GR440 High Dose Rate Self-Contained, Dry-Storage Research Irradiator

Hopewell Designs, Inc.

I. INTRODUCTION

Several high dose rate applications require the use of a research irradiator for supporting research and development activities. Current best practices embrace utilizing self-contained research irradiators to perform calibration irradiation on dosimeters, radiation effects studies, batch irradiation of biological samples, and radiation hardness testing of electronic components among other radiation processing applications. A majority of these systems, although solid workhorses, do not have the fresh capabilities offered by innovation in system design, control, feedback and automation. In addition, these systems suffer from uncertainties in terms of dose uniformity and to a lesser extent, isotopic assay. Moreover, many facilities which perform testing activities leverage institutional knowledge and experience to develop and adopt internal techniques to overcome shortcomings in these irradiator systems. These techniques include those that address dose uniformity, such as irradiation chamber design modifications, novel fixturing and source loading management as well those that address irradiation temperature control including, ad hoc cooling and heating schemes and automated process control. An additional challenge is the dosimetry systems employed require internal adjustments, within the constraints of applicable standards, in order to comply with testing guidance [1-2]. The bulk of these in-houses fixes are resource intensive and require testing facilities to continually address the rigidity of the legacy irradiator systems.

In response to some of these legacy systems no longer being supported, Hopewell Designs, Inc. has developed a turn-key solution to fill the role of these legacy systems while providing several improvements to meet the needs of a new host of applications. The Hopewell Designs, Inc. Model GR440 High Dose Rate Self-Contained Research Irradiator is a modern replacement for the legacy systems coupled with innovative design changes. The GR440 combines the well-known and understood capabilities and features of legacy systems with numerous state-of-the art design upgrades including larger chamber volume, a rotating chamber, higher precision timing/process control and greatly improved external (operator) dose rates. The new system (see Fig. 1) features a horizontal loading platform with a rotating irradiation chamber addressing irradiation field uniformity needs. Hopewell Designs, Inc. provides unparalleled service, preventative maintenance, technical support and source reloading for its entire product line. Additional features include irradiation chamber temperature control and application-based fixturing to tailor irradiation field parameters to meet irradiation requirements.

Fig. 1. Overview and cross section views of the GR 440 concept design. The schematic shows the vertical cross section at the top right displaying the system in the chamber loading orientation. The bottom image depicts a horizontal cross section of the system to visualize the horizontal loading operation. The inner half-moon shielding component rotates about a vertical axis to bring the irradiation chamber within a variable distance from the source pencils.

The chamber rotates in place in front of a dozen Co-60 sources with combined activity approaching 888 TBq (24kCi). This system is capable of irradiating samples within a 30.48 cm tall by 27.94 cm diameter cylindrical chamber, quadrupling the volume of the irradiation chamber without far exceeding the weight of similar legacy systems by integrated depleted uranium into the shielding design, which addresses both radiation protection needs and overall system weight/space requirements.

II. OPERATING PARAMETERS

In order to inform a novel irradiation chamber design baseline, monte-carlo studies were performed to optimize design parameter space. High-fidelity monte-carlo models utilizing the Los Alamos National Laboratory MCNP N-particle transport code (MCNP6) have been developed to investigate the absorbed dose distributions in air in the irradiation chamber [3]. Published data show MCNP simulations match to experimental data with relative error of less than 3% [4-5]. A detailed model of the GR 440 was developed including the irradiation chamber, the source pencil arrangement, the outer irradiator shielding and an array of alanine dosimeters to simulate dosimetry (used in model to tally dose). The radiation effects community commonly utilizes alanine dosimetry to characterize irradiation sources for testing as well as to implement traceable dosimetry processes [6-7]. Five columns of seventy (70) alanine dosimeters were modeled in the center of the irradiation chamber and moved radially in order to generate isodose curves.

The discretized mesh was analyzed to determine the dose uniformity ratio (DUR), the ratio of the highest dose in the chamber to the lowest dose, while in the irradiation position. Furthermore, the mesh analysis allowed for multiple orientations of the dose uniformity within the chamber to be visualized. The DUR for the GR440 was determined via simulation to be 2.37 over the entire irradiation chamber with a centerline dose rate of 127.0 Gy/min. By selectively isolating individual planes of the three-dimensional mesh, isodose contour plots were generated for the GR 440 showing contour lines along the radius of the chamber at the midline of the chamber height and over a range of radii with respect to the height of the chamber, as shown in Figure 2. These dose maps assume an approximate difference of 7-8% in source activity in each of the dozen Co-60 sources.

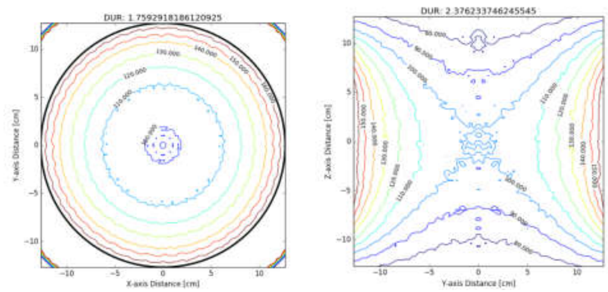


Fig. 2. Overall GR 440 irradiation field parameters including a dose uniformity ratio of 2.37 for the radius versus height isodose profile (right) and 1.76 for the horizontal radial plot at the midplane of the chamber height (left) with a centerline dose rate of 127.0 Gy/min. Field lines in the isodose profiles are labeled by percent with respect to the centerline dose rate.

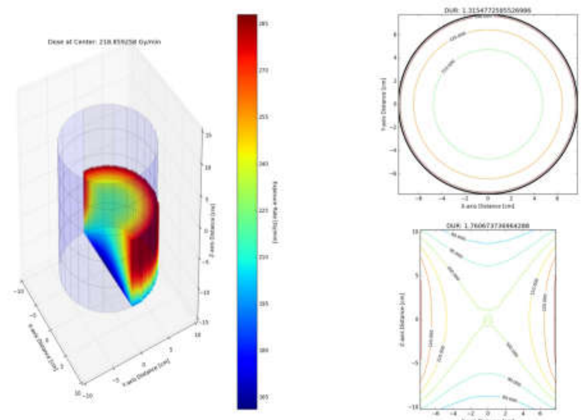


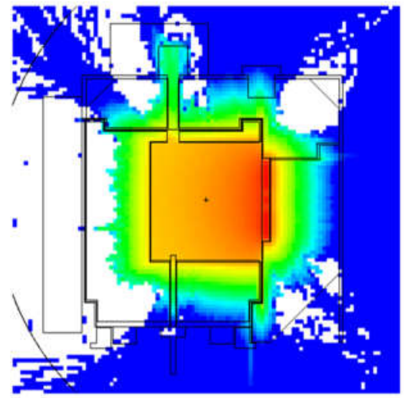
Fig. 3. GR 440 irradiation field with a reduced chamber size with ~15.5cm diameter has a dose uniformity ratio of 1.76 for the radius versus height isodose profile (bottom right) and 1.31 for the horizontal plane (upper right) with a centerline dose rate of 218.9 Gy/min. Field lines in the isodose profiles are labeled by percent with respect to the centerline dose rate. A lower quadrant of the reduced chamber is depicted (left) to visualize the absorbed dose gradient through the chamber in three dimensions.

The increased chamber size of the GR 440 allows for a tailoring of radiation fields depending upon the product or device being irradiated. For example, by reducing the rotational size of the irradiation chamber from 27.94 cm diameter down to 15.49 cm diameter (the standard size of one legacy irradiator chamber), the chamber may be uniformly irradiated over a shorter distance between the chamber centerline and the sources. A three-dimensional cross–section of this reduced size chamber with only the lower quadrant displayed is shown in addition to the previous isodose profiles so that the dose change as a function of multiple location parameters may be visualized (see Fig. 3). Additional isodose profiles were generated including a horizontal plane through the midsection of the sources, such as would be seen by a flat plate containing alanine pellets.

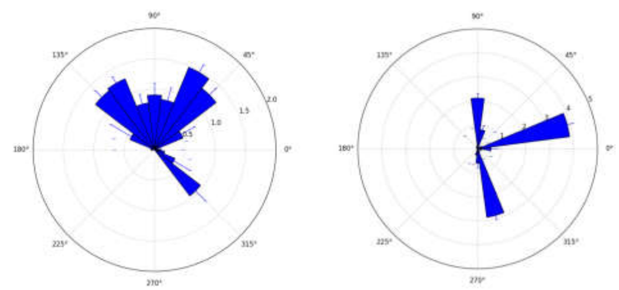
In the irradiation position, the chamber is positioned in front of a source arrangement which holds up to one dozen Co-60 source pencils (Nordion C-198 source capsules) arrayed in an arc. Each C-198 pencil source contains seven (7) individual Co-60 slugs and two stainless steel spacers ordered in the following convention (three slugs / spacer / one slug / spacer / three slugs) [8]. The rotation of the sample chamber removes the higher field intensity gradients due to isotopic non-uniformities in the source pencils, reducing the hot spots in the irradiation chamber and providing a more uniform irradiation field. This effect was verified through analysis of the average standard deviation of symmetric field lines within the chamber. Rotation of the chamber was found to markedly improve the accuracy of the dose delivered from non-rotational, concentric ring type self-shielded irradiator systems.

III. EXTERNAL PARAMETERS

The GR 440 irradiation chamber is arranged in a cylindrical configuration and rotates on its vertical axis between loading and irradiation positions. The approximate size and weight characteristics of the shielding design measure 1 meter in diameter and 1 meter tall and 4000 kg, without accounting for shield frame, motors, and electronics. Source loading is accommodated with dedicated tungsten shielding above the source assembly and transfer shield mating capabilities. To remove potential failure mechanisms, the primary rotational bearing is located outside of the irradiation chamber. The rotational shielding includes a pathway down the center of the irradiation chamber as a potential drain line as well as a vertical pathway, shielded with a lead baffle, allowing access for umbilical lines and tubing. The same vertical pathway allows for forced air cooling or heating for temperature control of the irradiation chamber. The overall weight of the system is further optimized by chamfering the edges of the primary shield where shielding is unnecessary.



(a)



(b)

Fig. 4. Vertical profile cross section of (a) the GR 440 with a dose rate scale showing the lowest dose (blue) below 50 μSv/hr and (b) the external radiation fields in units of mrem/hr (as shown on the diagonal axis) from twenty-four measurement points (left) around the circumference of the system and (right) from the left side and over the top to the right side of the system with respect to the orientation shown in (a).

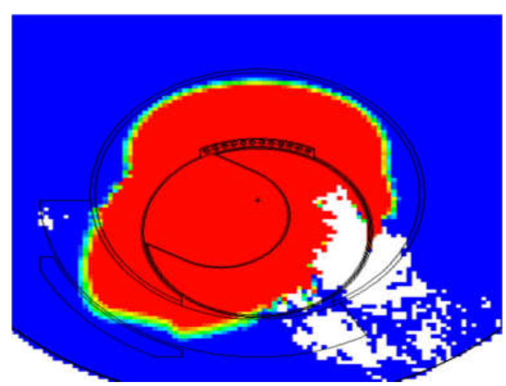


Fig. 5. Horizontal profile cross section of the GR 440 with a dose rate scale showing the lowest dose (blue) below 50 μSv/hr and highest dose (red) as greater than 0.5 mSv/hr at the point of greatest penetration of the transient dose to visualize the gradient at the edge of the lead door when changing between irradiation and loading modes of operation.

The external dose rates from one dozen Co-60 sources totaling 24 kCi have been determined through high-fidelity modeling with Monte Carlo methods for all modes of operation, including transient chamber modes. The highest external dose rate from the sources for the system in the irradiation position is located directly behind the sources and is calculated to be approximately 40±10% µSv/hr (4 mrem/hr) when measured at the surface. As the system rotates from the irradiation to loading position, the external dose rates remain low due to the presence of an interlocked lead door, configured to attenuate the transient dose as the chamber is moved between positions. Figures 4 and 5 display the monte carlo radiation transport simulation of the GR 440 where the blue field color represents dose rates below 50 µSv/hr (5 mrem/hr).

IV. SUMMARY

This work is an ongoing effort to characterize operating parameters and external dose rates of the Hopewell Designs GR440 High Dose Rate Self-Contained Research Irradiator. Preliminary results show that a critical aspect of a new design is the ability to rotate the chamber in order to gain improved uniformity and accuracy of dose delivered. Variable speed rotational irradiation chamber design matched with precision timing and process control provides a new tier of accuracy for dose delivered.

The irradiation chamber volume of 18,688 cc represents an almost five time increase in volume over similar legacy systems irradiation chambers. This increase in irradiation chamber size is not matched with a corresponding increase in the system weight. The utilization of depleted uranium (DU) as the primary shielding material instead of lead takes advantage of the 1.7 times higher density of DU, therefore maintaining a similar weight profile and form factor to legacy high dose rate research irradiator systems.

The maximum activity for the GR 440 design is 888 TBq (24kCi) of Co-60. Loading depends on customer requirements and is a function of the specific activity of each slug within each pencil and the arrangement of pencils within the arc. Straight line streaming pathways are minimized through utilization of a horizontal loading technique, and transient external doses are kept below maximum permissible radiation levels with the use of a moveable lead door. Both external dose performance and internal irradiation performance have been mapped through the use of monte-carlo methods to provide insight into the capabilities and characteristics of the Hopewell Designs GR440 High Dose Rate Self-Contained Research Irradiator. Further information on the system can be found in Table 1.

TABLE I. GR 440 OPERATING PARAMETERS SUMMARY.

Radiation Source Parameters	
Isotope	^{60}Co (uniform field) – Nordion C198 source pencils
Max. Activity	888 TBq (24 kCi)
Field Uniformity	(80% – 160%) of centerline dose rate within entire irradiation volume (as simulated with MCNP6)
Field Intensity	Characterized (simulated) within ±2.5%
Dosimetry	Target-dose (flat geometry) of 25 kGy: 1. Time to achieve dose between 100 – 160 min, dependent on positioning 2. Transient dose is ~ 6 Gy. Equates to 0.025% of target dose.
Dose Rate	
Condition A[1]	127.0 Gy/min [2.37 DUR]
Condition B	218.9 Gy/min [1.76 DUR]
Condition C	Specific to test (agreed to by test parties)
Temperature Parameters	
Temperature	1. Irradiation temperature chamber must maintain device under test at ±5°C and raise the temperature in a reasonable time (and cool in 20 minutes) [8]

[1]Conditions in the table are for simulated results only, simulated results representing the dose rates and field profiles due to one dozen Co-60 sources totaling 24 kCi. Conditions refer to positional arrangements of internal irradiation chamber. Condition A is the overall chamber 30.48 cm tall by 27.94 cm diameter. Condition B is the reduced size and distance to source chamber 20.47 cm tall by 15.49 cm diameter. Condition C represents flexible configuration chamber option, tailored specifically to meet requirements.

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