Dose on Demand

Radioisotope Generator (RIG) 2.0

Improvements in Beam Optics, Ion Source, and Targetry

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I. SUMMARY:

The purpose of this white paper is to describe the next generation Radioisotope Generator, termed RIG 2.0. The RIG 2.0 has a number of advancements that include an improved ion source that lasts at least 2 months and has double the current power on target, improved beam optics through the use of the next generation mapping system, termed Mapper 2.0, three different target options available for the design to support site scalability and a new hydraulic lift system to aid in on-site service and support. The RIG 2.0 is available for purchase now, with the Tantalum Target 2.0 available for purchase December 1, 2015. The RIG 2.0 is compatible with the BG 30 Minute, 1.0 GMP and 2.0 GMP configurations[1-3].

II. BACKGROUND:

To supplement the improvements in chemistry yield and Enhanced GMP compliance of the BG75 1.0 GMP system, ABT has invested considerable resources towards the improvement of the Radioisotope Generator. Improvements to the RIG will improve build-to-build variability and increase the dose produced in a given run. This will result in less cost/per dose for the customer. The following sections of this document describe the methods by which the RIG has been upgraded to the 2.0 configuration, namely by improving the center region, beam optics, target and shield lift system.

III. METHOD:

The sections below describe the technology improvements to the RIG 2.0[4]. The goal of these improvements is to improve the efficiency, reliability, output and serviceability of the design.

Center Region 2.0

Improving the efficiency of the ion source will also improve the lifetime of the ion source. To this end, ABT's cyclotron research group has developed simulation capabilities to model the electric, magnetic and RF fields generated by the cyclotron. COMSOL® and proprietary beam path code was used to generate orbit paths starting from the opening in the ion source out to the target radius.

Figure 1 illustrates the electric and magnetic field models along with the orbit graphs. The purpose of the orbit graphs is to illustrate what happens to the protons for different starting energies and directions from the ion source. The plots are based on a uniform magnetic field and the starting time relative to the RF voltage is varied to determine the acceptance window of the ion source puller.

The ion source to puller distance and starting rotation were varied to determine the optimal position. By determining the optimal angle, the ion source reliability can be improved along with the amount of current at target radius. The outcome of this optimization exercise is described in the results section.

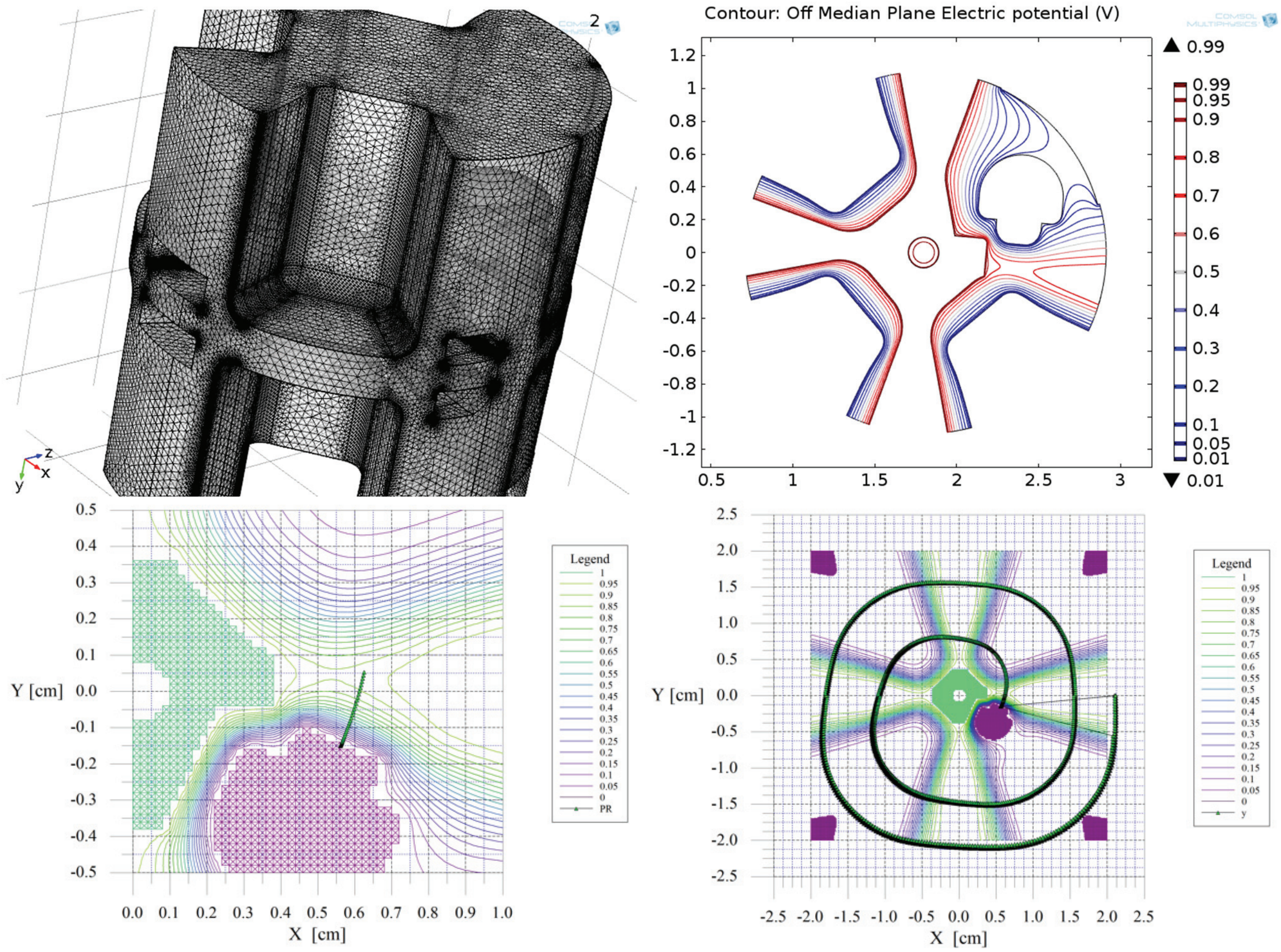

Figure 1. (Top Left) Finite element analysis was used to calculate the electric field for the cyclotron simulations. (Top Right) Isocontour electric fields generated by COMSOL® for the RIG center region. The simulation was used to calculate the (Lower Left) optimal rotation of the source and the (Lower Right) corresponding orbits.

RIG 2.0 Target Options

The RIG 2.0 target options include the released High Flow Stainless and Tantalum Target 1.0 designs, which are currently available for purchase. In order to support the roadmap of ABT that includes FLT and F-Choline, which have traditionally low yields, the Tantalum Target 2.0 has been developed in conjunction with Bruce Technologies BTI®. The purpose of this design was to optimize the target for heat removal in the limit 1 [in] target gap.

Figure 2 illustrates the Tantalum Target 2.0 concept along with the associated thermal simulations. Based on the simulations, the Tantalum Target 2.0 can remove 2x the heat compared with the Tantalum Target 1.0.

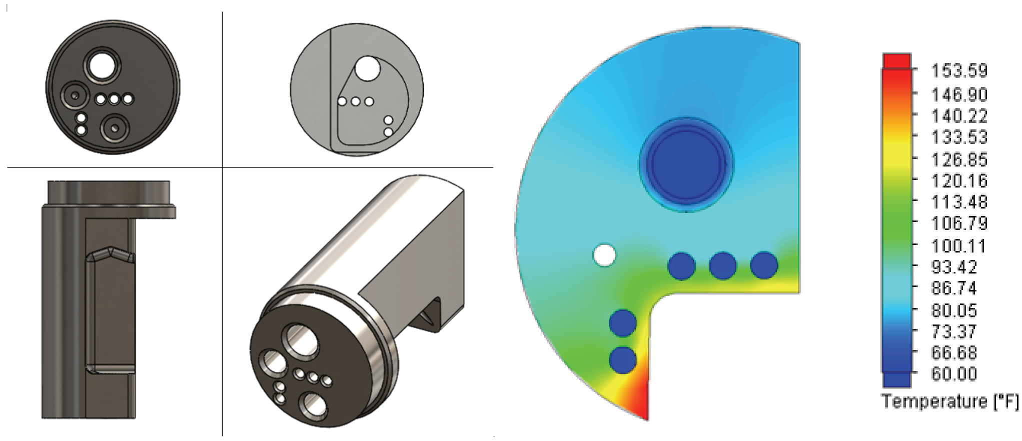

Figure 2. (Left) Tantalum Target 2.0 drawings and (Right) thermal simulations of the Tantalum Target 2.0. The Tantalum Target 2.0 can remove 2x as much heat as the Tantalum Target 1.0.

Mapper 2.0

The mapping of the magnetic field and the associated hill cuts are essential to proper beam optics at target radius. The existing mapper hardware and software, termed Mapper 1.0, was upgraded to include both radial and azimuthal encoders to achieve < 0.025 [mm] and < 0.01 [°] accuracy. Figure 3 illustrates the Mapper 2.0 system architecture.

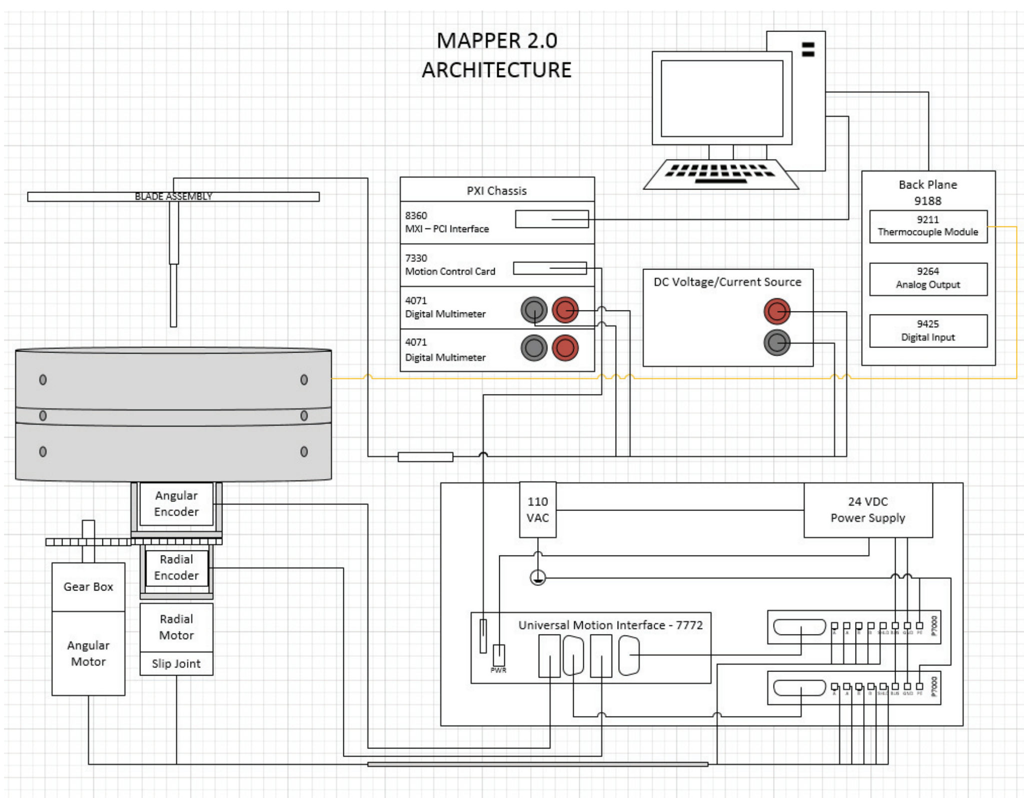

Figure 3. Mapper 2.0 architecture contains encoders in both the radial and axial directions to ensure accurate and repeatable magnetic field probe positioning.

Shield Lift 2.0

The serviceability of the cyclotron is critical for uptime and safety. The existing jack screw lifts are being updated to a hydraulic system. The new hydraulic system will be able to lift the system in < 1.5 [min] compared to the jack lifts that take 8 [min]. The hydraulic system will also have all of the required interlocks to ensure that the shield remains level during lifting.

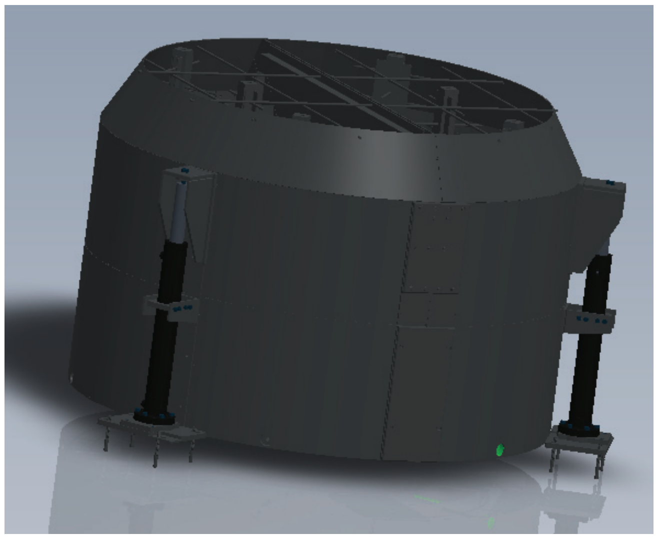

Figure 4. Schematic of hydraulic shield lift system.

IV. RESULTS:

Center Region 2.0

The ion source and puller have been optimized to increase the beam on current. The improvements are described in Table 2 comparing the Center Region 2.0 to the Center Region 1.0. The new center region design results in a 2x reduction in ion source power, which doubles the life of the ion source. This is both an improvement in ion source reliability and maximum achievable target current.

Table 2. Center Region 1.0 versus 2.0 Improvements on BG13, BG16, and Newcastle at the ABT Factory.

Ion Source Current [mA]	Center Region 1.0		Center Region 2.0	
	Ion Source Voltage [V]	Ion Source Power [W]	Ion Source Voltage [V]	Ion Source Power [W]
150	763	130	492	72
200	730	146	423	84
250	558	140	363	91
300	500	150	323	97
350	522	183	304	107

RIG 2.0 Target Options

Table 3 summarizes the heat removal of the targets and yield. The different target options support site scalability and require no other hardware or software upgrades to the system.

Table 3. F-18 Targetry heat removal and yield for the three different targets options for the RIG 2.0.

Property	Units	HF SS Target	Tantalum Target 1.0	Tantalum Target 2.0
Flow Rate	[gpm]	0.15	0.15	0.15
Pressure Drop	[psi]	15.2	19.7	25.4
Heat Transfer Rate	[W]	**26.4**	**51.7**	**96.3**
Max Fluid Temp.	[°F]	162	157	130
Yield in 1 [hr]	[mCi]	50	80	130*

*Estimate based on thermal simulations.

Mapper 2.0

The Mapper 2.0 has been implemented on the RIG 2.0.. Figure 4 shows the improvement in the maximum magnetic field difference between two consecutive Mapper 1.0 maps (blue) and three consecutive Mapper 2.0 maps. The improvement in accuracy will significantly reduce the cyclotron to cyclotron variation to ensure consistent beam optics and target yields on all future cyclotrons.

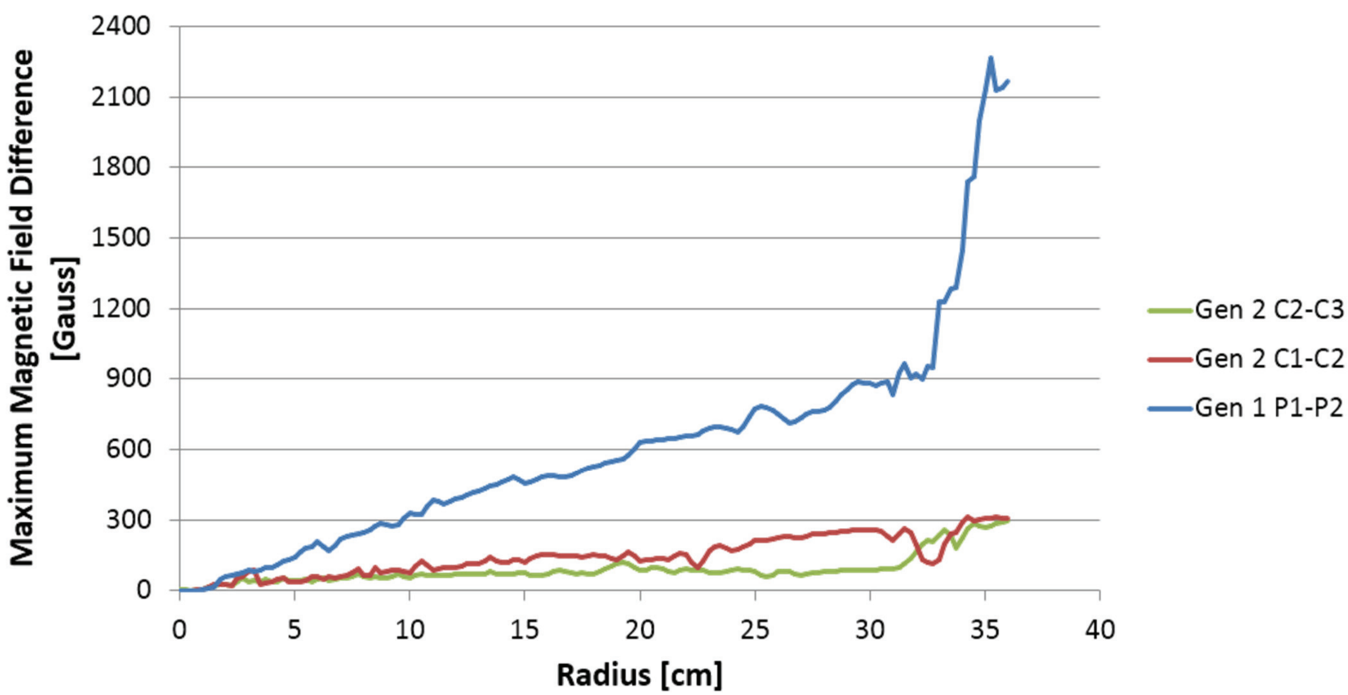

Figure 4. Maximum magnetic field difference between two consecutive Mapper 1.0 maps (blue) and between three consecutive Mapper 2.0 maps (red and green). The Mapper 2.0 is 2-8x more accurate than Mapper 1.0.

Figure 5 is an illustration of the improvement in first harmonic stability with the Mapper 2.0 compared to Mapper 1.0. The Mapper 2.0 lines are within 5 [%] of each other versus the Mapper 1.0 values that show up to a 45 [%] variation.

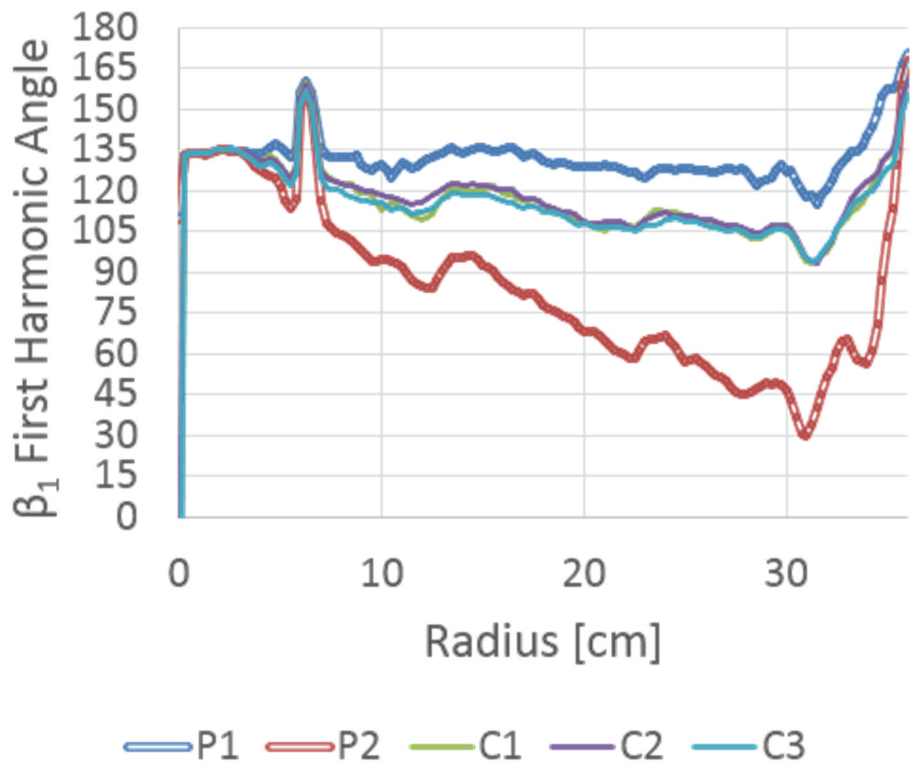

Figure 5. First harmonic angle calculated from two Mapper 1.0 maps (P1, P2) and three Mapper 2.0 maps (C1, C2 and C3). The first harmonic from Mapper 2.0 maps lie on top of another with < 5 [%] difference, the two Mapper 1.0 maps range from 0-45 [%] different.

Shield Lift 2.0

Shield Lift testing will commence in late June at ABT to ensure that the system will meet all functional and safety requirements. Figure 6 shows the shield lift system on the ABT BG 75 show system at the factory.

Figure 6. Hydraulic shield lift system at ABT factory tested on May 11-13. The shield testing passed all required specifications and lifted the shield in < 60 [s].

V. CONCLUSIONS:

The Radioisotope Generator (RIG) 2.0 was presented in this white paper. The RIG 2.0 has advancements in beam optics, ion source reliability and output, targetry options and a new hydraulic lift system to support site service and support. The RIG 2.0 is available for purchase now, with the Tantalum Target 2.0 available for purchase December 1, 2015.

VI. REFERENCES:

1) White Paper - 30 Minute Upgrade at Varna, Baltimore, MD. 2015. http://abt-mi.com/en/resources
2) White Paper - BG75 1.0 GMP, Baltimore, MD. 2015. http://abt-mi.com/en/resources
3) White Paper - BG75 2.0 GMP, Baltimore, MD. 2015. http://abt-mi.com/en/resources
4) Automated Radiopharmaceutical Production and Quality Control System, 14/618,795, Submitted March 6, 2015, ABT Molecular Imaging, Inc. Knoxville, TN