NUKLEONIKA 2017;62(4):303–309
doi: 10.1515/nuka-2017-0044

TECHNICAL NOTE

Development of the irradiation facility SIBO INRA/Tangier, Morocco by upgrading cobalt-60 in a temporary pool and enhancing safety and control features

Mouhib Mohammed, Chentouf Mouad, Guessous Amina

Abstract. An automatic control system is one of the most important parts of an irradiation facility. The level of this control is always maintained to comply with safety procedures during routine work in this field. Also sometimes it is limited to the minimum level of regulation required due to economical aspects; some commercial systems are generally made by manufacturers of industrial facilities and considered affordable by irradiators. In some cases specific irradiation facilities tailor their control systems to their needs. For this kind of irradiator the control system can be developed and upgraded according to personal and industrial experiences. These upgrading procedures are also used by others to develop their systems. The objective of this paper is to share a local experience in upgrading security, safety systems and the use of cobalt-60 for the irradiator. It is a composite experiment at SIBO INRA/Tangier, Morocco and concerns the: (i) upgrade of cobalt-60 in a temporary pool in the SIBO irradiator in Tangier. This operation was conducted in collaboration with the International Atomic Energy Agency (IAEA) and was a success story of 2014 according to the general conference of IAEA; (ii) safety and technical upgrade of the system in the SIBO irradiator made in collaboration with IAEA; (iii) installation and upgrade of the security system in accordance with the Global Threat Reduction Programme (GTRP) to reduce the threat of a Radiological Dispersal Device (RDD) in collaboration with The United States Department of Energy's National Nuclear Security Administration (NNSA).

Keywords: gamma irradiator • temporary pool • nuclear safety • dry store irradiator • cobalt-60 • security systems

M. Mohammed[✉], C. Mouad
National Institute for Agronomical Research (INRA), Regional Center of Tangier,
Irradiation Facility of Boukhalef (SIBO),
78 Av Sidi Mohamed Ben Abdellah, Tangier, Morocco,
Tel.: +2126 6125 8388, Fax: +2125 3993 8033,
E-mail: momouhib@yahoo.fr

G. Amina
La Faculté des Sciences IBN TOFAIL de Kenitra, Morocco

Received: 4 April 2017
Accepted: 29 December 2017

Introduction

It is estimated that more than 400 gamma ray irradiators are currently in operation all around the world. They exhibit advantages in comparison with other known methods, for example, gamma radiation processing is being more intensely applied for the sterilization of healthcare products including pharmaceuticals, in the irradiation of food and agricultural products, and in material modification processes, such as polymerization, polymer crosslinking and gemstone colouring. In the case of safety critical systems, such as at irradiation facilities, requirements concerning impeccable degrees of safety and reliability are of paramount importance. Based on principles concerning the initial design of the facility, on experience over more than 20 years and on the study of the performance of the equipment used in the facility, the Failure Mode and Effects Analysis (FMEA) [1], also known as Failure Modes, Effects and Criticality Analysis (FMECA), was used.

Failure Mode and Effects Analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. "Failure modes" means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual. "Effects analysis" refers to studying the consequences of those failures. Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the ones of highest priority. Failure Mode and Effects Analysis also documents current knowledge and actions about the risks of failures for use in terms of implementing continuous improvement. FMEA is used during the design process to prevent failures. Later it is used for control, before and during the ongoing operation of the process.

This paper will first present the organization, operation and safety elements of the panoramic irradiator with dry store at the facility [2]. Then the specific operation of cobalt-60 replenishment, the upgrading of technical and safety systems and finally the implementation and upgrade of the security system will be presented.

The system has been implemented by use of the latest advances in computer and information technology.

La Station d'ionisation de Boukhalef (SIBO) irradiation facility

The facility is a panoramic irradiator with dry store of cobalt-60 in a container used also as a transport container during the first loading. It is the first one in Morocco and was installed in 1995 [2]; in order to introduce this technology in Morocco the characteristics of this facility are as follows: irradiation cell – 6.1 m long, 5.8 m wide, 2.6 m high.

Three exposition systems have been installed around the source (Fig. 1):
- 4 big turntables for high doses
- 4 small turntables adjustable in two dimensions for medium doses
- 1 turntable for low doses
- type of the storage flask: SV-68 B(U)
- year of manufacture: 1994
- dimensions of the flask: Ø 770 mm × 1160 mm
- material: stainless steel case coated in lead
- weight: 4940 kg
- source holder: round holder with 20 pencil positions, at present two positions contain source pencils
- source dimensions: 11.1 mm (diameter) × 451.4 mm (height)
- cavity of the flask for sources: Ø 131.5 mm × 615 mm
- original source activity: 15 684 Ci (on 1st April 1995).

Safety condition: three independent interlock systems, two fixed gamma detectors (Fig. 2) and one personnel detector. The unit is controlled by a programmable logic controller (PLC) system (Fig. 3).

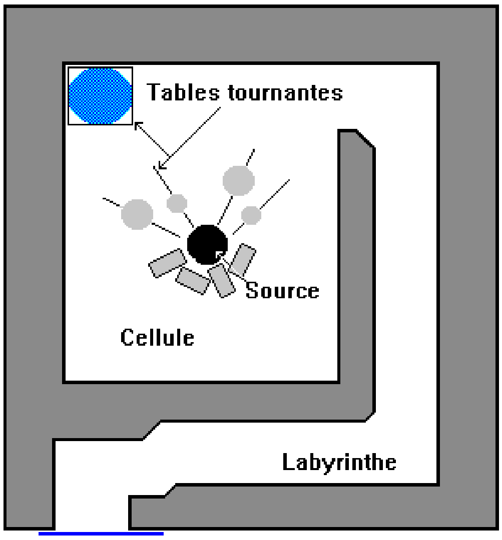

Fig. 1. Original turntable system.

Fig. 2. Initial radiation monitoring system.

Fig. 3. Operation panel of the initial control system.

The first upgrade was conducted by adding two big turntables and two calibrated points in order to have the possibility to irradiate more products in big turntables and have a calibrated point used for the calibration of dosimetry systems [2] (Fig. 4).

Twelve cages (75 × 50 × 153 cm) to place on the six big turntables for semi-industrial purposes have also been realized.

This operation was conducted in the year 2000 in order to prepare the facility for the upgrade of cobalt-60 to 60 kCi.

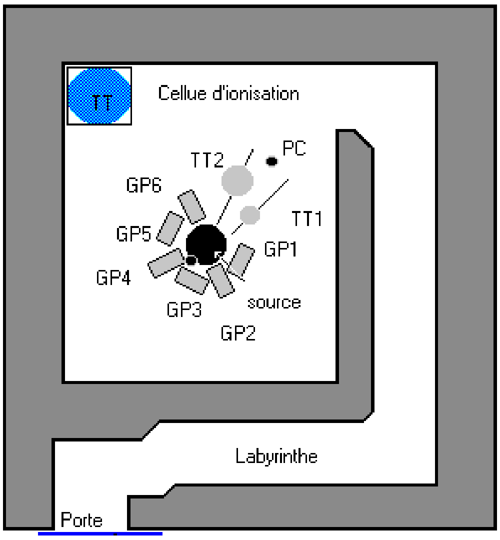

Fig. 4. Modified turntable system.

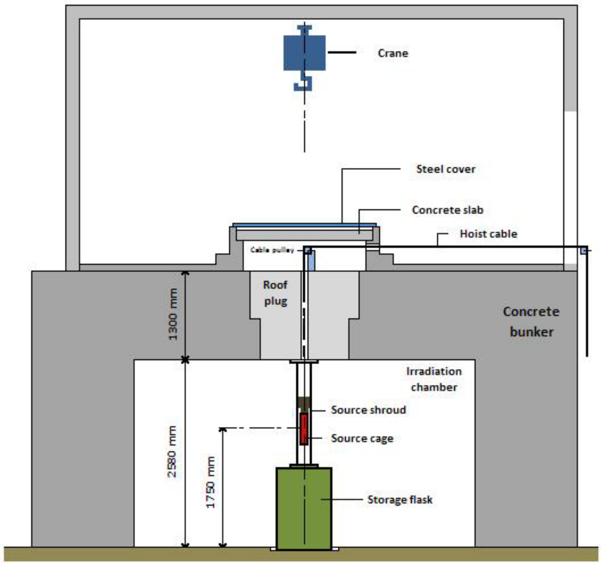

Fig. 5. Vertical cross-section of the bunker with the actual dimensions.

Upgrading of cobalt-60 at the SIBO irradiator in Tangier

All preparations had been made to send the container to the cobalt-60 supplier in the year 2000 and at the last minute the maritime transport companies refused to transport the container with no logical reason. From this day onwards all contacts were informed, facilities used and documents produced from the port authority but with no success.

After 11 September 2001 the situation became more difficult at the international level as did the transportation of any radioactive material.

Another area of difficulty was added in 2004 when the transportation licence of the container expired. As a result, another solution had to be proposed:

(a) Transport the container in another licensed container, send it to the cobalt-60 supplier and return it to the irradiator. Everything was prepared but sea transportation was still a problem – this solution was abandoned over time because of the remaining difficulty in terms of finding a maritime transporter.

(b) Bring a new source in a container of a supplier and transfer the cobalt from the supplier's container to our container in a pool which should be constructed on the premises of the facility. This solution has been adopted by all parties and security procedures [3] have been laid down with IAEA assistance.

In 2012 a company accepted the project and work started between 2013 and 2014 in accordance with a better solution according to the safety principles of the operation: the pool will temporarily be inside the bunker [4].

Preparation of the site and SIBO irradiator for upgrading cobalt-60

The bunker will be emptied and the water pool installed. Then the existing sources from the SV-68 irradiation will be unloaded to facilitate a technical inspection of the mechanism of the source holder of the SV-68 irradiation [1]. Upon completion the existing two sources will be reloaded in the SV-68 flask, and the flask will be temporarily stored in the technical room located on the top of the bunker. The supplier's container of the source would be accepted at Casablanca Airport then transported to the SIBO INRA site in Tangier. The new sources from the supplier together with the existing two sources will be loaded into the SV-68 irradiator. Finally the SV-68 irradiator will be operational using the replenished sources with an activity of approximately 62 kCi.

Figure 5 shows the vertical cross-section of the bunker with the actual dimensions. The product-turning systems have been omitted from the figure to make it clearer to understand. The SV-68 storage flask is located in line with the centre line of the bunker exactly underneath the round-shaped roof plug. The roof plug is a single item consisting of one piece. The combined thickness of the ceiling and the roof plug is 1.3 m.

Installation of the temporary water pool

When the cavity in the ceiling of the bunker is open, the temporary water pool will be installed there. The water pool will be lowered into the bunker through the hole in the ceiling plug of the bunker. The dimensions of the pool will be smaller than the size of the hole. The thickness of the stainless steel wall of the pool will allow for an easy and safe welding procedure to be conducted.

Then once the water pool has been installed and determined to be leak-proof, the flask of the SV-68 irradiator will be placed into the pool. Prior to installing the flask into the pool the old sources in the flask will be checked for contamination. For this reason a certain small volume of deionized water will be poured into the SV-68 flask then the water will be released through the drain plug of the flask to measure the level of radiation.

Since the volume of the flask in comparison with the volume of the pool is reasonable, the water level will increase by approximately 425 mm once the SV-68 flask becomes entirely immersed in the water. To avoid spillages from the pool, the pool will be provided with a balancing system that pumps a certain volume of water between the pool and a reservoir tank when necessary.

The pool will be equipped with an internal barrier about 1 m above its bottom (this barrier is not shown in the figures). This is designed for two functions. Firstly, to separate the pool into two parts: one part will be used to maintain the two heavy source containers, namely the SV-68 and supplier's transport containers, in a certain position when they are loaded into the pool. Another part of the pool is exclusively reserved for the sources, and the barrier ensures a safe distance [5] between the source and the container at all times to avoid any unintentional mechanical damage of the sources caused by the container when it is manipulated under the water. The second function of the barrier is to hold an underwater turntable which will be used for several tasks during the operation. When a source flask is located in the pool a small turntable is operational in the pool.

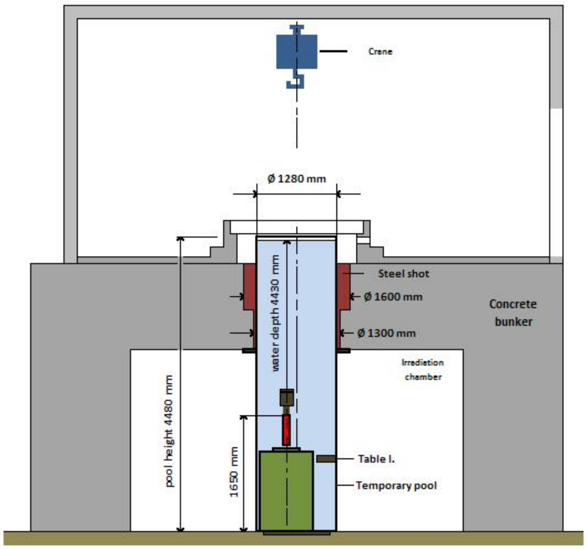

Fig. 6. Lifting the source drawer out of the SV-68 flask.

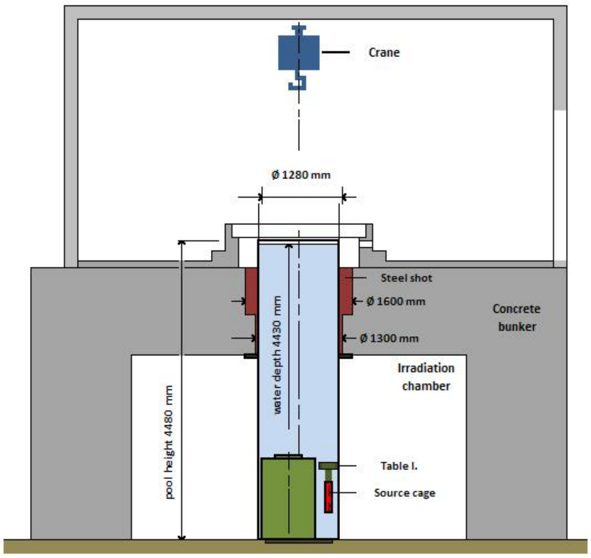

Fig. 7. Placing the sources into the cavity of Table I.

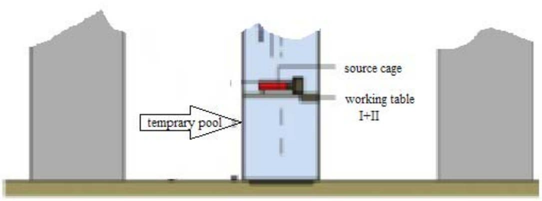

Fig. 8. Magnified diagram of working tables I and II whilst the source cage is manipulated over the entire table system.

Once the SV-68 flask is inside the pool, its top plug (source drawer) will be removed carefully (Fig. 6). Since it holds the existing two sources, this part will be carefully placed into the cavity of Table I in the pool (Fig. 7).

As soon as the source drawer holding the source cage is safely and firmly located on Table I, the SV-68 flask will be carefully removed from the pool. Once the SV-68 flask has been removed, a second part of the table system will be installed (Fig. 3). Together these two tables will completely cover the surface of the pool, and will provide a stable and exactly horizontal surface for source manipulation. The sources will be manipulated from the top of the pool by bars and remote tongs.

The sources will be removed from the cage (source holder) and placed in the cavity of Table I (Fig. 8) which has been especially designed for this purpose. Then the source cage (holder) of the SV-68 flask, free from radioactive material, will be taken out of the pool for investigation. At the same time the two old sources will be placed in a new, temporary source holder that is yet to be provided. Then Table II will be removed and the SV-68 flask placed back into the pool again. The two old sources will be placed into the SV-68 flask then the flask closed with its own top plug. The SV-68 flask will be removed from the pool and left on the top of the bunker in the technical room until Phase 2 begins. The water will be removed from the pool depending on the expected arrival time of the new sources.

When the two transport containers of the supplier arrive at Casablanca Airport in Morocco they will be securely transported by road under the escort of Gendarmerie Royale and National Security and the control of the National Center for Radiation Protection to the INRA site in Tangier, from there they will be lifted up to the technical room one by one.

A smear test on the external surface and a leak test on the content will be carried out on both packages to prove that neither external contamination nor leakage of the sources occurred. Then the temporary pool will be re-checked and filled with water. The water level and quality will be maintained precisely. An additional 500 mm-thick shielding will be installed around the upper part of the water pool to improve the shielding capacity [6] of the pool and its surroundings and facilitate the higher activity of the fresh sources. This extra shielding will be

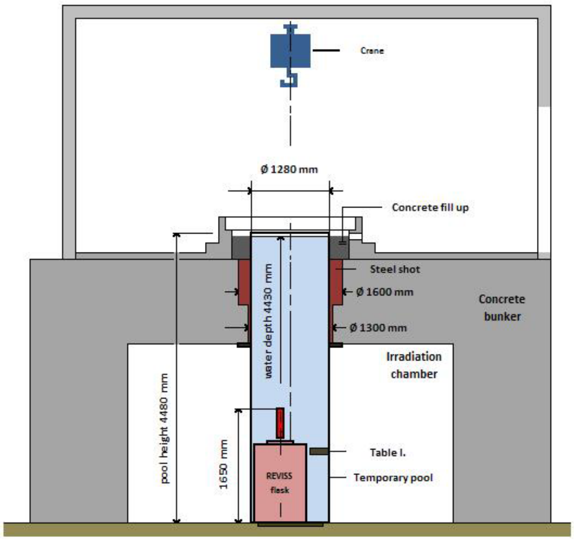

Fig. 9. Removal of the fresh sources from the transport container of the supplier.

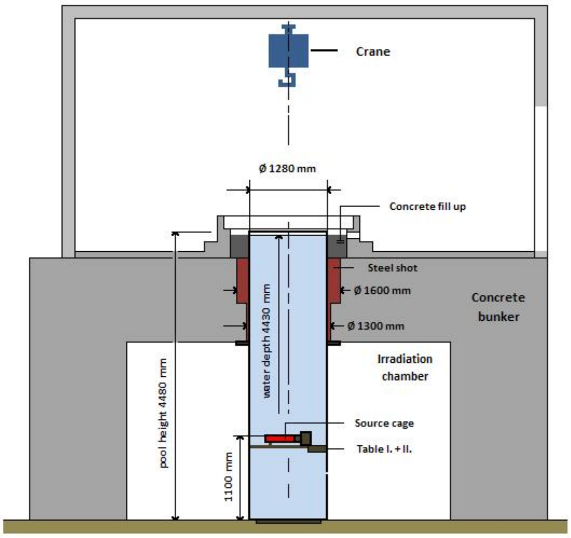

Fig. 10. Source loading as carried out on the table system inside the pool.

implemented by filling the cavity around the pool with concrete blocks. Additional shielding will be applied by filling up around the top of the pool with temporary concrete.

Once the pool shielding has been improved and both supplier containers proven to be free from contamination, one of the supplier containers will be lowered into the pool (Fig. 9).

The required water level will be maintained during the sinking process. The top plug of the transport container of the supplier will be removed and the three new source pencils removed from the cavity of the transport container. The sources will be moved within their own source cage as provided by the supplier (Fig. 10). The sources will be placed into the cavity of Table I. The same procedure will be repeated with the second transport container of the supplier as well.

As soon as all six new sources have been loaded into the pool, the SV-68 flask will be placed into the pool. The two old sources will be taken out and put on the cavity of Table I. Then the SV-68 flask will be temporarily removed from the pool again to provide sufficient clearance for the loading operation of the safe source. Once all eight sources have been positioned on Table I, Table II will be installed and the source cage of the SV-68 irradiator placed onto the table system.

Once all the sources have been installed in the source holder of the SV-68 irradiator and the holder fixed to the top plug of the SV-68 flask, the plug and holder assembly will be placed in the cavity of Table I. Then Table II will be removed from the pool and the SV-68 flask put back into the pool. Subsequently the source holder will be returned to the SV-68 irradiator flask.

Following the successful loading of all the sources in the SV-68 flask, it will be removed from the pool then the water will be checked for contamination. The pure water will be pumped out from the pool then the pool will be cut into two pieces and removed from the cavity of the bunker.

The SV-68 flask will be placed in its original position and adjusted precisely then the roof plug will be placed into its roof cavity, and the hoist cable of the source reinstalled in its original position and checked for ease of operation. Then the covering lids will be returned.

The turning systems of the product will be reinstalled in their original positions and tested for reliability and consistency. The source guiding and protection tubes will be reinstalled and adjusted precisely. Finally all the systems will be checked to ensure they operate as expected.

Radiation protection considerations and dose assessments will be conducted in accordance with regulations applicable to the task [7].

All licences for importation and transportation have been received from all authorities concerned.

This operation was conducted successfully and the empty container of the supplier returned within one week under comprehensive supervision from the National Center for Radiation Protection in addition to the National Security Department and Gendarmerie Royale during its transportation and throughout the operation. It was considered a success story of the year 2014 according to the general conference of IAEA.

Safety and technical upgrading of the system of the SIBO irradiator

After solving the problem concerning the replenishment of cobalt-60, the upgrading of technical and safety systems of the facility became necessary because this equipment had been in operation for 18 years and needed to be replaced and the system updated so during 2015 work commenced concerning the following:
1. Replacing the big tables with a new system of motorization.
2. Replacing the door of the irradiator.
3. Replacing the emergency bottom with an emergency cable.
4. Replacing the source-loading equipment.

Fig. 11. Operation panel of the control system after the upgrade.

5. Replacing electrical components.
6. Installing a laser detector.
7. Installing a camera with an internal mirror reflexing in inox in order to visually control the process continuously.
8. Replacing the round bottom.
9. Replacing the monitoring and PLC systems (Fig. 11) with new ones connected to the Internet [8].
10. Installing a database for the system and integrating all aspects of managing the irradiator [9, 10].
11. Replacing the fixed gamma radiation detectors (Fig. 12).
12. Replacing the fire alarm.
13. Installing a 10 kVA power bank for the facility.
14. Connecting the system to be informed in real-time and record all processes [11].

In general all pieces of equipment have been updated according to the Failure Mode and Effects Analysis (FMEA) and facilitate comprehensive control of safety and irradiation processing (Fig. 13).

Installation and upgrading of the security system

Radioactive sources are widely used in many industrial processes, agricultural research and at medical facilities and are commonly available in nuclear facilities. Control and accountability of these sources is mainly conducted from a health and safety point of view and not from a security perspective which is common practice in terms of the control and accountability of special nuclear material. There is growing concern that terrorist groups are able to access radioactive sources and may plan attacks on nations worldwide [12]. The identification, consolidation, and securing of radioactive sources is in the best interests of all parties.

Fig. 12. Radiation monitoring system after the upgrade.

Fig. 13. The irradiation cell after upgrading the system.

The security requirements included are based on the performance objectives from the IAEA Nuclear Security Series [4], and the practices and policies of the Global Threat Reduction Initiative (GTRI) [13] of the National Nuclear Security Administration (NNSA) [14].

This system has been installed over several phases, the first of which was conducted with only two cameras in 2002.

The objective of this task was to implement security enhancements at the site. The enhanced security systems were incorporated into the existing site access control system, intrusion detection system and CCTV system in 2016.

The main tasks completed are related to the Irradiator Building and Central Alarm Station (CAS) with the installation of specified equipment in the control room at the police station and concern:

1. Installation of a hardened (steel) door of substantial construction to replace the entrance door to the control room.
2. Installation of an electromagnetic-locking mechanism in the doors to the irradiator and control rooms.
3. Installation of a dual credential biometric access control device on the doors to the irradiator and control rooms.
4. Installation of a security window film on the windows in the control room. In the future there will also be a security grating on the interior windows to prevent access.
5. Installation of a colour CCTV system appropriate for the environmental conditions providing video surveillance of the area surrounding the irradiator and outside the entrance doors to the irradiator and control rooms. The cameras will be focused on both the exterior and interior.
6. Installation of dual technology (passive infrared and microwave) motion sensors.
7. Installation of fixed duress buttons and the provision of mobile duress buttons for the members of staff.
8. Installation of a TID (IR Barrier or BMS switch) on the irradiator cap to detect any unauthorized tampering with the irradiator.
9. Installation of a strobe light and local siren that will annunciate in the vicinity of the room at a level exceeding 100 dB.
10. Installation of a proximity card access control system on the front door of the building which utilizes an electromagnetic-locking system with an emergency release on the inside of the door that accesses the control system (dual credential requiring a proximity card and PIN).

11. Installation of an exterior intrusion detection system on the fence surrounding the perimeter of the irradiator building to detect any intruders during daylight hours as well as at night.
12. Replacement of the pedestrian gate with a turnstile system. The turnstile will be equipped with an automated proximity card access control system which utilizes dual credential authorization that requires a proximity card and PIN to grant access. The turnstile allows only one person to enter at a time.
13. Automation of the vehicle gate by installing an automatic closure device on the gate which can only be opened from the CAS.
14. Installation of static vehicle bollards on the inside of the gate to prevent a vehicle from ramming the gate to gain access to the irradiator building.
15. Programming the electromagnetic door locks in such a way that the irradiator door cannot be opened unless all other doors are closed and locked.
16. Replacement of the door to the CAS with a hardened steel door that utilizes an electromagnetic lock with an emergency release on the inside of the door and a proximity card access control device with a keypad to assure two levels of authentication.
17. Construction of fences around the irradiator building to replace the previous ones topped with razor wire.
18. Installation of a remote monitoring station at the local police station which incorporates all video and sensor alarms from the site.

With this upgrade of the technical and security systems of the SIBO irradiator the tractability of irradiation processing has been improved and the safety system enhanced. The system controls, monitors and records the entire irradiation process, from the reception of products at the facility to the production of post-irradiation documentation which is necessary for the future steps of accreditation of irradiation processing.

An alarm management system capable of integrating all sensor alarms and CCTV video, incorporating CCTV images and opening images on the screen for assessment purposes has been installed. This system can also send encrypted video and alarm information to the dispatch centre of the police in Tangier. The system is implemented by the use of the latest advances in computer and information technology.

Conclusion

Over the last three years much work has been conducted on the facility concerning the upgrading of cobalt-60, safety and technical controls of the facility and the security system of the SIBO irradiator in line with the latest regulations and norms using cutting-edge technology and 20 years of work experience in the field. Cobalt-60 upgrading was considered a success story of the year 2014 according to the general conference of IAEA and many countries that face the same difficulty are now trying to do the same to upgrade their cobalt-60.

This combined system upgraded in terms of security, safety and processing offers a new larger system which utilizes the most modern interventions as far as each of the three aspects above are concerned and provides a specific global solution for similar facilities which need to upgrade their control systems.

The SIBO irradiator is a research development facility and its accreditation as an irradiation processing and dosimetry laboratory is in progress.

References

1. Carlson, C. S. (2012). *Effective FMEAs: Achieving safe, reliable, and economical products and processes using failure mode and effects analysis*. Hoboken: Wiley.
2. Mohammed, M. (1997). *Radioprotection et dosimetrie de la station d'ionisation de Boukhalef SIBO Crra-PTN Tanger Maroc Septembre 1997*. INRA Annual Report–Rapport de titularisation.
3. International Atomic Energy Agency. (2010). *Radiation safety of gamma, electron and X ray irradiation facilities*. Vienna: IAEA. (STI/PUB/1454).
4. International Atomic Energy Agency. (2009). *Security of radioactive sources*. Vienna: IAEA. (STI/PUB/1387).
5. International Atomic Energy Agency. (2016). *Safety glossary. Terminology used in nuclear safety and and radiation protection. 2016 Revision*. Vienna: IAEA. Available from http://www-ns.iaea.org/downloads/standards/glossary/iaea-safety-glossary-rev2016.pdf.
6. International Atomic Energy Agency. (1996). *Manual on panoramic gamma irradiators*. Vienna: IAEA.
7. International Atomic Energy Agency. (2015). *Preparedness and response for a nuclear or radiological emergency*. Vienna: IAEA. (Safety Standards Series no. GSR Part 7). Available from http://www-pub.iaea.org/MTCD/Publications/PDF/P-1808_web.pdf.
8. Vickoff, J. P. (1996). *Développement Rapide des Application RAD Méthodes et out ils, les règles à respecter dans le développement d'applications client-serveur*. Macmillan.
9. Mohammed, M. (2003). *Influence de quelques paramètres sur le débit de doses à différentes positions de la source radioactive Et élaboration d'un logiciel sous Windev permettant d'intégrer toutes les données relatives aux conditions de traitement des différents produits dans la station SIBO Inra – Crra-URTNEQ Tanger Maroc*. Unpublished Thesis for professional promotion to Chief Engineer.
10. Scott Barker, F. (2000). *Microsoft access 2000. Programmation Edition 2000*.
11. Thu-Quang, Pham, & Gonin, J. J. (1995). *Réussir la conduite de projets informatiques*. Paris: Editions Eyrolles.
12. World Institute for Nuclear Security. (2011, September). *Nuclear Security Culture Rev. 2 (A WINS International Best Practice Guide*. WINS publication.
13. Messick, C., & Galan, J. (2012). *U.S.-Origin nuclear fuel removals*. US Department of Energy, Global Threat Reduction Initiative (GTRI). Available from https://energy.gov/sites/prod/files/em/GlobalThreatReductionInitiative.pdf.
14. *The practices and policies of the NNSA* (2016). Workshop in Tangier with NNSA documentation.