Waste Management Protocols for Iridium-192 Sources Production Laboratory Used in Cancer Treatment in Brazil

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Abstract*—Objective: The iridium-192 wired sources production results in radioactive waste that needs to follow the guidelines. The aim of this study is to do a radioactive waste management of wastes from iridium-192 sources production laboratory used in cancer treatment in Brazil. Methods: The wire is acquired in an alloy form with 80% platinum and 20% iridium encapsulated with 100%. Electronic microscopy, X-ray fluorescence, and posterior iridium neutron activation (to determine contaminants) are performed to ensure quality. A 50-cm twisted wire is placed in an aluminum tube. The tube is sealed and place inside the reactor irradiator system and is left for decay during 30 hours to wait for the others undesired activation products to decay. The wire is prepared for treatment with 48 cm length with 192 mCi maximum activity. All the equipment use inside the hot cell must be calibrated every four months. All the waste must be removed from the hot cell. Results: The solid waste is previously characterized in the analysis phase. The contaminants are already known and they are insignificant due to their fast half-life. The iridium-192 half-life is 74.2 days, classified as very short half-life waste. The reminiscent activity is 8mCi. Conclusion: The radioactive waste generated during the I192 wires production is solid, was a short half-life and a weakly activity of 9.7 GBq.g-1. According to the standards, this activity is too high to be discarded into the environment (limit 10 $Bq.g^{-1}$). The waste must be managed by the R&R (retain e retard) system.*

***Keywords*— Iridium-192, Radioactive waste, Sealed sources, Sources production, Waste management.**

I. INTRODUCTION

According to the International Agency for Research on Cancer (IARC)[1]27 million new cases of cancer are expected in the world in 2030 and around 17 million deaths. This astonishing estimate considers the increase life expectancy due to new forms of treatment. The highest incidence of cancer is observed in developing countries of South America, Africa and Asia.[1]

The "Registro de Câncer de Base Populacional e Hospitalar", People and Hospital Cancer Registry (RCBP - RHC) and the "Instituto Nacional do Câncer", National Cancer Institute in Brazil released the 2015 estimative[2]allowing the study of each cancer and for each region of the country.According with this document, 576.000 new cases occurred, and around 14 million deaths. Cancer is a major public health issue in Brazil.

Among the forms of treatment, brachytherapy is largely used due to efficient radiation dose delivery. In this form of radiotherapy, radioactive seeds, wire or pellets are placed in contact (during a period of time) or inside the region to be treated, maximizing the radiation dose inside the targeted areas.

Iridium-192 is being used in brachytherapy since 1955. It presents emission energy in the "therapy region" (370keV, 74.2 days half-life) and is easily produced in a nuclear reactor ($^{191}Ir\ (n, \gamma) \rightarrow {}^{192}Ir$).[3]Wires are an iridium-platinum alloy with 0.36 mm diameter and they can be cut in any needed length (even 3mm to be used as a radioactive seed). They can be used in severaltypes of cancer as shown in FIG. 1. The linear activity is between 1mCi/cm (37MBq/cm) and 4mCi/cm (148MBq/cm) with variations of 10%in 50 cm maximum. This activity values classified the treatment and low dose rate (0,4 à 2 Gy/h).[4]

FIGURE 1: a) Iridium-192 wire;[5]b) Example of treatment using the wire;[6]c) cartoon of a breast cancer treated with wire;[7]

1.1 Radioactive Waste management in sources production

The iridium-192 wired sources production results in radioactive waste that needs to follow the guidelines. The production facility must guarantee that radioactive exposure, for workers and public, is inside the limits presented in the guidelines. In Brazil, the "Comissão Nacional de Energia Nuclear" (CNEN), Nuclear Energy National Commission establishes the regulations for all nuclear and radioactive research and production.

Accordingto CNEN-NN 6.08 standard, radioactive concentration levels in which a waste is consider radioactive is presented for each radionuclide. To be consider common trash or chemical waste the activity value must be below the one presented. The discharge levels are calculated by the effective dose (E) received by any person, worker or public, is no greater then 10μSv/year.[8]

The solid waste management applied to the iridium-192 brachytherapy sources production is presented in FIG. 2.

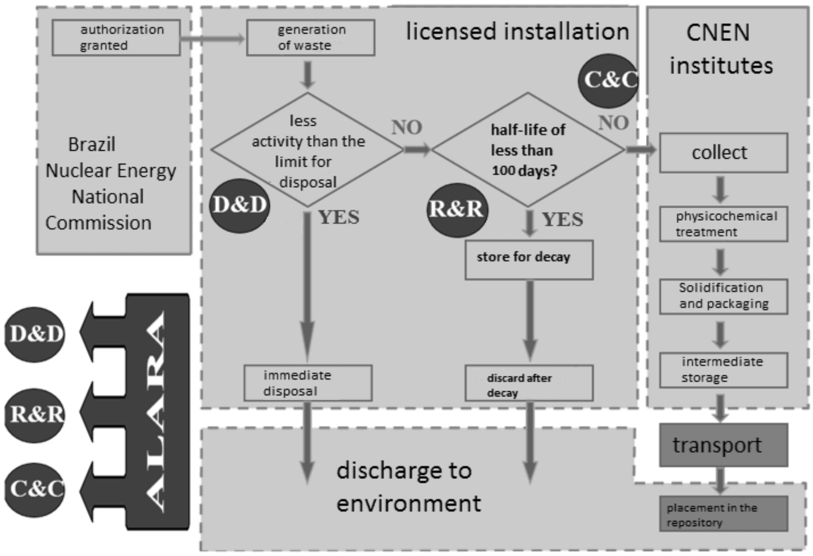

FIGURE 2: Flowchart of Brazil's radioactive waste management –D&D: Diluteand dispense; R&R: Retain and retard; C&C: Containandconfine[9].

The characterization step is where the waste is generated. This is a critical phase and requires especial attention since the results will determine the following steps. Waste can be classified by radioactive concentration (class 1, 2 or 3), physical state (solid, liquid or gaseous), and half-life (very short < 100 days, short < 30 years or long)[8].

After the characterization, the waste can be eliminated, temporarily confined for decay or permanently confined. The decision lies directly on the characteristics previously determined.

The general strategy involves minimize quantities and management cost, maintain control on every step, and understate workers and public exposure. Recommendations such asdilute and dispense (D&D), retain and retard (R&R),contain and confine (C&C) are also part of this strategy[9].

II. METHODOLOGY

The Iridium-192 wires produced in the "Instituto de PesquisasEnergéticas e Nucleares" (IPEN), Nuclear and Energy Research Institute havethe following manufacture steps:

2.1 Purchase of the iridium/platinum wire (*Goodfellow*)

The wire is acquired in an alloy form with 80% platinum and20% iridium encapsulated with 100% iridium 100%.[10]

2.2 Analysis of the material

Electronic microscopy, X-ray fluorescence, and posterior iridium neutron activation (to determine contaminants) are performed to ensure quality.

2.3 Wire activation on the IEA-R1 nuclear reactor

A 50cm twisted wire is placed in an aluminumtube (2cm diameter, 7cm length, FIG. 3.). The tube is sealed and place inside the reactor irradiator system.The irradiation parameters are: 30 hours irradiation with $5x10^{13}$ $n/cm^{-2}.s^{-1}$neutron flux. The tube is left for decay during 30 hours to wait for the others undesired activation productsto decay(Pt-197 e Pt-199).

(a) (b)

FIGURE 3: a) Wire before irradiation; b) Twisted wire inside irradiation tube.

2.3.1 Quality control

Before its use, the wire is checked for irradiation homogeneity in its entire 50 cm length. The procedure is performed in an iridium specific hot cell. The activity is measured by an ionization chamber with lead shielding (FIG. 4). The system is attached in a *Keithley electrometer model617* charge counter. The measurement is performed at a 1cm/120s rate. The variation, in comparison with the average, must be less than 10%.[10]

2.3.2 Activity measured

The specific activity is measured by a*specific "homemade"* ionization chamber.The wire is prepared for treatment with 48 cm length (2 cm cutted) with 192mCi maximum activity (4 mCi/cm).[11]

2.3.3 Equipment maintenance

All the equipment use inside the hot cell (FIG. 4) must be calibrated every four months. All the waste must be removed from the hot cell.

FIGURE 4: Hot cell interior: Lead shielding protecting the ionization chamber and the electrometer.

The cutting of the wire is needed due to the activation discontinuity in the extremity. This happened as a result of geometry measurements inconsistency in positioning the wire in the detection system. The cutted ends are radioactive waste.

III. RESULTS

The solid waste is previously characterized in the analysis phase. The contaminants are already known and they are insignificant due to their fast half-life. The iridium-192 half-life is74.2 days,classified as very short half-life waste. The reminiscent activity is 8mCi ($2.96x10^8$ Bq).According to theCNEN-NN 6.08 standard, that presents the discharge levels, the limit is 1 $kBq.kg^{-1}$($2.7x10^{-5}$ $mCi.kg^{-1}$).[12]

In order to estimate the total activity, the amountsare:

- Production estimate: 10 wires/week;
- Each wire (50 cm total) produces 2cm of waste;
- The discharge levels for Ir-192 waste is: 1 $kBq.kg^{-1}$; [12]
- The mass for the 50 cm wire is 0,73 grams;
- Waste mass and activity: 0.015 g/cm, 1-4mCi/cm, 10 wires/week, 20cm waste/week. Converting the data to mass = 0.3g/week;
- The hot cell undergo through maintenance every 4 months. The internal space needs to be clean, without any waste;
- The total waste activity per week is: 4 mCi x 20 cm waste resulting in80 $mCi.week^{-1}$ or $2.9x10^9 Bq.week^{-1}$.

Weakly, 0.3 g with 2.9 GBq of Ir^{192} waste is produced. To immediate discharge, the following condition needs to occur:

0.3 grams of Ir192------- 2.9 GBq

1 gram of Ir192 -------- 9.7 GBq (greater than 1 $kBq.kg^{-1}$ limit)

Thus, the waste cannot be discharge. It must bemanaged through the R&R (retain e retard) system, that means, temporary storage and posterior discharge. Equation 1 is used to determine the total storage activity considering the decay (it takes into account the decay of the already stored waste for every new waste added).

$$A = \frac{f}{\lambda}\left(1 - e^{-\lambda.t}\right) \tag{1}$$

A: activity per time (t)

f: Entrance activity per second (Bq/s)

λ: decay constant (s^{-1})

t: time (s)

Assuming that f is obtained by the weakly waste activity generated per decay contestant (λ) and the storage time is (t: 4 months or 16 weeks):

$$f = 2.80\ x10^9\ {}^{Bq}/_{s}$$

$$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}} = \frac{\ln 2}{74.2\ x\ 24\ x\ 60\ x\ 60} = 1{,}081\ x10^{-7} seg^{-1}$$

$$t = 4\ months = 9.676\ x10^6 s$$

Calculating the final activity in 4 months (scheduled maintenance):

$$A = \frac{f}{\lambda}\left(1 - e^{-\lambda t}\right) = \frac{2.8\ x10^9}{1.081\ x10^{-7}}\left(1 - e^{-1.081\ x10^{-7} x\ 9.676\ x10^6}\right) = 1.680\ x10^{16}\ {}^{Bq}/_{s}\ for\ 16\ weeks$$

$$m = \frac{0.3\ g}{week} x\ 16 = 4.8\ gin\ 16\ weeks$$

The time that it would take to be discarded in the environment will be calculated by the decay law (Eq2):

$$A = A_0\left(e^{-\lambda . t}\right) \tag{2}$$

A: limit activity per time (t)

A_0: initial activity per time (t)

λ: decay constant (s^{-1})

t: time (s)

$$A = A_0\left(e^{-\lambda t}\right) \rightarrow \frac{10\ Bq}{g} = \frac{1.68\ x10^{16} Bq}{4.8\ g}\left(e^{-1.081\ x10^{-7} xt}\right) = 3.10\ x10^{8} s^{-1} = 9.8\ years of storage$$

The device used for shielding and storage is presented in FIG.5:

FIGURE 5: Shielding and storage device. Dimensions: 10 cm height and 5.2 cm diameter. Volume = 212.37 cm³.

Considering that one device used every 4 months and the waste is stored during 10 years, 30 devices are needed. Thus, all the devices will occupy:

$$V = 212.37\ \ cm^3 x\ 30 = 6{,}370\ cm^3$$

This volume is equivalent to a cube with ℓ=18.54 cm. The laboratory has a space (FIG. 6) delimitated by double 4.5 cm lead bricks with ℓ= 27 cm, which is enough space for store the devices for 10 years.

FIGURE 6: Waste storage area.

IV. CONCLUSIONS

The radioactive waste generated during the I^{192} wires production is solid, was a short half-life (<100 days) and a weakly activity of 9.7 $GBq.g^{-1}$. According to the standards, this activity is too high to be discarded into the environment (limit 10$Bq.g^{-1}$).The waste must bemanaged by the R&R (retain e retard) system, that means, temporary storage and posterior discharge.

Since there is maintenance every 4 months, the waste must be removed from inside the hot cell. That adds to a total activity of 1.68 x 10^{16} Bq and 4.8 g. This amount is stored inside a device made of lead that has 212.37 cm^3 volume. The waste will take 9.8 years to decay to the discharge levels.

To store 30 shielding devices during 10 years a space with 6,370 $cm^3$is necessary. The laboratory has enough space for this storage. Thus, the radioactive waste management can be performed through the R&R (retain and retard) system safely.

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