Problems associated with scheduling a medical cyclotron

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Subsequent to the issuance of a patent for "an apparatus for the acceleration of ions" to E.O. Lawrence on February 20, 1934 <1>, the medical community has utilized a variety of radionuclides for both routine clinical applications and basic investigations. In 1936, the cyclotron-produced radionuclide Phosphorus-32 was first administered to a 28-year-old female patient by Dr. John Lawrence.

Usage of radionuclides has been toward the short-lived, biologically equivalent isotopes incorporated into specific compounds or complexes. In the past decade, the number of cyclotrons operational has grown from eight in 1970 to forty-two by 1980. Unfortunately<2>, the literature has few references to problems involving scheduling and efficient utilization of beam time. Therefore, two facilities have been chosen to serve as models of both encountered problems and potential solutions. Perhaps the comments elicited will provide insight for the various centers attending this workshop.

The Cyclotron Facility at Mount Sinai Medical Center is an established facility for the production of radionuclides used in diagnostic nuclear medicine. Its central feature is a CS-30 cyclotron, a 36" isochronous machine manufactured by "The Cyclotron Corp., Berkeley, California". As this facility manufactures radionuclides for "in house" clinical research purposes and also supplies radionuclides to other programs on a routine production schedule, it can serve as a microcosm of the present technological state in achieving a balance between various programs <3,4>.

The Cyclotron Facility currently nearing completion at the National Institutes of Health, Clinical Center, Bethesda, Maryland is an excellent example of the incorporation of current technlogy in anticipation of satisfying the multitude of "on site" requests for radionuclides. Unlike the Cyclotron Facility at Mount Sinai Medical Center there will be two cyclotrons in this facility. One is a CS-30, four particle machine manufactured by "CTI-West, Berkeley, California". The second is a BC1710, Baby Cyclotron purchased from "The Japan Steel Works, Ltd., Tokyo, Japan". Various automated radiopharmaceutical syntheses systems are included with this latter accelerator.

At Mount Sinai Medical Center, the cyclotron staff produces medically useful radionuclides not currently available to the clinical community due to either the limited capabilities of other accelerators or the constraints of short half-life, and incorporates them into designed radiolabelled compounds. Effective utilization of the machine has lead to many innovative undertakings such as unique targets, procedures for chemical separations and recoveries of enriched materials, syntheses of labelled radiopharmaceuticals, and radiation material effect studies <5-11>. As exciting and challenging the clinical research areas are, the concurrent utilization of the facility for "in house" radiopharmaceutical preparations as well as radionuclide production for external users requires the cyclotron to operate reliabily. Moreover, since the demand for cyclotron irradiations continues to increase, precipitated by research involving chemical reaction mechanisms and clinical PET needs, it is mandatory to streamline repair procedures and to minimize retuning for targets on the multiple beam lines for both financial and time perspectives <12–13>.

The major logistical problem is the programming of an operational schedule to satisfy the multitude of requests for finished products considering such variables as machine reliability and capacity, target availability, processing capability including personnel, equipment and space, as well as radiation safety. Many of the variables mentioned are constrained by the institutional needs.

Based on personal experiences there are numerous solutions to utilize effectively the cyclotron operational beam time. Characteristics of each machine and the acceptable limits on radionuclidic purity, staffing, and processing requirements will dictate whether enriched or natural targets are to be considered. In this respect, comments have been made that single particle accelerators may fulfill most institutional requirements <12–14>.

Accelerator solutions to this logistical problem have been achieved in a variety of ways including multiple cyclotrons, switching magnets for multiple beam lines, moveable beam lines, tandem targetry for the simultaneous preparation of several nuclides, simultaneous dual irradiations, and surplus irradiations employing modifications to the accelerator components such as beam stops and deflector components <9–10,15–18>.

The mechanics of irradiating targets have generally utilized fixed targets with on-line synthetic trains for rapid syntheses, robots or remote handling for reduced personnel exposure as well as automated loading and unloading of targets <19–22>. The bulk of information on these automated target systems can be supplied by commercial manufacturers of cyclotrons. Not addressed is the preventive maintenance schedule for the cyclotron. One of the primary reasons any institution undertakes the installation of an accelerator is to gain access to production of short-lived radionuclides. Such programs are jeopardized without inclusion of financial commitments in terms of staff, material, time and space allocated to maintain and repair the cyclotron and radiation protection consideration.

In conclusion, my goal in this workshop has been to illustrate some of the concerns of various accelerator facilities for operating an efficient and functional facility and to stimulate those assembled into a discussion of their experiences and comments concerning scheduling difficulties.

References:

1. Lawrence, E.O., "Method and Apparatus for the Acceleration of Ions", U.S. Patent 1, 948, 384 (February 20, 1934).
2. Lamb, J.F., "Commercial Production of Radioisotopes for Nuclear Medicine, 1970–1980", IEEE Trans. Nucl. Sci., NS–28, 1916 (1981).

3. Finn, R.D., "Basic Concepts for the Economic Utilization of a Cyclotron", IAEA Consultants Meeting, Uppsala, Sweden, June 13–15, 1984.
4. Finn, R.D., "Radionuclides and Radiopharmaceuticals at Mount Sinai Medical Center, Prog. Nucl. Med., (Karger Basel, 1978), 108.
5. Dwyer, J.P., Finn, R.D., Koh, K. et al., "Extenal Cyclotron Targetry System For The Effective Loading Of Precious Gases", Tenth Intern. Conf. on Cyclotrons and Their Applications, MSU, 29 April – 3 May, 1984 (IEEE Publishing Servide) 440–441.
6. Rubio, F., Finn, R.D. and Gilson, A.J., "Alchemy With Short-Lived Radionuclides", IEEE Trans. Nucl. Sci., NS-28, 1921 (1981).
7. Campbell, J., Finn, R.D., Smith, P., "A Generator System for Thallium-201", J. Label. Compds. Radiopharm. 13, 437 (1977).
8. Kayfus, G., Boothe, T., Campbell, J., Finn, R. and Gilson, A., "Chemical Recovery of Thallium-203 Following Production and Separation of Lead-201", J. Radioanal. Chem., 68, 269 (1982).
9. Finn, R., Boothe, R., Sinnreich, J., et al., "Ancillary Cyclotron Production of Technetium-95m For Clinical and Chemical Research", in Radiopharmaceuticals and Labelled Compounds, 1984 (IAEA, Vienna, 1985), 47.
10. Koh, K., Finn, R. et al., "External Tandem Target System for Efficient Production of Short-Lived Positron Emitting Radionuclides", IEEE Trans Nucl. Sci., (in press).
11. Finn, R., Vora, M. et al., "Radiation-Induced Defects as Illustrated by the $^{81}Rb-^{81m}Kr$ Target System", Int. J. Appl. Radiat. Isotopes, 33, 349 (1982).
12. Wolf, A.P. and Fowler, J.S., "Small Cyclotrons and the Production of Positron Emitters", in Radiopharmaceuticals and Labelled Compounds 1984, (IAEA, Vienna, 1985), 23.
13. Evens, R.G., Siegal, B.A., Welch, M.J., Ter-Pogossian, M.M., "Cost Analysis of Positron Emission Tomography for Clinical Use", Amer. J. Roent., 141, 1073 (1983).
14. Comar, D., "Production of Cyclotron Radioisotopes and Radiopharmaceuticals for Medical Use", Ninth Intern. Conf. on Cyclotron and Their Application CAEN University., 7–10 Sept. 1981 645–52.
15. Lee, R., Dahl, J., Bigler, R., Laughlin, J., "Design for a Multiple Target System for a Medical Cyclotron", Med. Phys., 8, 703 (1981).
16. Ruth, T., "Production of $^{18}F-F_2$ and $^{15}O-O_2$ Sequentially from the Same Target Chamber", Int. J. Appl. Radiat. Isotopes, 36, 107 (1985).
17. Robinson, Jr., G., Jones, S., et al., "A Series Target System for the Rapid Sequential Production of $^{15}O-H_2O$ and O_2, and $^{18}F-F_2$", Int. J. Appl. Radiat. Isotopes, 36, 435 (1985).
18. Suzuki, K., Iwata, R., "A Multi-Target Assembly in an Irradiation with High Energy Particles", Int. J. Appl. Radiat. Isotopes, 28, 663 (1977).
19. Russell, J., Wolf, A.P. "Robotics at a Biomedical Cyclotron Facility", NATO ASI Series Robotics and Artificial Intelligence (M. Brady, L.A. Gerhardt and H.F. Davidson, Eds.) Springer-Verlag (1984).
20. Various Automated Target Systems are Available from the Current Cyclotron Manufacturing Companies such as Scanditronix, Computer Technology and Imaging, Inc., Japan Steel Works, Sumitomo Heavy Industries, and others.

21. Jongsma, H.W., Verheul, H., "Rapid Transfer System for the Study of Cyclotron Activated Short-Lived Isotopes", Nucl. Instrum. Methods, 72, 51 (1969).

22. Sauermann, P.F., Friedrich, W., Knieper, J. et al., "Radiation Protection Problems at Compact Cyclotrons For Medical and Other Use", Radiat. Prot. Proc. Congr. Int. Radiat. Prot. Soc., (Pergamon: Oxford), 1, 518 (1980).