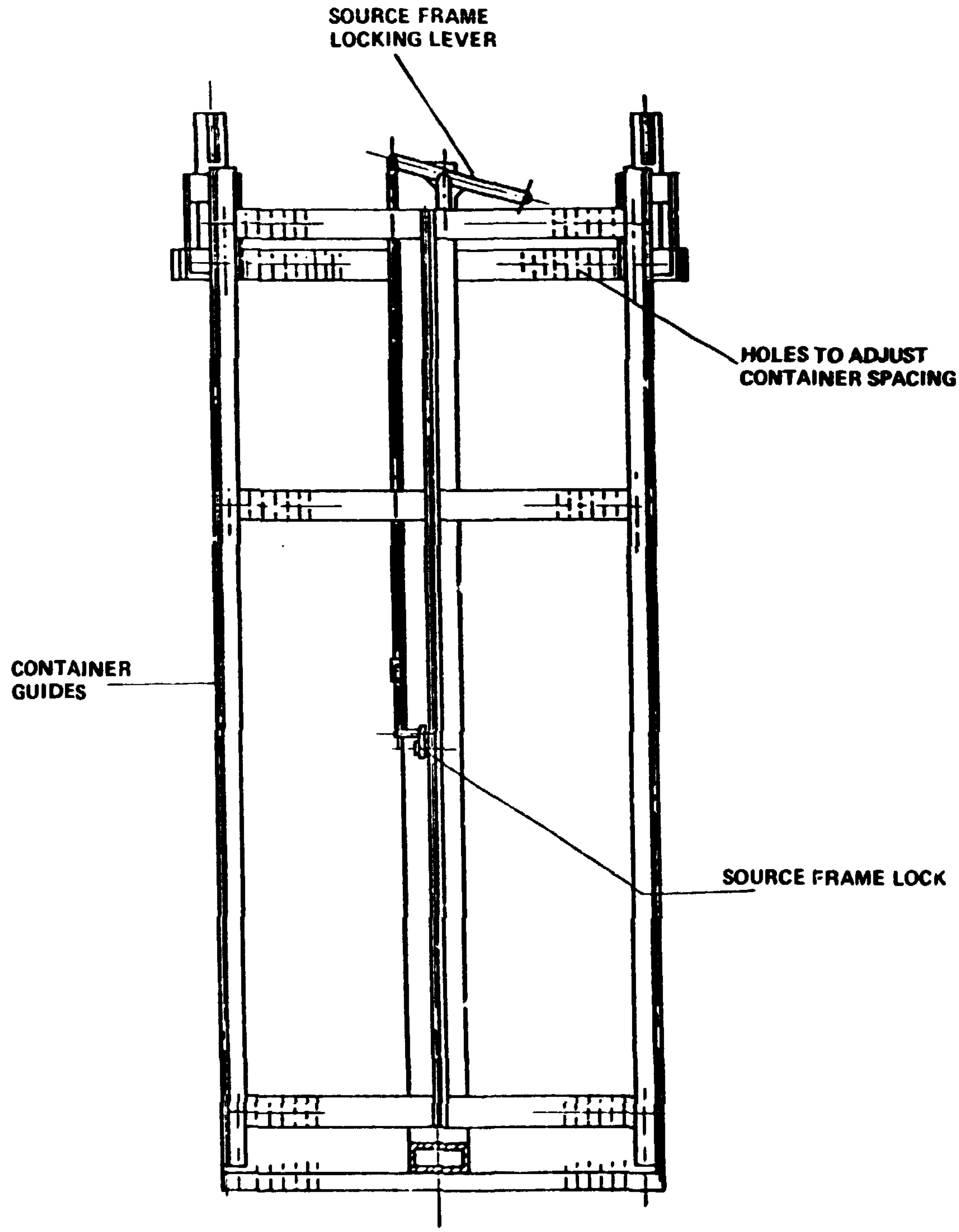


FIGURE 2B
MAIN-FRAME CONSTRUCTION

2.3 Source-Frame Construction

The source frame (Fig. 3) is also constructed of austenitic stainless steel (M 316) and is fitted with guides to locate it centrally within the main frame. This frame has provision to house 12 source modules which can each carry 30 active source pencils or non-active spacing rods (dummy pencils).

2.4 Source-Module Construction

The 12 source modules are constructed of austenitic stainless steel (M 316). The top and bottom channel sections provide a captive guide to retain the source pencils and non-active spacing rods (Fig. 4).

The source modules are sequentially laid horizontally on a loading table attached to the pool wall. After each source odule has been loaded the locking lever is rotated and the loaded module transferred to the source frame.

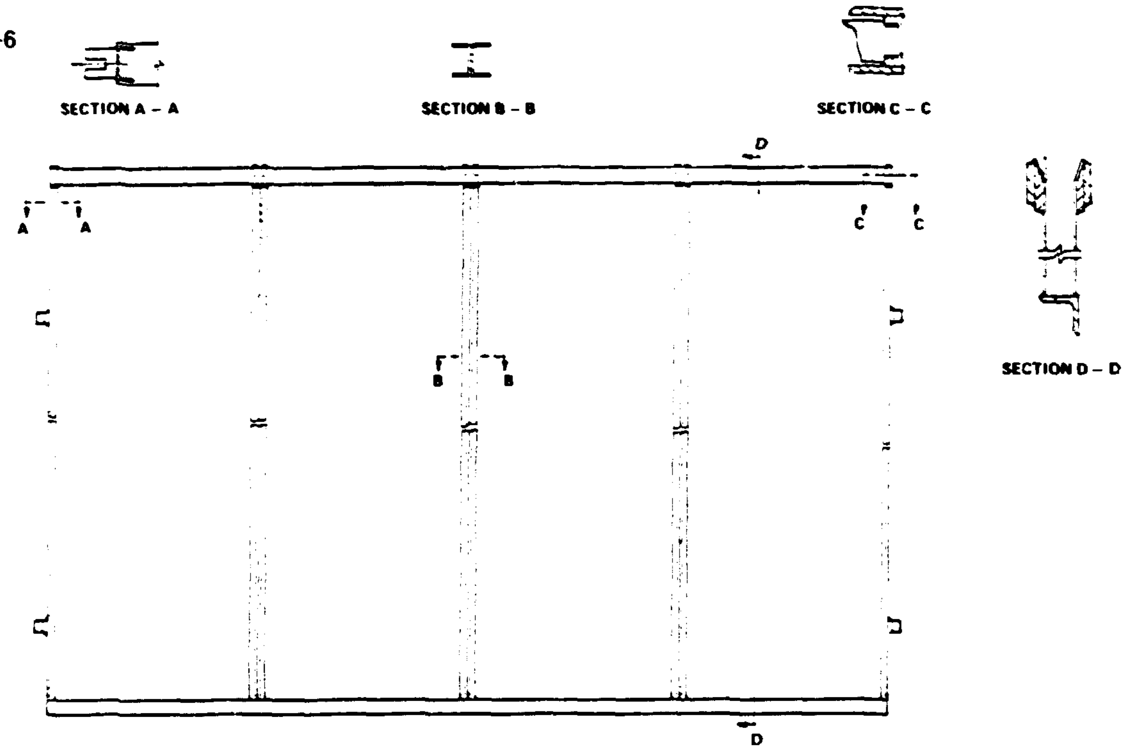


FIGURE 3
SOURCE-FRAME CONSTRUCTION

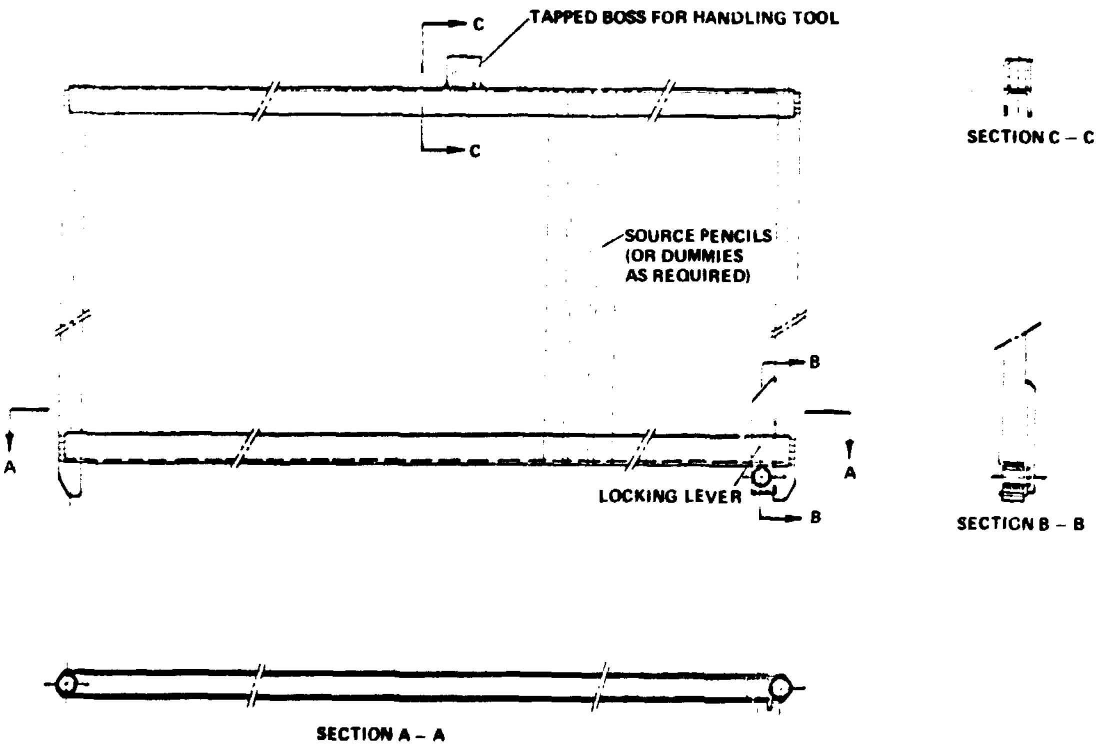


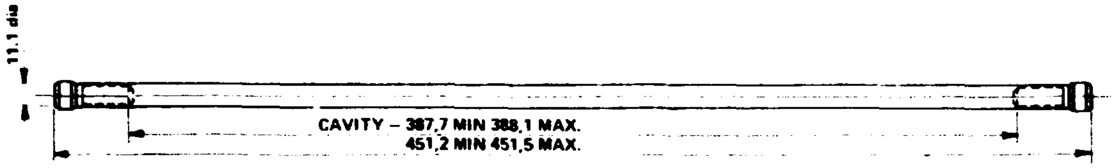
FIGURE 4
SOURCE-MODULE CONSTRUCTION

2.5 Cobalt-60 Pencils

The active cobalt is doubly encapsulated in austenitic stainless steel (Fig. 5). Each encapsulation forms a vacuum-tight welded assembly.

Initially a total of 46 active pencils, with a nominal activity of 45 kCi, spaced by non-active stainless steel rods, will be installed to provide the correct radiation profile at the irradiation-container face. A maximum activity of 500 kCi may be installed before cooling of the pool water will become necessary.

The initial cobalt-60 source consists of 22 pencils of Canadian design and manufacture (type C-188 source element assembly) [6] and 24 pencils of South African manufacture to Canadian specifications. The specific activity of these pencils is 9 Ci/g at time of installation.



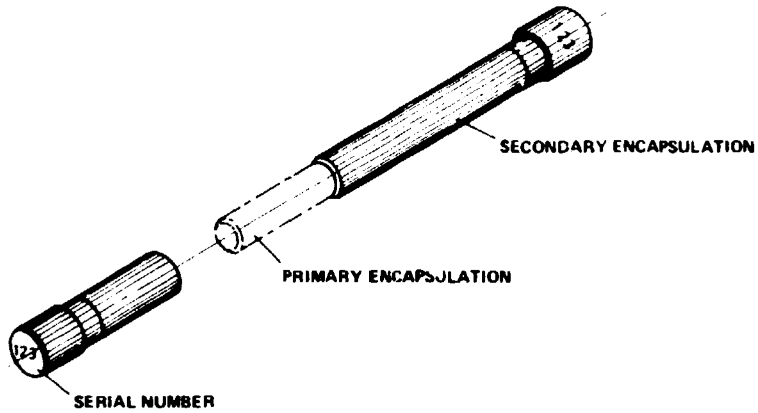


FIGURE 5
COBALT-60-PENCIL CONSTRUCTION

2.6 Irradiation Containers

The irradiation containers are constructed of aluminium (B51S) and are guided by the main frame when being either raised or lowered (Fig. 6). The decision to manufacture the irradiation containers from aluminium was based purely on economic considerations. Irradiation containers manufactured from stainless steel will be required if the project extends to the long term because of the inherent corrosion problems associated with demineralised water.

The irradiation containers are designed to withstand an external pressure of 100 kPa. The water pressure on the containers during irradiation at a depth of 5,8 m is 50 kPa and the containers are therefore structurally sound at this depth.

The containers can be opened at one end for loading purposes. The lid/container interface is sealed by a Neoprene rubber gasket and screw-operated pressure clamps. The loaded mass of a container is about 600 kg.

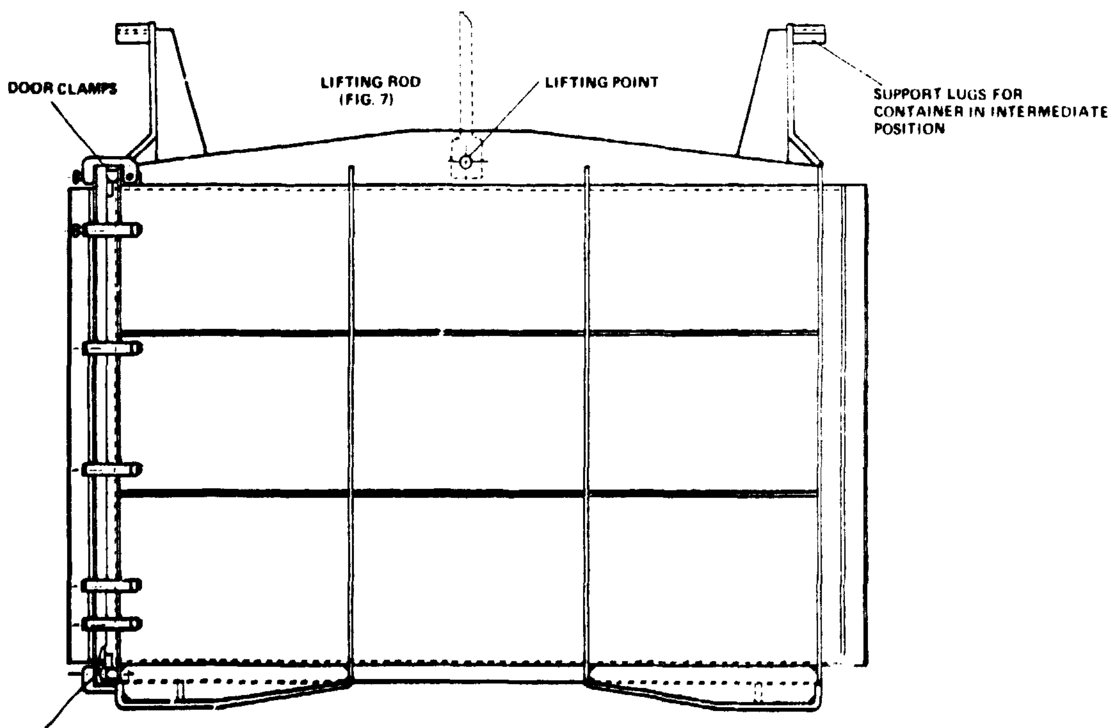


FIG. 6. IRRADIATION CONTAINER

FIGURE 6
IRRADIATION CONTAINER

2.7 Irradiation-Container Lifting Rod

Each irradiation container is lifted initially by means of the overhead crane with a standard shackle fitted to the containers. The container is then supported on the support lugs on the main frame while the standard shackle is removed and the lifting rod (Fig. 7) fitted. With the lifting rod attached to the crane hook the rotating support lugs are turned through 180° and the container finally lowered to the irradiation position. The same procedure is subsequently followed for the second container. The use of the lifting rod avoids having to submerge the crane hook and wire rope in the demineralised pool water.

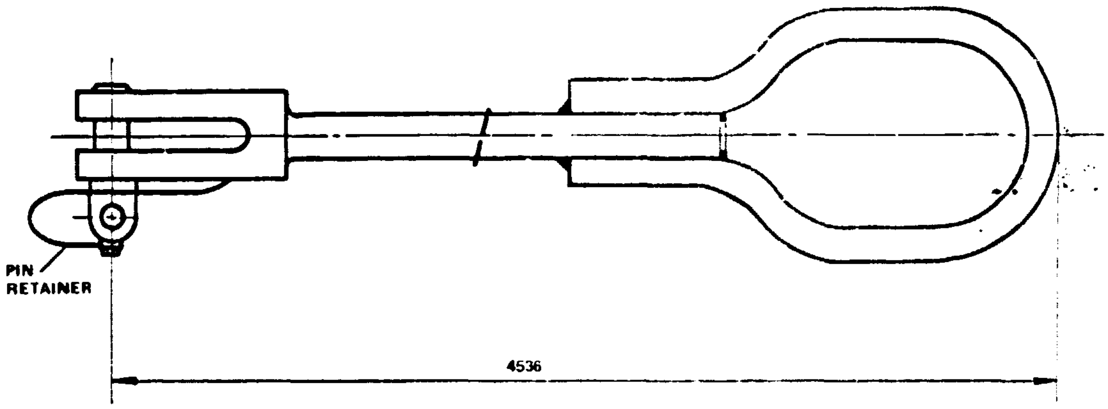


FIGURE 7
IRRADIATION-CONTAINER LIFTING ROD

2.8 Water Treatment Plant

The water treatment plant is a series system comprising a self-priming pump, a 5 μm cartridge-type filter and a deioniser unit. The deioniser unit is rented under an exchange service. The unit carries an indicator light which is lit under normal operating conditions and goes out when the ion-exchange resin is depleted to a conductance of 5 μS

2.9 Radiation and Contamination Monitoring Equipment

A gamma alarm is situated 1 m from the edge of the pool at a height of 3 m above floor level. This level was chosen to obviate any possible damage during operation of the plant without affecting the efficiency of the monitor. This monitor serves as a background monitor, and also as an alarm should either an active scurce be raised inadvertently or the pool water drop to an unsafe level. The alarm is preset to operate at an exposure rate of 2,5 mR/h (at this point the exposure rate on the pool surface will be 150 mR/h).

A portable battery-powered radiation monitor is provided to be used whenever the irradiation building is entered.

A contamination monitor with an adjustable audio threshold is situated next to the ion-exchange column to monitor any radioactive contamination collected, such as that originating from a leaking source pencil. This monitor is set to operate at a rate representing 100 counts/s (i.e. about three times the normal background level).

2.10 The Irradiation Building and Services

The building is constructed from two massive A-frames clad with corrugated steel sheet (Fig. 8). The concrete floor is [illegible] 1,5 m above ground level. A central I-beam at the apex of the building carries a one-ton electric hoist to handle the irradiation containers. This I-beam can also accommodate a five-ton mechanical hoist to handle the source transport container during source loading operations.

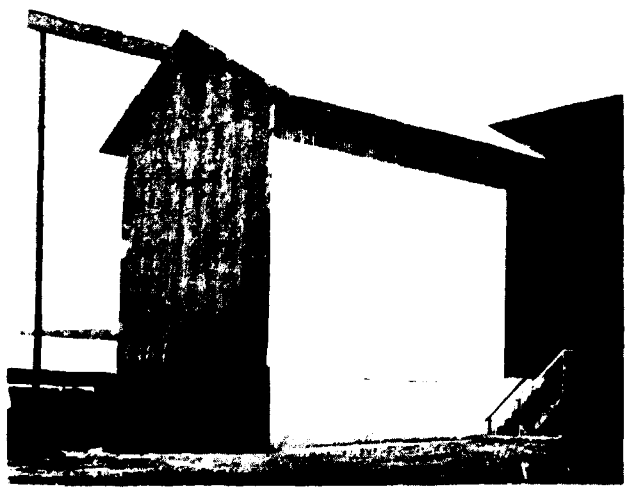


FIGURE 8
THE IRRADIATION BUILDING

No permanent domestic water supply is laid to the building, but provision is made to supply emergency make-up water to the pool via a 25 mm galvanised pipe feeding municipal water at a pressure of about 400 kPa. The control valve for this supply is situated approximately 10 m from the irradiation building and below the building floor level.

Normal domestic electricity and a 380 V 3 phase supply is fed to the building. A light situated at the entrance to the irradiation building and fed directly from the mains without any in-line switch, is illuminated to verify that power is supplied to the building.

Radiation warning signs are prominently displayed at the entrance to the irradiation building, prohibiting all unauthorised entry to the building. The names and telephone numbers of the Plant Supervisor and his Deputy are also indicated.

3. PLANT COMMISSIONING

3.1 Prior to Source Loading

As each facility component is installed it is checked for correct operation before proceeding with the next stage of assembly. The component checks include the following:

- The integrity of the main frame is first checked.
- Each source module is loaded with non-active spacing rods and placed into the main frame.
- The complete assembly is then lowered to the bottom of the empty pool to test its free movement in the main frame.
- Whilst the source frame is at the bottom of the pool, a positive check on the correct functioning of the locking device must be carried out.
- Both irradiation containers are subsequently positioned in the main frame and lowered to the bottom of the pool to ensure their free movement.
- The handling table is lowered onto its brackets in the pool wall.
- With the irradiation containers positioned at the bottom of the pool, the pool is filled with water to the appropriate level.
- The previously mentioned mechanical checks are repeated, and the non-active spacing rods are removed from the pool, using the remote handling tools.
- The water-level monitor is checked for correct functioning during the initial filling of the pool.
- The underwater visibility must be such that a radioactive pencil dropped during loading operations can be easily seen and retrieved, before commencing with the source loading.
- Prior to the admission of the transport container carrying the active pencils into the irradiation building, all radiation and contamination monitors must be checked and calibrated by the health physicist from the Atomic Energy Board, to check their correct functioning and preset alarm levels.

3.2 Source Loading

Source loading must be carried out to a pre-determined pattern by the personnel of the Radiation Technology Subdivision of the Atomic Energy Board in the presence of a health physicist. A copy of the source loading pattern must be included in the permanent Plant Record Book. No amendments to this pattern may be made by anyone other than the personnel of the Radiation Technology Subdivision who are also responsible for recording the source-plaque configuration.

4. PLANT DOSIMETRY

4.1 Dosimetry System to be Used

Various techniques for dosimetry pertinent to gamma irradiation sources are available for measuring absorbed dose in a quantitative manner [7]. For the relatively low irradiation doses associated with food irradiation, the ferrous sulphate dosimeter (Fricke dosimeter) should be used for both dose-distribution measurements and routine dosimetry. Full details of this system are described in reference 7.

4.2 Determination of Absorbed-Dose Distribution

In order to establish the dose distribution throughout the product to be treated, dosimeters must be placed in suitable numbers throughout the irradiation containers, with the specific fruit to be irradiated in position. These dosimeters must be placed at such positions as to give the best indication of absorbed-dose variability in order to determine the dose-uniformity ratio for a specific product. Once the dose distribution is established and the mean value determined, the irradiation time which will ensure that at least the specified minimum dose is given and that the allowable maximum dose is not exceeded for a specific application, must be established.

Whenever the source size or its geometry is changed, or the type of product to be processed is changed, the procedure described above must be repeated and the results recorded.

Initial dose-distribution determinations must be carried out by suitably qualified personnel of the Atomic Energy Board, or by personnel of the Letaba Co-operative Limited under the supervision of Atomic Energy Board personnel. These initial dose distributions must be submitted for scrutiny to personnel of the Radiation Technology Subdivision, who will check for any possible anomalies between the measured and theoretical values.

4.3 Routine Dosimetry Required

Since the bulk densities of the products to be irradiated may vary over wide limits, and the procedures are not automated, it is essential that each irradiation container carries at least two dosimeters in order to verify that the correct dose is given to the product. These dosimeters must be placed in the maximum and minimum dose-rate positions in the irradiation containers, as determined experimentally.

As the dose-uniformity ratios associated with this type of plant are necessarily large, it is mandatory that the irradiation containers be turned through 180° after half of the irradiation time has elapsed.

The dosimetry results obtained for every irradiation must be recorded in the permanent Plant Record Book.

5. PLANT OPERATING PROCEDURES

Basic operating procedures on this type of irradiator are extremely simple and merely consist of the following:

- **Packing each irradiation container as uniformly as possible, together with the routine dosimeters.**
- **Closing the containers to ensure a watertight seal.**
- **Lowering the containers to the source plaque for half of the pre-determined irradiation time.**
- **Lifting and rotating the containers through 180°.**
- **Removing the containers from the pool.**
- **Loading the second pair of irradiation containers whilst the first irradiation is under way (if necessary).**

6. PLANT REGULATORY CONTROL

This irradiation facility will be operated by the Letaba Co-operative Limited with the authorisation of the Atomic Energy Board (in respect of the possession and utilisation of radioactive material) and the Department of Health (in respect of the control of irradiated food).

6.1 Plant Supervisor

One person must be designated as Plant Supervisor by the Letaba Co-operative Limited management to be responsible for the overall supervision of the experimental irradiation facility. This person must be named and acceptable to both the Atomic Energy Board and the Department of Health and must be qualified for such responsibility. He must have direct access to both production management and top management of the Letaba Co-operative Limited. Laboratory facilities and suitably qualified personnel for radiation dosimetry must be at his disposal.

A Deputy to the Plant Supervisor must also be nominated. This person must also be named and acceptable to both the Atomic Energy Board and the Department of Health and must be qualified for such responsibility.

6.2 Plant Operators

The day-to-day running of the irradiator is carried out by plant operators under the direct supervision of the Plant Supervisor or his designated Deputy. Such plant operators are only allowed to carry out the radiation processing of food in the presence of either the Plant Supervisor or his Deputy.

6.3 Permanent Plant Records

The Plant Supervisor must ensure that a permanent Plant Record Book is kept. In this logbook the following information must be recorded:

- The geometry of the source plaque and all subsequent amendments.
- Detailed dose-distribution measurements for all products irradiated.
- The date of treatment, the nature of the product treated, the irradiation time, and the dosimetry results for all the individual irradiation containers of a particular batch.
- Any malfunctioning of the plant or its associated equipment.
- All relevant details of the periodic tests made on the water-level alarm, pool water analyses for radioactivity, the contamination monitor and the radiation monitors.

6.4 Administrative Controls

The following general administrative controls must be exercised in the course of the normal day-to-day running of the plant.

- Personal monitoring devices must be worn by all personnel employed in the plant. The Isotopes and Radiation Division of the Atomic Energy Board is responsible for the specifications of such monitoring devices.
- The incoming product must be physically separated from the outgoing irradiated product.
- The access door to the irradiation building must be lockable and the keys under the direct control of the Plant Supervisor.
- Emergency procedures to be followed in the event of any incident described in paragraph 7 occurring, must be prominently displayed in the irradiation building.
- If the power indicator light at the entrance to the irradiation building is extinguished, the building must not be entered until it has been verified that there is no power failure. In the case of a power failure the building must not be entered until such time as the power has been restored.
- Should any warning system become activated, all activity in the irradiation building must cease and the building must immediately be evacuated. The Plant Supervisor must then decide what further steps should be taken.

- The Plant Supervisor must ensure that only products which have received the necessary clearance by the Department of Health are irradiated for release to the public. The particular stipulations in the clearance for a specific product must be strictly adhered to.

- The Plant Supervisor must inform the Department of Health of the commissioning of the plant and provide them with a plan of the source geometry, the nominal installed activity of the source and the results of the absorbed-dose distribution measurements for every particular product that may be irradiated. Any subsequent changes in the source geometry or activity must also be submitted to the Department of Health.

- Nobody is allowed to enter the building unless the Plant Supervisor or his Deputy is present.

- There must be at least two persons present whenever any operations in the pool are carried out.

6.5 Physical Controls

The following physical checks must be carried out:

- A weekly inspection of the contamination monitor, gamma alarm and the radiation monitor must be carried out by the Plant Supervisor using a radioactive test source supplied by the Isotopes and Radiation Division of the Atomic Energy Board. Instructions on the use and storage of this test source must be given to the Plant Supervisor by the Inspecting Physicist from the Atomic Energy Board. The results of these tests must be recorded in the permanent Plant Record Book.

- A monthly functional test of the water-level alarm must be carried out. This test must be carried out by immersing the conductivity probe in a water-filled closed container and then siphoning out the water to test whether the alarm becomes activated. The results of these tests must also be recorded in the Plant Record Book.

- Pool-water samples must be taken monthly and sent to the Chemical Operations Division of the Atomic Energy Board for radioactivity monitoring. The results of these analyses must be forwarded by the Atomic Energy Board to the Plant Supervisor for inclusion in the Plant Record Book. A copy of these results must also be retained by the Chemical Operations Division of the Atomic Energy Board. Instructions on the sampling of the pool water must be given to the Plant Supervisor by the Inspecting Physicist from the Atomic Energy Board.

- The depleted ion-exchange resin of the water treatment plant must be monitored with the contamination monitor before being returned to the rence [illegible]. Should the measured count rate exceed 100 counts/s the resin must not be returned and the Radiation Technology Subdivision of the Atomic Energy Board must be informed.

If any of the abovementioned instruments are found to be defective, all radiation processing must cease until the fault has been rectified.

7. PLANT SAFETY HAZARDS AND REMEDIAL ACTIONS

The safety hazards associated with the [illegible] facility and appropriate remedial actions to be taken should they occur, are as follows:

7.1 Massive Leak in Storage Pool

Should a massive leak occur in the storage pool it would result in a loss of radiation shielding. The depth of the pool would provide a reasonable degree of collimation to radiation from completely exposed sources. An estimate of the radiation levels to be expected from a completely exposed 50 kCi cobalt-60 source at the bottom of the pool was made from experimentally determined figures obtained from measurements made at a similar pool at Pel[illegible].

The values are as follows:

Location	[illegible] level
Poolside	[illegible] R/h
Immediately outside building	[illegible] R/h
Emergency water make-up valve	[illegible] mR/h

The Le[illegible] laid down by Atomic Energy of Canada Limited. Pools to these specifications have so far accumulated more than [illegible] 000 pool-years of use without a single breach occurring.

In the event of a serious leak occurring the first action must be to immediately evacuate the building and to open the valve controlling the emergency water supply (as described in paragraph 2.10) in an attempt to maintain a safe water level. All further activities must be suspended and the building locked to await further action by the Atomic Energy Board.

7.2 Raised Source

If a source (or part of a source) should become attached to one of the irradiation containers being raised out of the pool, a very intense radiation field would result. In the event of the entire source plaque, containing 50 kCi of cobalt-60, being raised to the pool surface, an exposure rate of the order of 25 000 R/h would be experienced.

No specific figures are available to enable a probability level to be assigned to a radioactive source being raised inadvertently. The design of the main frame assembly is such that the chances of a source being raised are considered to be extremely remote. As it is not possible to raise an irradiation container very quickly, the poolside radiation monitor alarm will warn the operator before the dose rate reaches unacceptable levels, as described in paragraph 2.9.

In the event of a source being raised together with an irradiation container, the immediate action must be to lower the container and investigate the cause. After lowering the irradiation container the power supply to the electric hoist must be cut and the Atomic Energy Board informed.

7.3 Personnel Falling into Storage Pool

It is considered that the conventional risk associated with a person falling into the pool is greater than the radioactive risk.

To minimise this hazard, as much of the pool surface as is consistent with normal operations must remain covered by foot boards. During all operations there must be a minimum of two plant operators present.

7.4 Radioactive Contamination

Contamination of the pool water would take place in the event of a leak occurring in any of the radioactive source pencils. Experience with the open-pool irradiation facility at Pelindaba has shown that any radioactive contamination in the pool water is quickly and efficiently collected on the filter and ion-exchange column of the water treatment plant. Such an incident occurred at Pelindaba during the dismantling of an obsolete self-contained irradiator, the source pencils of which were only singly encapsulated and thus much more prone to leaking than the standard Atomic Energy of Canada Limited design.

Since the source pencils used in this facility are manufactured to an extremely rigid specification and undergo a series of stringent leak tests, the probability of a leak occurring in a specific batch of source pencils is considered to be less than that described in paragraph 7.1 for a massive leak in the storage pool. During the fifteen years that pencils have been manufactured to these specifications no incident of a leaking pencil has been reported.

Should contamination of the pool water be detected, through the contamination monitor on the ion-exchange resin and or the monthly analyses of the pool water by the Atomic Energy Board, the plant must be evacuated and the door locked, pending the arrival of Atomic Energy Board personnel.

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