Use of the Accelerators in the Socio-Economic Development in Tunisia

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Abstract. The demand of radiation technology, especially for medical and industrial applications, is continuously increasing (5-10% per year). This technology is playing a great role in improving the sanitary quality of food stuffs and healthcare products. Since Tunisia has an agricultural and industrial economy and it is located in a strategic position on Mediterranean Sea, economic constraints are forcing it to adopt this emerging technology in order to have competitive products dedicated for export to European Union countries. According to this purpose, the first irradiation facility in Tunisia has been put in operation since 1999. This facility is equipped with Cobalt-60 source located in National Centre for Nuclear Science and Technology (CNSTN). Moreover, this irradiation infrastructure is reinforced by the installation of a semi-industrial electron beam machine in proximity of the gamma irradiator. This electron accelerator is planned to be exploitable in the second half of 2009.
This paper will highlight the recently and ongoing promising research and development applications of radiation technology in Tunisia in the fields of industry, food irradiation and preservation of art objects.

1. Introduction

Radiation processing technology started in Tunisia by the installation of a pilot plant gamma irradiator in 1999 in National Centre for Nuclear Science and Technology (CNSTN) situated at about 20 km in north of the capital Tunis. This facility was established with the support of the International Atomic Energy Agency (IAEA) in the frame of the technical co-operation assistance program (TUN/5/013) and the French Atomic Energy Commission (CEA).
In order to increase the productivity and widen the field of applications, CNSTN capabilities are presently reinforced by the installation of a semi-industrial electron beam accelerator. This machine has a variable beam energy ranging from 5 to 10 MeV and has a maximum power of 5 kW.
These two irradiation facilities are designed to be used for the promotional activities of radiation processing applications, in particular for conservation of foodstuff and sterilisation of medical devices and will also be dedicated to play a great role in enhancing research and development work and providing services to industrials mainly in the fields mentioned above.

2. Irradiation Facilities in Tunisia

2.1. Pilot Scale Gamma Irradiator

Tunisian gamma irradiation facility is designed for conservation of foodstuff and sterilisation of medical devices. The source consists of encapsulated cobalt-60 source pencils. The initial activity of the source is 100 000 curies (May 1999). Current activity is less than 30 000 curies (April 2009). The irradiation facility consists of an irradiation cell protected by a concrete shielding including a labyrinth, a conveyor system, a control room, a dosimetry laboratory, a warehouse for irradiated and non-irradiated products and refrigerated rooms. The products to be treated are transported inside the irradiation cell using five carriers moved by electromechanical conveyor system fixed on the ground (see Figure1).

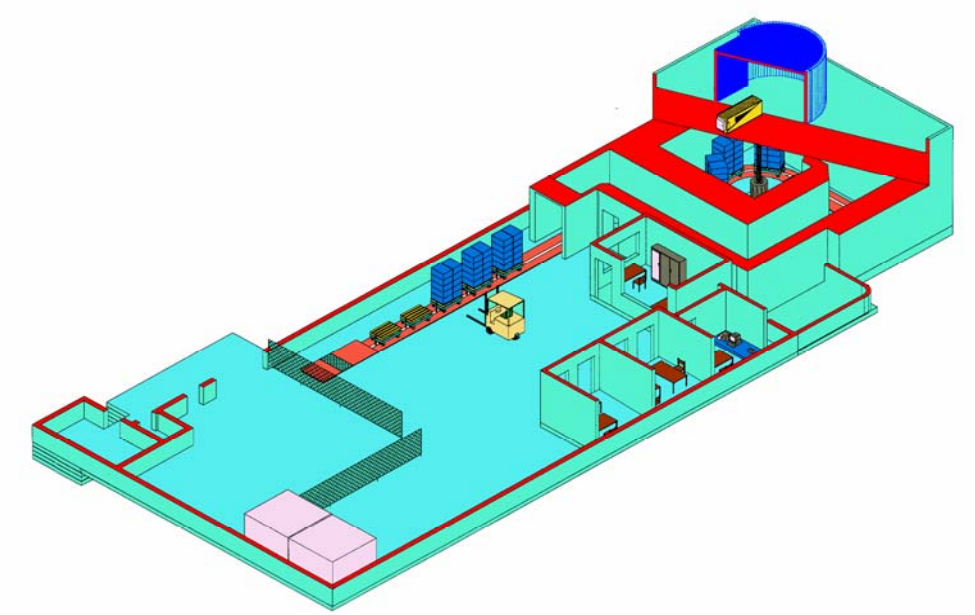

FIG. 1. Pilot plant gamma irradiator

The main activities of this irradiator are providing services for manufacturers in the following applications:

- Sterilization of single-use medical products
- Food irradiation
- Conservation of art objects
- Insect sterile technique

A part of the capacity of the plant is dedicated to research and development works in the following domains:

- Food irradiation
- Radiation processing of polymers
- New materials and techniques for radiation processing dosimetry (glasses, polymers, sugar, electronic devices...)
- Textile coloration
- Monte Carlo simulation

2.2. Electron Beam Accelerator

CNSTN is actually reinforced by a semi-industrial electron beam accelerator with assistance of the IAEA in the frame of technical co-operation and assistance project (TUN/8/016) from 2003 to 2008.

This electron accelerator will be used:

- for the development and tests for this new technology
- as unit of accompaniment in the development of industrial treatments on standby of the future investments by the industrialists

Consequently, this new irradiator should answer the needs expressed by the manufacturers and researchers for the development for new and concrete applications.

Characteristics:

- Linear Accelerator
- Variable energy : from 5 to 10 MeV
- Maximum power: 5 kW
- Average beam current: 0.5 mA
- Scanning width: from 30 to 60 cm
- Productivity :
    - ~ 3,2 m3/h (sterilization ; density = 0,1 at 25 kGy)
    - ~ 1 ton / h (treatment of spices at 10 kGy)

Technology : LINAC Technologies (France)

Main Components:

- Accelerator section
- Conveyor with rollers to convey products to be radio-treated under the electrons beam. The speed of the conveyor which is under the beam vary from 0,15 to 5 m/min
- Data processing equipment dedicated to order and control the accelerator
- Electric and safety system
- Cooling system (regulated) for the control of the temperature of accelerator section
- Dosimetry system

Planning of Realization:

- Building construction: 2006-2007
- Assembly and tests on factory: 2005
- Assembly and tests on CNSTN's site: 2008-2009
- Exploitation date (planned): July 2009

3. Industrial Applications of Radiation Processing

3.1. General Informations about Tunisia

Geography:

- Location : Northern Africa, bordering the Mediterranean Sea
- Area: 163.610 sq km
- Coastline : 1.148 km
- Natural resources: phosphates, iron, lead, zinc, salt

Population: 10.3 millions (2008)

Main languages: Arabic, French

Economy: Tunisia has a diverse economy, with important agricultural mining, tourism, and manufacturing sectors.
The main products per sector are:

- Agriculture: olives, olive oil, grain, tomatoes, citrus fruit, sugar beets, dates, almonds, beef, dairy products
- Industry: petroleum, mining (particularly phosphate and iron ore), textiles, footwear, agribusiness, beverages

National Regulations for Radiation processing:

1- Legislation have been promulgated for radiation processing of the following ***Agro-food products*** (April 2002):

- Spices & Aromatics;
- Potatoes;
- Onions & Garlics;
- Dried Fruits and Vegetables.

2- Legislation for the sterilization of ***single-use medical and pharmaceutical devices by ionizing radiation*** have been also promulgated in December 2003.

3.2. Radiation Sterilization of Health Care Products

Two radiation sterilization techniques are employed for health care products. The first involve gamma irradiation and the second utilize electron beam accelerators. In this field, the benefits and the advantages of this technology had been put forward and were well documented.

In Tunisia, the application of radiation sterilization will certainly promote the business export of the products toward the European Union's countries. In fact, the export of pharmaceutical products showed a significant increase from one million dinars in 2001 to 13 million dinars in 2007 (see Figure 3). The export of medical and surgical products reached an amount of 362 million dinars in 2007 against 9 millions in 2001 (see Figure 4).
With respect of the full expansion of the production and export of medical and pharmaceutical products (see Figures 2, 3 and 4), large opportunities are offered to CNSTN to process these products by ionizing radiation [1, 2].

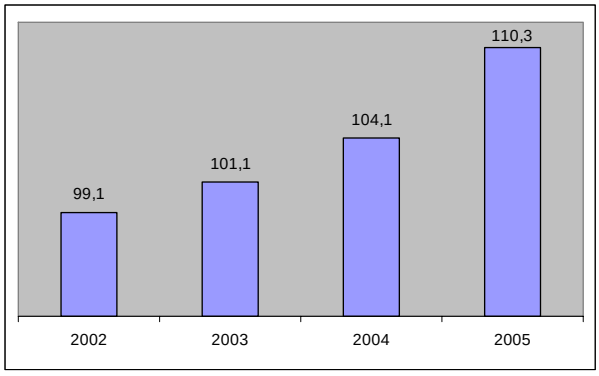

FIG. 2. Evolution of production of pharmaceutical products (index 100 in 2000)

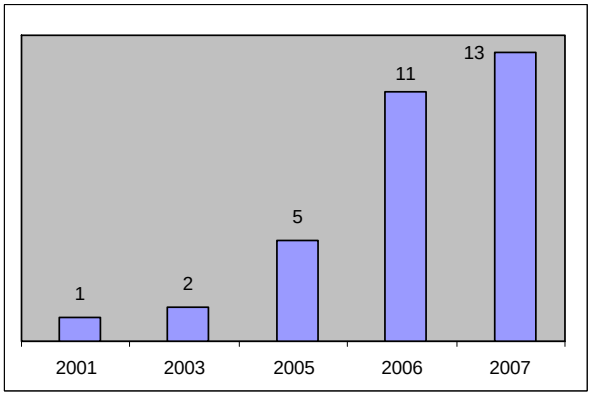

FIG.3. Evolution of export of pharmaceutical products (Million Dinars)

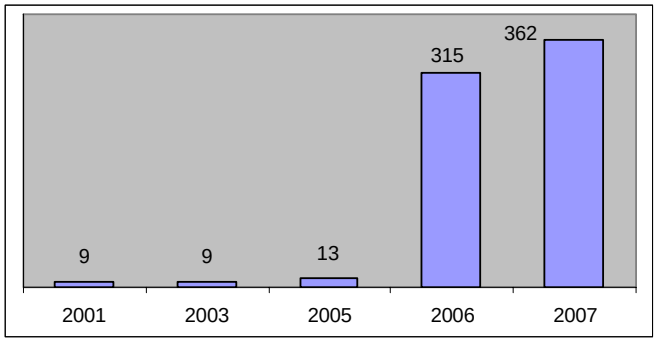

FIG. 4. Evolution of export of medical and surgical products (Million Dinars)

The number of Tunisian pharmaceutical manufacturers reached 42 in 2008. Eight of them are totally exporters (Table I) [3].

TABLE I: PHARMACEUTICAL MANUFACTURERS IN TUNISIA

Product	Number of industrials
Administration set	4
Dressing	4
Single use pharmaceutical products	14
Veterinarian use pharmaceutical products	3
Syringes	2

3.2.1. Single-Use Surgical Material

Probes, catheters, administration set, extra-bodily lines of circulation generally represent an important volume of consumption. The estimated sterilized volume by CNSTN's electron beam accelerator can reach 4000 m3 / year [4].

Syringes represent a very large market for the radiosterilization. In general, Europe uses in average 4 syringes per year and per person, what represent for Tunisia an extrapolate market of 40.10^6 syringes / year [4].

Compresses and bandages are generally sterilized by steam because of their weak density. On the other hand, bandage articles, impregnated compresses, collagen, hemostatic and self adhesive bandages are more sophisticated than the classic gazes. That can not be sterilized by steam nor by ethylene oxide. Tunisia exported in 2008 about 10 times more than 2002 of these products (see Figure 5) [1].

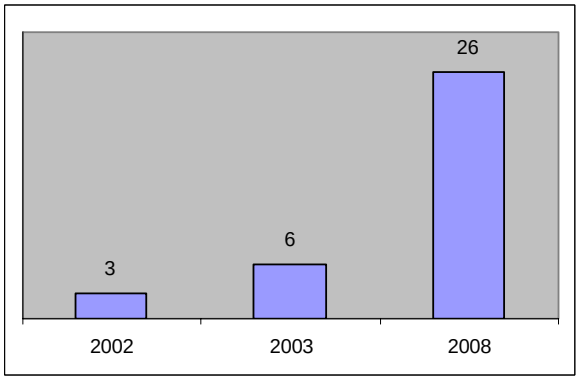

FIG. 5. Export of dressings and bandages (1000 Dinars)

The following health care products are radio-sterilized in CNSTN:

- Suture thread
- Tulle gras
- Dressings
- Adhesive bandage
- Petri dishes
- Nasal solution
- Solution for cleaning contact lens

Table II shows income generation of CNSTN relative to services providing to manufacturers for health care products.

TABLE II: CNSTN'S INCOME GENERATION
FROM RADIOSTERILIZATION OF MEDICAL PRODUCTS

Year	**2006**	**2007**	**2008**	**2009 (April)**
Amount (DT)	2 200	1 730	10 750	15 000

3.3. Cosmetics

The export of cosmetic products in Tunisia demonstrates a significant increase from 16.3 million dinars in 2001 to 50.3 million dinars in 2007 (see Figure 6) [1].
The estimated number of Tunisian cosmetic manufacturers is 37 in 2008. Five of them are totally exporters [3].

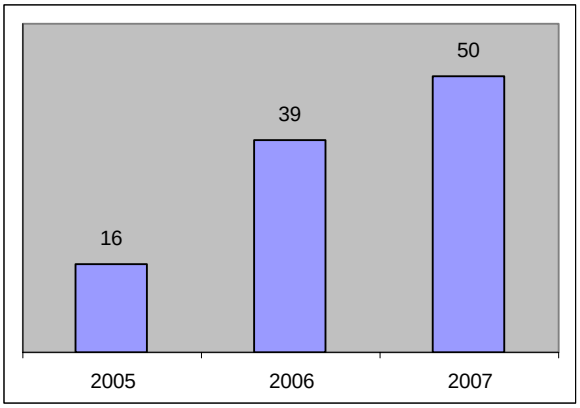

FIG. 6. Export of cosmetics (Million Dinars)

3.4. Food Irradiation

Agriculture represents a large component of Tunisian economy. Several agro-food products are exported every year. According to the national institute of statistics, exports of the agro-food sector increased from 557 million dinars in 2002 to 1616 million dinars in 2007 [1]. Figure 7 shows the distribution of principal exported foodstuffs in 2007 [1].
Noting that techniques of storage and conditioning not being always satisfactory, the technique of treatment by ionizing radiation represent profitable alternative. It can also improve the food availability destined to the self-consumption and to assure a better chain of distribution**.** There is many published evidence showing the enormous potential of this method for extending shelf life of several foods by eliminating certain spoilage and pathogenic organisms without deterioration of food quality.

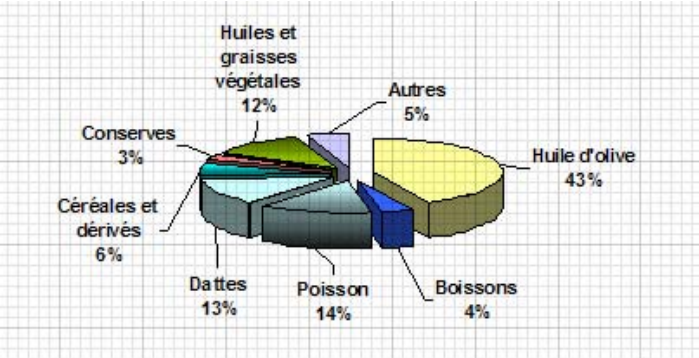

FIG. 7. Distribution of principal exported food products in 2007 [1]

CNSTN's Gamma irradiator has been mainly employed for decontamination and/or sterilization of dehydrated vegetables, fruits, seasonings and animal foods and then to prolong the storage period of other cooked dishes.

Dates

Dates constitute an important export commodity. "Deglet Nour", the best variety on the market occupies 30% of the world exchange value and satisfies more than 40% of the needs of the European Community [5]. The export of this product reached in 2008 the value of approximately 200 million dinars against 99 million dinars in 2004 (see Figure 8) [1]. Unfortunately, dates are frequently subjected to microbial contaminations as several works showed that dates are contaminated regularly by moulds [6].

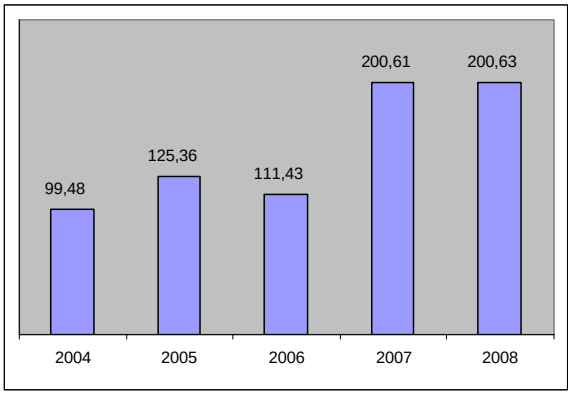

FIG. 8. Evolution of export of dates « Deglet Nour » (fresh state or dry) (Million Dinars)

Spices, Herbs and Dried Vegetables Condiments

The demand for herbs and spices grows as meal manufactures try to keep pace with increasing consumption of "ethnic" foods**.** Irradiation is more effective than ozone treatment in reducing the microbial load of aloe powders [7]. Irradiation services have been done to industrials. For example, about 50 tons of spices have been irradiated in the period from 2003 to 2008.

Sea Products

Tests had been performed on sea products such as fishes and shrimps. The fishery industry constitutes a key sector of the national economy which generates good revenues from the export of shrimps, fishes and octopus (see Figure 9) [1]. The impact of ionizing radiation doses on the decontamination of shrimp wrapped and refrigerated at 4°C has been studied. The results showed that doses of 4 and 5 kGy allow the destruction of the total and faecal coliforms completely and to maintain the total germs to a very low level [10].

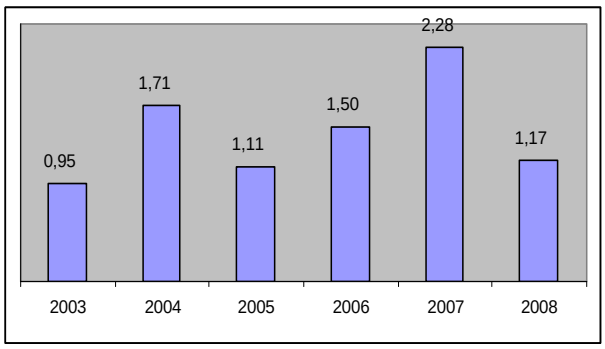

FIG. 9 . Export of Royal sea-breams of sea, expenses or refrigerated, except nets and fish (Million Dinars)

Meat

Meat and meat products are rich media which are characterized by a high safety risk and most of the incidences of food–borne illnesses are attributed to pathogenic bacteria in meat. There is many published evidence showing the enormous potential of irradiation for extending shelf life of meat by eliminating certain spoilage and pathogenic organisms. The assurance of the shelf life of meat represents an important challenge for meat industries in Tunisia. Table III illustrate the national meat production by type of animal [3].

TABLE III: PRODUCTION OF MEAT BY TYPE OF ANIMAL (1 000 TONS)

	2000	**2006**
Bovines	52	49
Sheep	47	49
Goats	8	9
Poultry	108	110

Other Studies

Several irradiations studies have also been elaborated in CNSTN, for example:

- Effect of gamma irradiation of wheat and flour of wheat
- Presensitization of microorganisms in beef minced meat to low dose gamma irradiation with special reference to *Bacillus cereus*
- Effect of gamma irradiation combined with coated essential oils on the red meats
- Control weevils by radiation of food pasta
- Cooked dishes irradiation “cotelettes royals” of chicken
- Effect of irradiation of physicochemical, rheological characteristic of the Tunisian mile varieties
- Effect of gamma irradiation on the functional properties of corn starch

3.5. Crosslinking of Thermoplastics

By the installation of its two irradiators (Cobalt 60 and electron beam accelerator), CNSTN undertook a survey of market and a technico-economic feasibility study [4]. These studies showed that many Tunisian companies are strongly interested by radiation reticulation. Indeed, the electric cable domain recorded an important growth at the level of the export since 2001 (see Figure 10) [1]. The value of the export can progress again during the next decade, if the Tunisian industry aims to solve several technical problems in order to improve some physic-chemical properties of cables.

Packaging materials also represent a big market for treatment by ionizing radiation. There are 97 manufacturers in Tunisia in this domain which 7 of them are totally exporters [3].

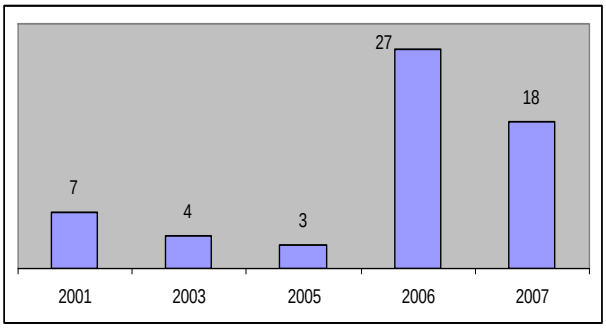

FIG. 10. Evolution of export of electric cable (Million Dinars)

3.6. Coloration of Glass Articles

An important optical property of a glass is its color. Color is imparted to glass by several methods. One is by dissolving transition metal ions into glasses, which give rise to optical absorption due to the well-known *d-d* optical transitions [8]. Currently, the used colored glass is unrecyclable, and the used glass is treated as a waste. Development of the recyclable colored glass represents a great interest from the economical and environmental point of view.

It is widely known that the high-energy ionizing radiation (X-ray, gamma rays and electrons) can induce numerous changes in the material properties of glass, with one of the most observable effects being visible coloration. The recent application of radiation-induced color centers of glass has prompted a renewed interest in order to develop a recyclable glass in the glass industry, due in part to the reversible nature of color center generation and bleaching. Indeed, the most induced color disappeared after being treated at 300°C for 20 min [9].

In Tunisia, the production of glass currently totals almost 140 Million dinars in 2007 [3]. Figure 11 shows the evolution of national glass industry for the period from 2004 to 2008 [1]. In June 2008, we estimate at 34 the number of industrial glass companies in Tunisia [3]. The colored flat glass is mainly used in the automotive vehicle industry in Tunisia.

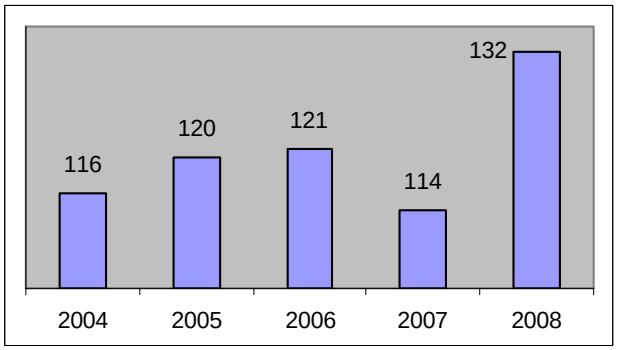

FIG. 11. Evolution of export of glass industry (index 100 in 2000)

The process of coloration is very well applied to the small bottles of perfume and drugs. SOTUVERRE Company, one of the most important glass industrials in Tunisia, is interested by the coloration by ionizing radiation. This company even considers raising its manufacture at 50 million small bottles of perfume per year, with a demand for coloration of about 10 % [4]. This technique of coloration will allow this company to avoid difficult coloration carried out by fusion and to get coloration in a more satisfactory quality than surface treatments.

3.7. Conservation of Art Objects

Agreements had been done with National Museums in order to benefit from this new technology for the conservation and the restoration of our cultural heritage. Figure 12 shows the volume of treatment of art objects in CNSTN during the three past years (2006-2008).

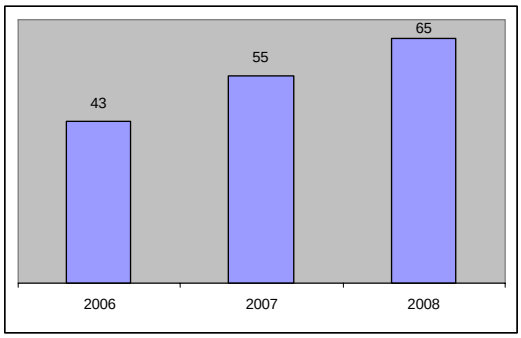

FIG. 12. Volume of radiation processing of art objects in CNSTN between 2006 and 2008 (m^3)

3.8. Environment

Tunisia is investing in sustainable waste management projects. In fact, Tunisia saw its Sustainable Municipal Solid Waste Management Project approved by the World Bank in 2007. It's a US $22 million project aiming to assist the Government in strengthening the key elements of sustainability of municipal solid waste management. This objective will be achieved through the operationalization of a planning and implementation system of solid waste management at the national and local levels and through the rehabilitation of a number of environmentally harmful dumpsites [11].

Ionizing radiation technology offers an alternative method since existing purification systems are close to their limit ability (toxicity) in treatment of incoming wastewater. In CNSTN some research studies were carried mainly for sewage sludge treatment by gamma irradiation. Table IV illustrates the waste production and waste disposal in Tunisia [12].

TABLE IV: TUNISIAN WASTE PRODUCTION AND WASTE DISPOSAL

Waste production (1 000 tons)			Waste Disposal (number of controlled landfills for non-hazardous waste)
Hazardous Waste	Industrial Waste	Municipal Waste	
144 (2002)	320 (2002)	2025 (2004)	5 (2006)

A technico-economic study is very important to prove the advantage to establish a dedicated irradiation facility for wastewater purification and for use the residue as agricultural fertilizers.

4. Future Research and Development Themes

Throughout CNSTN, Tunisia considers to develop the following research items related to radiation technology:

- Heat Shrinkable materials
- Radiotreatment of hospital wastes
- Polymer degradation
- New materials and techniques for radiation processing dosimetry (glasses, polymers, sugar, electronic devices...)

- Monte Carlo Simulation of dose distribution in treated product
- Radiotreatment of Dates
- Biodegradability of margines (olive waste)
- Surface curing
- X-Ray Convertion

5. Conclusion

It is difficult to state all the different applications that the Tunisian economy would benefit from the radiation technology process. However, it is well clear that the products we mentioned in this paper, will certainly take advantage quality and quantity wise.

Electron beam constitutes a promising technology, compared to conventional technologies, for several industrials applications mainly for the sterilization of health care products and for food preservation.

For the next years, it is expected that radiation technology industry in Tunisia will have more development along with the economic development. Thus, the main objective of CNSTN is to promote radiation technology in Tunisia among the end-users and to prove the technico-economic advantages in order to install their own industrial scale facilities.

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