TREATMENT VOLUME OF AEDES ALBOPICTUS WITH X RAYS GENERATED FROM ELECTRONS

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Abstract. Irradiation is a common method used for sterilizing objects in several fields. In the entomology sector, insects are sterilized through irradiation and released in to the wild to sexually compete with the population at large reducing the chance for reproduction. This practice is the Sterile Insect Technique (SIT). Traditionally irradiation sources for SIT purpose are radioisotopes but many reasons compelled to getting efforts to develop other radiative technologies. Since gamma rays and electrons have similar sterilizing effects, the choice of source for SIT irradiation is based on considerations about penetration and environmental factors.

Gamma irradiators are usually simpler to operate, and less expensive, than electron accelerators, at least within the range of power required for SIT applications. Currently, the increased difficulties to manage and ship radioisotopes is being successfully resolved by the introduction of novel X-ray irradiators that enable a safer use of irradiator machines and procedures for SIT applications.

In the ENEA Frascati research center we developed irradiators for clinical radiotherapy consisting in a radiation converter from electrons to X-rays. Since X-rays penetrate deeper than the electrons from which they are generated, we used this technology in a configuration that delivers a uniform dose on large targets to irradiate insects for SIT aim.

In this topic, we gained practical experience working with Aedes albopictus, a mosquito vector of various tropical diseases such as dengue and zika. Several dosimetric studies have been conducted to achieve male sterility without affecting male mating competitiveness in comparison with untreated males. Lower doses have been also tested on an Ae. albopictus strain modified with the bacterium Wolbachia, which also determines male sterility, to sterilize the females eventually escaping the sexing procedures preliminary to the releases of the males.

1 INTRODUCTION

The Particle Accelerators and Medical Applications Laboratory (APAM) at ENEA Frascati research center, develops particle accelerators for medical, industrial and research applications [1-3]. Some electron accelerators were developed as stand alone accelerators or as parts of a larger facility.

A 4.8 MeV 180 mA S-band electron on-axis coupled linear accelerator (linac) was completely designed and built inside the accelerator laboratory. This design was used as a basis for the IORT accelerator development with industry [4].

This medium energy linac offers some suitable services to scientific community in the several applications fields in which e-beam and X rays are useful and often it has been used as a test facility for material processing. Examples of test of radiations already carried out are in the following table 1.

Table 1: Examples of irradiations with the 4.8 MeV linac at ENEA Frascati research center.

Crosslinking of polymers
Degradation of pesticides
Degradation of phenols in waters of washing of the olives
Degradation of policlorobiphenols (PCB) present in oils of isolation of the transformers
Cracking of oil products
Water sterilization infected by pathogenic agents
Control of the effects of the on the functionality of the cells of the blood
Production of color centers in alkaline crystals in presence of drugging for employs in solid state laser
Generation from metallic targets of x-rays radiation
Damage tests of hard materials for nuclear fusion applications

The APAM laboratory unit dedicated to the electron accelerator system studies the physics parameters and the dosimetry of the particle beam up to the "radiation effects" investigating the whole chain of processes starting from the elementary interactions between ionizing radiation in matter up to the formation of the effect (eg, radiation damages to soft and hard materials [5]).

Monte Carlo methods are developed and employed for the simulation of radiation field and the induced processes for radiation response studies and radiobiological experiments.

Recently, within the COBRA project [6], a new irradiation chamber for treatment volume in order to remove biodegradation of artistic and cultural assets [3] has been realized. Investigations in this topic have led to the interest in the generation and characterization of radiation fields for radiobiological experiments with X-rays produced by the accelerated electrons. On this line we have devoted a study to the effects of radiation on insects.

Aedes albopictus is a mosquito vector of various severe diseases including dengue, zika, yellow fever and chikungunya. Insecticides did not show the ability to obtain the suppression of this dangerous insect species on the long term, mainly due to the development of resistant populations. Thus, innovative strategies of control are required to supplement the existing means to maintain this population's population density below the epidemic risk threshold. The production and release of sterile males capable of reducing the fertility of the wild-type population is proving to be a suitable approach to achieving this goal. ARwP Ae. Albopictus is a line capable of producing sterile males due to infection of a specific strain of the endosymbiotic Wolbachia bacterium. Herein, we tested various X-ray dosages as a mean to achieve the sterilization of females eventually escaping the sexing procedures which could be undesired during releases in the field.

The present work was mainly aimed at the definition of a radiation protocol for the treatment volume of Aedes albopictus with X rays generated by electrons.

LINEAR ACCELERATOR

The linear accelerator employed in this work is an S-band standing wave on-axis coupled machine delivering 900 W maximum average power at 4.8 MeV and operating in the π/2 mode. The operating parameters are given in table 2. In figure 1 a drawing of the on-axis coupled accelerator and a picture of the brazed structure are given.

Table 2: 4.8 MeV linac parameters.

Mode Frequency	2999 Hz
Q0 factor	12000
Coupling Coefficient	1.9
Shunt Impedance ZS	72.7 MΩ/m
Number of accelerating cavities	7+2 halves
Number of Coupling Cavities	8
Cavity Length	48 mm
Pulse Duration (FWHM)	3.5 μs
Current at 4.8 MeV	200 mA
Frequency Repetition Rate	100 Hz (max)

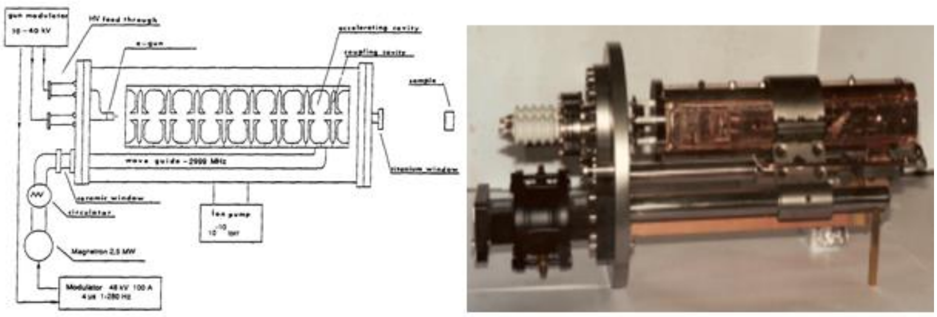

Figure 1. Left: drawing of the linear accelerator; right: the 4.8 MeV on-axis coupled linear accelerator.

Figure 2 shows the irradiation facility consisting on the described linear electron accelerator and the irradiation chamber.

The energy of electrons is determined by measuring the electrons range in aluminum: the obtained energy depends on whether the transmitted beam is measured in peak current from the beginning of pulse or measuring the average current and by transforming it to peak value using duty cycle of beam pulse.

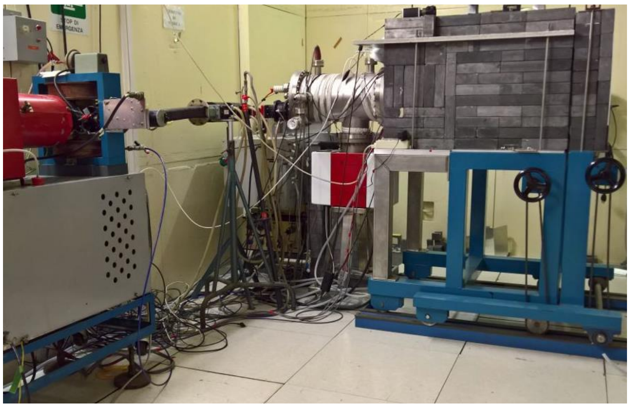

Figure 2. View of the e-beam/X-ray irradiation facility.

X-RAY IRRADIATION

Several set-ups are available using the e-beam irradiation facility described above.

The irradiation campaigns for the treatment volume of Aedes Albopictus depicted before were performed with X-rays.

The accelerated electrons exiting from the linac were collimated by stainless steel flange with an aperture of 5.5 mm and then shoot a target to generate X-rays through the bremsstrahlung effect. The produced X-rays passes through a lead conic collimator with 30 mm diameter as shown in figure 3.

Figure 3. Left: view of the e-beam exit. Right: X-rays lead collimator in front of the e-beam exit.

The MCNPX6 Monte Carlo Method was used to find the best thickness and material of target with biggest conversion efficiency. A simulation with the single material target model for scanning parameters calculates the conversion efficiency and estimates the dose rate. By the optimized calculation we choose a tungsten conversion target 1.64 mm thick [7] with a further aluminum, 0.5 mm thick, to block both any remaining primary electrons and the secondary ones produced.

Figure 4 shows the X-rays source, tungsten converter, housed between the electron collimator, just outside the linac exit window, and the X-ray beam lead collimator.

The insect sterilization protocol, afterward outlined, was developed working with the operational parameters summarized in Table 3.

Figure 5 shows the X-ray source spectrum calculated by MCNPX6.

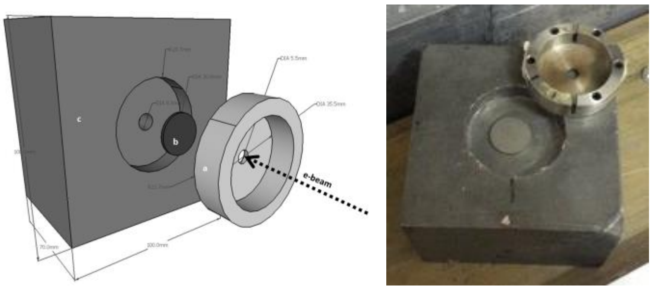

Figure 4. Schematic view (left) and photo (right) of the e-beam collimator (a); tungsten converter for X-rays (b); lead collimator (c).

Table 3: 4.8 MeV linac operational parameters set for the insect sterilization protocol.

Cathode Current	4 mA
Cathode Voltage	2 kV
High Voltage (power supply)	19 kV
Mean Current Accelerated Electrons	140 mA
Repetition Frequency	14 Hz
Pulse length	3 μs

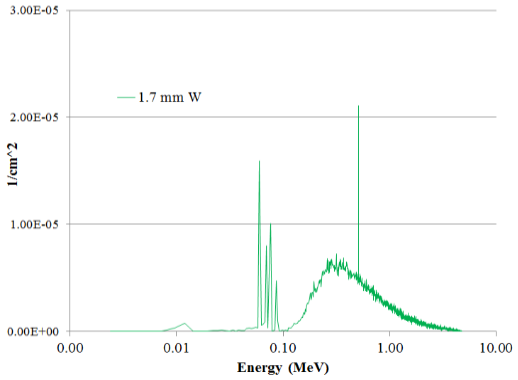

Figure 5. X-ray fluence distributions for source particles: the peak at 511 keV due to the pairs production and the characteristic fluorescence X-ray peak at 1.02 MeV are visible. [7]

The shield used for X-ray irradiation is a lead chamber positioned after the linac vacuum chamber (figure 2) and encloses both the electrons output terminal and the X-ray source as shown in figure 6. The internal volume of this irradiation chamber is: 410 x 810 x 400 mm^3.

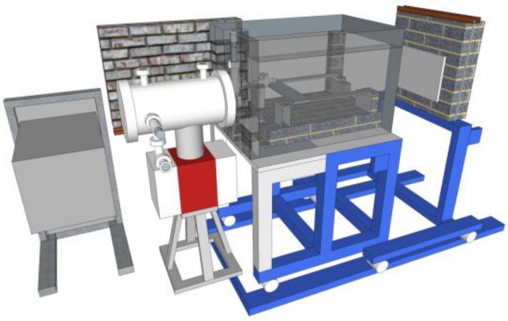

Figure 6. Sketch of the irradiation setup with the lead shielding room (410 x 810 x 400 mm^3) for the X-rays tests.

The half-value layer (HVL) method (effective up to 3 MeV photons) was used to measure the X-ray spectrum using thicker copper layers and also a Monte Carlo simulation was carried out interposing the filters on the previously calculated photonic spectrum.

The dosimetric control measurements were executed in the volume of the shielding room by a FWT IC-17A ionization chamber having an active volume of 1 cm3, suitable for high dose rates, calibrated at the LAT-231 calibration center with 60-Co, 137-Cs [7]. This dosimeter has a linear calibration factor in the energy region between 50 keV and 1.25 MeV showing a maximum, acceptable, variability of 10%. The calculated uncertainties are associated as follows: 1.5% the calibration factor, 5% the measurements, 3% the positioning. These should also add to the variability of the irradiation intensity of the converter due to variability of the e-beam cathodic emission.

The ionization chamber, powered by 300 V, was connected to a Keithley 6514 electrometer with a feedback capacity of 400.97 nF.

AEDES ALBOPICTUS

Female pupae (46±2 hour old) of the ARwP Ae. albopictus line were irradiated at various doses. The emerging adults were then mated with fertile males and then allowed to lay eggs to check for their fertility.

IRRADIATION MODALITY

A preliminary X rays dose and dose rate measurements campaign allowed to assess the distribution of dose inside the irradiation chamber. An ionization chamber sensor (model PPC05 from IBA) coupled to a reference class electrometer for measurements of absorbed dose (model Dose 1 from IBA-Wellhofer-Scanditronix) has been used to measure the dose rate in several points inside the lead shielded room. The sensor inside the irradiation chamber was moved by a remote handling system. In order to have a relatively low dose rate and, at the same time, a greater homogenous dose distribution, we decide to move far from the beam source point. In particular, for the insects sterilization process a distance of 30 cm from the X rays exit window has been considered. In this position, the measured dose rate is 0.952 Gy/min.

Then, a Petri dish containing water and the ARwP Ae. albopictus pupae has been placed perpendicularly at X rays beam axis, as shown in figure 7. Two Petri dishes have been irradiated for 31’30” and two other samples for 20’50”

Figure 7: Petri dish with Aedes albopictus pupae inside the irradiation room.

CONCLUSIONS

Currently we're going to run the way of experimental campaigns to define the best irradiation protocol in the entomology sector of the Sterile Insect Technique (SIT), to sterilize the dangerous insects Ae. albopictus that released into the wild sexually compete with the population at large reducing the chance for reproduction.

The reason of the interest in this X-rays application is related to the conditions of both radiation field and penetration improving sterilizing effects with simpler and safer process.

To evaluate the absorbed dose appropriate for male and female specimens of Ae. albopictus modified with the Wolbachia bacterium, as described above, we're setting up the right X-ray exposure procedure also performing the photon beam simulations using the EGSnrc Monte Carlo code. This system, available for non-commercial purposes, of radiation transport, is a code specifically designed to model the transport of radiation. It includes BEAMnrc software component can meet the requirements for modeling beams traveling through consecutive material components ranging from a simple to a complex geometry of the linac head terminal. Also the EGS tool is used to estimate the dose distribution on the sample target and the data will be compared with Fluka simulations. In this way, we are simulating the fluency profile on our sample within the irradiation chamber, described in the above paragraphs, to optimize the delivering of the prescribed radiation dose to the sample and new several experimental tests are foreseeing.

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