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The Status of Low Dose Rate and Future of High Dose Rate Cf-252 Brachytherapy

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Abstract

This work describes the current status of the U.S. low dose rate (LDR) Cf-252 brachytherapy program. The efforts undertaken towards development of a high dose rate (HDR) remotely afterloaded Cf-252 source, which can accommodate 1 mg or greater Cf-252, are also described. This HDR effort is a collaboration between Oak Ridge National Laboratory (ORNL), commercial remote afterloader manufacturers, the Gershenson Radiation Oncology Center (ROC), and Wayne State University. To achieve this goal, several advances in isotope chemistry and source preparation at ORNL must be achieved to yield a specific material source loading of ≥ 1 mg Cf-252 per mm^3. Development work with both radioactive and non-radioactive stand-ins for Cf-252 have indicated the feasibility of fabricating such sources. As a result, the decreased catheter diameter and computer controlled source placement will permit additional sites (e.g. brain, breast, prostate, lung, parotid, etc.) to be treated effectively with Cf-252 sources.

Additional work at the Radiochemical Engineering and Development Center (REDC) remains in source fabrication, afterloader modification, and safe design. The current LDR Cf-252 Treatment Suite at the ROC is shielded and licensed to hold up to 1 mg of Cf-252. This was designed to maintain cumulative personnel exposure, both external to the room and in direct isotope handling, at less than 20 μSv / hr. However, cumulative exposure may be greatly decreased if a Cf-252 HDR unit is employed which would eliminate direct isotope handling and decrease treatment times from ~ 3 hours to an expected range of 3 to 15 minutes. Such a Cf-252 HDR source will also demonstrate improved dose distributions over our current LDR treatments due to the ability to step the point-like source throughout the target volume and weight the dwell time accordingly. Preliminary Monte Carlo studies of HDR Cf-252 neutron dose distributions have shown lower anisotropy than an HDR Ir-192 of identical dimensions. Thus, photon and neutron brachytherapy may finally be compared for the first time in the HDR regime. Finally, additional modalities such as neutron capture therapy may be possible given the increased neutron flux with respect to elimination times of current capture agent drugs.

1. INTRODUCTION TO Cf-252

In 1950, the element californium (Cf) was first created at the Berkeley Crocker Laboratory in California through bombardment of helium nuclei onto a Cm-242 target [1]. While the product was identified as Cf-245, Cf-252 was not created until the MIKE thermonuclear test in 1952 [2]. However, macroscopic amounts of Cf-252 were first made in 1958 at the Idaho National Engineering Laboratory through successive neutron captures by a Pu-239 target. Later, a large-scale effort was undertaken by the Savannah River Laboratory (SRL) to evaluate the market potential of Cf-252 as a compact and long lived source of neutrons. While Cf was discovered in the remnants of extragalactic supernova explosions, the first sale of mg quantities occurred in 1971 for activation analyses on specimens retrieved from the moon [3]. Through the generous donations by the U.S. Department of Energy (DoE), various labs have been able to accurately determine the half-life, neutron and photon energy spectra, and chemical properties of Cf-252. Since 1973, most of the Cf-252 supply for the western world has been produced at Oak Ridge National Laboratory (ORNL) in the High Flux Isotope Reactor and recovered at the Radiochemical Engineering Development Center [4].

Due to its high yield of neutron emissions and relatively long half-life (2.645 years), Cf-252 is the most useful neutron emitter out of all the ~ 3000 radionuclides [5]. Though Md-260 and Cf-254 have higher rates of spontaneous fission, and thus increased neutron yield, their half-lives are prohibitively short considering the necessary steps for medical source fabrication. Though Cf-252 mainly decays (96.9%) through alpha emission to Cm-248 releasing He gas, 3.1 % of Cf-252 decays are by spontaneous fission. Through this decay channel, 3.768 neutrons per fission are released for a total neutron yield of 2.31434×10^{12} neutrons per gram-second, and a Watt fission neutron energy spectrum with a most probable neutron energy of 0.7 MeV. Though this energy regime is similar to that from a nuclear reactor, Cf-252 affords the opportunity for a compact and easily shieldable neutron source for both research and clinical applications.

Cf-252 was first suggested for clinical applications by Schlea and Stoddard in 1965 [6]. To explore this opportunity, manually afterloaded sources were fabricated at SRL, and designed similarly to the popularly used radium

needles of the time. Since then, applicator tube (AT) sources have been used successfully for over 25 years in the field of radiation therapy [5]. The AT source geometry has a Cf-252 active length of 15 mm, is doubly encapsulated in Pt-10 wt% Ir tubes, is 23 mm long, and 2.8 mm diameter. As only 3.1% of Cf-252 decays produce neutrons, and almost four neutrons are made in this event, a departure from the conventional measures of source strength (curies or Becquerel) is made. In practice throughout the world, Cf-252 source strength is measured in mass (mg or μg) of Cf-252 present. Though a Cf source is chemically pure of transactinides, it typically contains up to 85% atom Cf-252 where the radiological impact of Cf-249 through Cf-251 is typically negligible for the application at hand.

2. BACKGROUND

At the ROC, the current maximum loading that is licensed for AT type Cf-252 sources is 33 μg. As of September 15, 1997, there are twelve sources of 8 μg each, and new sources (33 μg each) are expected before February 1998. Thus dose rate may vary causing treatment times to range from 30 minutes to over three hours. Treatment planning is currently performed with Theraplan v 5.0 and confirmed through hand calculations. In Michigan, Drs. Jim Fontanesi and Paul Chuba have treated thirty patients, with tumors being of both high and low grade sarcomas; prescribed doses have ranged from 4 to 9 N-Gy with 1 N-Gy fractions delivered twice a day. Though patients have been treated at the ROC with Cf-252 for just two years, Drs. Yosh Maruyama and Jacek Wierzbicki have treated over 1000 patients at the University of Kentucky before coming to Michigan in 1993. To our knowledge, these clinics have been the only places in the western world in which neutron brachytherapy was available.

Though WSU has AT sources on loan from the U.S. DoE, a cost analysis of a proposed Cf-252 HDR source, at a rate of $55,000 / mg, shows it to be competitive against Ir-192, the current HDR photon source. A Cf-252 HDR source would last five years, while Ir-192 is replaced four times a year at $35,000 per year. Including $40,000 for routine Cf-252 HDR fabrication costs and shipping equates to a savings of $16,000 per year for a high LET source.

3. DESCRIPTION

3.1 RADIATION DOSIMETRY AND RADIOBIOLOGY OF Cf-252

Cf-252 emits both photons and neutrons of varied energy which interact with human tissue in different manners. Though neutron energies as high as 20 MeV from ^{252}Cf have been observed, the neutron energy spectrum peaks at 0.7 MeV and falls off rapidly at both higher and lower energies for an unmoderated Cf-252 source in air [7]. These neutrons interact through inelastic scattering with hydrogen nuclei, and are readily thermalized *in vivo*. As these neutrons reach equilibria, they are mainly captured by hydrogen (0.33 barns) in the $^{1}H(n, \gamma = 2.225\ MeV)^{2}H$ reaction, and with nitrogen (1.83 barns) in $^{14}N(n,p)^{14}C$ [8]. While the atom percent of nitrogen in human tissue is low when compared to that of hydrogen, the energy deposition from the proton causes high linear energy transfer (LET) which has been shown to be more effective at cell killing than photons [9].

For a ^{252}Cf source within a medium of water or tissue, the neutron energy spectrum changes as a function of distance. Since the kerma factors of elements H, C, N and O are strong functions of the incident neutron energy, the rate and manner of dose deposition changes for increasing distances from the source as the neutrons are increasingly moderated. At distances of greater than 5 cm, the fast neutron component is greatly diminished, leaving thermalized neutrons to interact with the $[velocity]^{-1}$ cross-sections of H, C, N, and O. Here, the (n,p) reaction on nitrogen and the elastic reactions on hydrogen are much less likely.

The prompt photons from alpha decay and Cm-248 relaxation are of high energy, and react via pair production and the Compton effect. Other photons emitted through decay of the spontaneous fission products are generally of much lower energy, are attenuated to a greater extent by the Pt/Ir encapsulation, and react via the Compton effect and photoelectric effect. While roughly one third of the radiation dose (Gray) at 1 cm is due to photon emissions, their effect is minimized when the relative biological effectiveness (RBE) of the neutrons is considered. Though RBE is a function of many factors, a value of 6 for low dose rate (1 N-Gy/hr) irradiation with Cf-252 neutrons has been adopted for various tumor sites. As the neutron RBE as a function of dose rate varies only slightly, the RBE is considered fixed for a given treatment distance (e.g. ½ cm) for the entire usable life time of the sources (~ 5 years). For HDR (Gy / minute) neutron brachytherapy, the RBE is expected to decrease to about three. While this may seem disadvantageous at first, the therapeutic gain due to the differences in RBE of healthy versus cancerous tissue increases at increasing distances which may offer improved local control at the periphery of the target volume.

The dose distributions about Cf-252 sources may be measured and calculated by a number of ways. Monte

Carlo modeling of Cf-252 was first performed by Krishnaswamy in 1971, and later confirmed experimentally in 1972 using paired chambers [10]. Later, more advanced means of neutron detection and modeling using foil activation techniques, chambers, and MCNP4A have confirmed Krishnaswamy's results while providing information about neutron spectra and near-source data [5]. With the constant advances in computer processing power, it is expected that Cf-252 treatment planning will shift from treatment planning look up tables of along-away dose data to eventual full physics Monte Carlo modeling of *in vivo* patient dosimetry.

4. RESULTS

4.1 Cf-252 SOURCE CALIBRATION PROCEDURES AT ORNL

4.1.1 Cf-252 Source Strength Assay at NIST

Cf-252 sources were calibrated by comparing their strength to that of the National Institute of Standards and Technology (NIST) primary Ra-Be photo-neutron standard source, NBS-1, whose emission rate has been absolutely determined. Its emission rate was 1.239×10^6 neutrons per second on December 1993 with an assigned uncertainty of ± 0.85%. The neutron emission rate of the submitted source was then determined.

4.1.2 Experimental Methods at NIST

Comparison of source strengths were made by activating a manganese sulfate bath and continuously counting the induced, saturated manganese-56 activity with a scintillation counter. The Cf-252 source to be assayed was located in a small Teflon cavity at the center of a 1.2 m diameter spherical bath. The purpose of the cavity was to reduce thermal neutron absorption of the source. The manganese sulfate was circulated to the scintillation counter, which is located in a shielded stainless-steel beaker. The following corrections have been applied: 0.63% for fast neutron capture by oxygen and sulfur in the bath, 0.19% for fast and thermal neutron capture by fluorine in the Teflon source holder, 0.05% for escape from the bath, 0.15% for thermal neutron absorption in the source, and 0.95% for other neutron capture reactions in the encapsulation materials.

4.1.3 Cf-252 Source Strength Assay at the REDC

The Cf-252 assay was made by inserting sources ranging from 10 μg to 60 mg into the center of a polyethylene moderator and measuring the resulting thermalized neutrons with fission detectors. Three Westinghouse type WL-6376A fission detectors, located in the polyethylene moderator, were used in the current mode; fission detectors are relatively effective in discriminating against photon radiation from Cf-252 sources. The detectors were 5.24 cm in diameter and 29.69 cm long with a neutron-sensitive length of 15.24 cm. The detector output current was measured with a digital picoammeter.

4.1.4 Background Determination

The procedure for background determination at building 7930 of ORNL's REDC follows:

- Select the source holder insert to fit the type of source being assayed.
- Clear all known neutron sources and contamination out of Cell C, or move them to the He-leak testing station to achieve the minimum picoammeter reading.
- Install the source holder in the Final Assay System (FAS) moderator.
- After the system has stabilized, typically, 20 minutes, obtain eleven readings using the picoammeter, and record them on the data run sheet under *BKG*.
- Circle the median value, that is, the value for which there are 5 numbers larger and 5 numbers smaller. Use the median value in further computations.

4.1.5 Picoammeter Standardization

Transfer the reference source designated on the data sheet into Cell C, Workstation 6. Place the reference source in the FAS moderator. Note, in order to optimize the peak picoammeter reading, it may be necessary to adjust, or re-position the source within the FAS moderator. Allow the readings to stabilize (~20 min.), then record the eleven values on the data sheet in the column *REF. SOURCE*. Again, circle the median value. Perform the calculations indicated on the data sheet to determine the calibration constant of the FAS. This value should be within the limits indicated on the data sheet. Possible reasons for variation include changes in ambient conditions (temperature, pressure) both in the moderator and in the electronics, extraneous neutron moderating or absorbing materials within the source holder region, contamination of the source holder, a change in the inventory of neutron sources in Cell C or possibly Cell G between the time the background was measured and the reference source was measured.

4.1.6 Remeasurement of Background

The background determination must be repeated if there is reason to believe the background has changed due to movement of high activity sources in neighboring Cell G, for instance, or if more than 8 hours elapsed between measurements of the reference source and the test source.

4.1.7 Test Source Measurement and Methodology

The test source is then measured by transferring it from either Cell G, the storage pool, or a shipping container. All fabrication and inspection procedures should be complete, including smear test of surface activity. Then, the proper source holder is selected, the test source is placed into the source holder, and then the source holder assembly is moved into the FAS moderator. After the FAS stabilizes, record eleven current readings from the picoammeter on the data run sheet in the column *TEST SOURCE*. Again, the median value is chosen and circled. Calculations indicated on the data sheet are performed to determine the neutron source strength and the Cf-252 content. These calculations use the following data:

F	Fraction Cf-252 neutrons (with respect to all Cf isotopes)
NCR	Neutron Count Rate (n / s)
BKG	Background, median
REF	Reference source, median
TEST	Test source, median

The following equations are used in determination of Cf-252 mass content for the test sources.

Standardization:	[REF – BKG] / NCR	= (1) [μA-sec / neutrons]
Neutron Emission Rate:	[TEST – BKG] / (1)	= (2) [neutrons per second]
Cf-252 Source Strength Assay:	[(2) x F] / 2.31434×10^6	= μg Cf-252

4.2 NOVEL FABRICATION TECHNIQUES AT ORNL

In the 1970s Savannah River Laboratory (SRL) developed several Cf-252 medical sources with the most successful being the AT source shown in Figure 1. Note the presence of three core wires used to distribute Cf-252 uniformly among many AT sources. In the 1980s ORNL took over the Cf-252 Sales / Loan program. The need to make replacement AT sources and develop techniques to be able to fabricate HDR sources for brachytherapy research and treatment has been the subject of research at REDC for the past several years. Building on techniques developed at SRL and experience gained at the REDC, ORNL will soon complete the fabrication of replacement AT sources to be loaned to WSU. Some of the techniques used to fabricate the new AT sources and the initial fabrication results are described below.

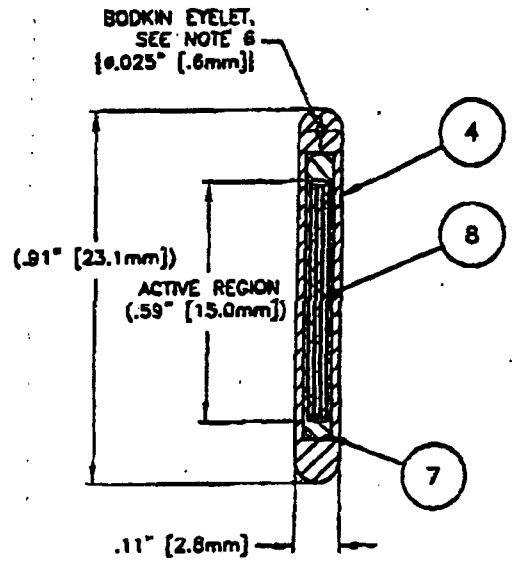

Figure 1. Cf-252 Applicator Tube (AT) Assembly

4 – Outer Capsule
7 – Inner Capsule
8 – SRL Core Wire(s)

Development of the core wire containing the Cf-252 was the first obstacle. Techniques and equipment used to fabricate source wires at SRL were not compatible with the REDC hot cells. Cf-252 ceramic-metal (cermet) wire for industrial sources is routinely rolled in a square wire jewelry rolling mill. Rolling to the size needed for AT fabrication was accomplished by continuing to roll the wire through the smallest groves in the rolling mill, never before attempted, with frequent annealing intervals to provide structural integrity. A melt of palladium and Cf-252 oxide produced a pellet calculated to give ~30 μg Cf-252 in a length of 15 mm when rolled to the required size. This produced a modified square wire, 0.91 mm across the flats which was pulled through a 1.22 mm round die such that it fit inside the inner capsule. It is noteworthy that the finished wire was 0.38 m long when rolled, making it the longest wire ever rolled at the REDC.

The core wire was sectioned in a specially fabricated pneumatic precision wire cutter, and the wire pieces measured for length and assayed for Cf-252 mass as presented in Table 1. The wires, which were 15.0 $\pm$0.25 mm in length, were considered for encapsulation with one core wire per AT source. The goal was to supply WSU with 12 to 16 replacement sources of 30 μg each. The several short wires resulted from kinks in handling the wire in the hot cell. The inner and outer capsules were both fabricated from a Pt/Ir-10% mass alloy. As of this writing, the inner capsule cans have been fabricated and are ready for primary encapsulation. The outer capsules are still being machined. Both capsules will be sealed by TIG welding after insertion of a plug to prevent gaseous expansion. A description of the source / encapsulation geometry, as well as its neutron dosimetry can be found in Rivard *et al.* located within these Proceedings [11].

Experience gained in small wire handling, sectioning, cold tests in cermet loading, and alloy fabrication will provide the background required to fabricate core wire for a HDR Cf-252 source that can be remotely afterloaded. Advances in radiochemistry techniques and yields have demonstrated the initial goal of 1 mg Cf-252 per mm^3 to be feasible. However, it is expected that a proto-type HDR source of 0.3 to 0.4 mg will be made in light of safety issues. These HDR fabrication efforts will be undertaken in collaboration with WSU and commercial remote afterloader manufacturers following successful fabrication and shipment of the aforementioned ORNL AT sources to WSU.

Table 1

Wire #	µg of Cf-252 on 01/23/98	Length (mm)
PD-CF-124-2	28.59	15.21
PD-CF-124-3	29.91	15.09
PD-CF-123-4	32.62	15.21
PD-CF-123-5	32.46	15.14
PD-CF-124-6	32.46	15.16
PD-CF-124-7	32.68	15.16
PD-CF-124-8	30.98	15.09
PD-CF-124-9	31.34	15.09
PD-CF-124-10	31.57	15.21
PD-CF-124-11	31.97	15.54
PD-CF-124-12	30.24	15.11
PD-CF-124-13	29.71	14.73
PD-CF-124-14	31.27	15.14
PD-CF-124-15	23.27	11.38
PD-CF-124-16	30.59	15.06
PD-CF-124-17	19.42	9.80
PD-CF-124-18	19.70	10.67
PD-CF-124-19	28.87	15.14
PD-CF-124-20	22.27	11.38
PD-CF-124-21	23.25	13.26
PD-CF-124-22	28.41	15.14
PD-CF-124-23	29.89	15.14
PD-CF-124-24	27.25	15.04

4.3 RADIOCHEMISTRY TECHNIQUES FOR Cf-252 SOURCE FABRICATION

Neutron therapy has demonstrated increased efficacy for certain cancers as compared with standard photon radiotherapy. Although there are many manners in which to provide neutron therapy, use of Cf-252 has been found to be very promising. For optimization of Cf-252 neutron brachytherapy, sources which provide higher dose rates are desired that can be used in automated after-loader devices, to minimize unnecessary doses to both the patient and medical personnel. To acquire this capability it was necessary to prepare special Cf-252 sources, which in turn demanded that certain material science issues be addressed and resolved. One of the important issues concerned the Cf cermet matrix used for the sources. The matrix had to be stable, be able to be shaped and formed by remote metallurgical techniques in hot cells, and have a high specific Cf-252 content. One of the most promising matrices, based on considering several different factors, was a Cf-Pd matrix and / or compound. This has been successfully used for preparing lower yield Cf sources (e.g. ~ 1 % mass Cf). The challenge was to increase the Cf loading to perhaps 20% mass Cf to achieve specific source strengths of 1 mg Cf-252 per mm^3.

In pursuing this challenge, a series of preparation techniques together with testing of their mechanical properties were carried out with lanthanide-Pd matrices, where the lanthanide was used as a chemical stand-in for Cf-252. These studies considered the phase behavior known for lanthanide Pd materials. It was evident that a major component in

these preparations would be MPd_3 (M = lanthanide or Cf); excess Pd or M could also be present, depending on the atom percent of the metal and Pd. It was presumed that composites of MPd_3 and the noble metal Pd would be preferred for making the sources so as to adequately contain the Cf, as well as provide useful mechanical properties. These mechanical properties, and preparation of these materials, was then pursued for the limiting case of fitting a single Cf-252 core wire into an HDR capsule. These investigations have shown a non-sheathed core wire of Pd-MPd_3 may be fabricated (swaged) to an outer diameter of 0.6 mm while retaining the desired source strength of 1 mg Cf-252 per mm^3. here Tb was the M stand-in for Cf.

Direct union of the elements is one general, potential route for preparing Cf-Pd composites; however, the chemical properties of Cf presents two major difficulties. One is the necessity for preparing Cf metal, which is very difficult considering the small mass scales desired, the limited amounts of scarce and costly Cf-252 ($55,000 / mg), and that all operations must be performed remotely in a hot cell. The second major concern is the high volatility of Cf metal, which would bring about high losses and preclude melting the Cf and the Pd due to vaporization. The most attractive route based on these facts is the generation of such Cf-Pd alloys via the reaction of Cf oxide with Pd under reducing atmospheres. The thermodynamic stability of the Pd compound formed drives this reaction, and the reaction is known to occur with lanthanide and actinide oxides and many of the platinide metals. This approach for preparing Cf-Pd alloys is particularly attractive as it avoids the necessity of first preparing the Cf metal, and uses Cf (III) oxide which is readily prepared. This approach has the drawback that it is often difficult to avoid residual amounts of oxide (e.g. difficult to achieve total reduction). However, small amounts of Cf oxide may be tolerated, and not be detrimental to the products, if excess Pd metal is present (e.g. formation of a Pd-$CfPd_x$ matrix with some oxide inclusions) We have investigated the formation and properties of lanthanide-Pd intermetallics by both this oxide reduction process and by arc melting the elements. Arc melted products employed lanthanide metals having lower vapor pressures such as Gd, but this method still had to contend with the volatilization of Pd. For oxide preparations, other lanthanide oxides were employed. The preferred lanthanide in this case was Tb, as its oxide system and oxide behavior is very similar to that of the Cf oxides.

In one set of experiments involving arc melting of Gd-Pd mixtures, six compositions were prepared and the products were evaluated. This evaluation included both x-ray diffraction analyses to ascertain the phases present and metallurgical structural testing to determine the mechanical properties of the alloy. From these studies at ORNL, it was determined that composites were formed which contained, Gd + $GdPd_3$, $GdPd_3$, or Pd + $GdPd_3$. It was further determined that $GdPd_3$ by itself was too brittle and hard to be satisfactory for the end product, and that the best materials for formation of sources were Pd-rich $GdPd_3$ composites. The optimum behavior was observed when the $GdPd_3$ mole percentage was below 20 %, or 25% Cf mass equivalent.

In the majority of the Tb-Pd alloy preparations via oxide reduction, the presence of residual Tb oxide was observed. These reductions were performed using a variety of atmospheres (principally 4% hydrogen-argon) and temperature cycles up to 1500°C for periods of up to 40 hours. Most of these operations avoided intermediate grinding and re-heating steps, as these would be particularly difficult and would lead to high Cf losses in hot-cell environments. However, satisfactory Tb-Pd composites could be prepared via this non-labor intensive route for the Pd-rich composites, and this was chosen to be the preferred preparative route for making Cf-Pd alloy materials for future Cf-252 HDR source development.

4.4 HDR UNIT DEVELOPMENT

There are a number of reasons to strive for fabrication of smaller Cf-252 sources with increased specific source strength. These current AT sources are quite large, 23 mm long, 2.8 mm diameter, and the choice of clinical sites with which it can be successfully treated is limited. In addition to these physical limitations, personnel exposure has been an additional concern. Our clinic has adopted the practice of radiation oncology physicians loading the catheters while medical physicists unload at the end of each fraction. Patients are monitored remotely via cameras, monitors, and intercoms. In the past two years, whole body personnel exposure from Cf-252 has been kept below 3 mSv, while exposure to the hands as measured by neutron sensitive film within a wrist worn detector has been under 25 mSv. Here, a quality factor of 20 was used to correlate neutron exposure to dose equivalence. Of course with the advent of Cf-252 HDR brachytherapy and adequate safe design, personnel exposure is expected to fall to only a fraction of that received currently through manual afterloading techniques.

A collaboration of ORNL, WSU, the ROC, and commercial HDR manufacturers aim to develop an HDR remote afterloader which can accommodate a high activity (≥ 1 mg) Cf-252 source. To achieve this, advances in radiochemistry at ORNL must yield a source strength in excess of 1 mg Cf-252 per mm^3 for insertion into the source capsule. This has

recently been shown to be possible [12]. Thus, the decreased catheter diameter and computer controlled source placement will permit additional sites such as brain, breast, prostate, lung, and parotid to be effectively treated.

Work now lies in afterloader source and electronics modification, as well as safe design. Our current Cf-252 Treatment Suite is shielded and licensed such that up to 1 mg of Cf-252 may be present. This was devised so that personnel exposure external to the room was less than 20 μSv / hr. However, this exposure rate may be greatly decreased should the Cf-252 HDR unit be placed in a similar radiological vault as our Ir-192 HDR unit. As treatment times are expected to range from 3-15 minutes with a ≥1 mg Cf-252 source, this location may be reasonable considering available facilities and realistic patient loads.

A Cf-252 HDR source would also demonstrate improved dose distributions due to the ability to step the source throughout the target volume and weight the time accordingly. Preliminary Monte Carlo studies of Cf-252 HDR source neutron dose distributions have shown lower anisotropy for a Ir-192 HDR source of 4 mm in length. Thus photon and neutron brachytherapy may finally be compared for the first time in the HDR regime.

Finally, with the increased neutron flux, additional modalities such as neutron capture therapy may also be possible with the increased neutron flux ad considering the elimination times of current capture agent drugs. As the kerma values for all incident radiations and reaction products are known, calculative modeling using MCNP, may provide accurate and timely dosimetric data on a per patient basis.

5. CONCLUSIONS

Results presented herein summarize the current status of Cf-252 AT source development, novel calibration and fabrication techniques, and demonstrate the feasibility of a Cf-252 HDR source to permit widespread use of neutron radiotherapy. Should a Cf-252 HDR proto-type be manufactured, cost-effective high LET radiation could then be available to a greater number of patients with malignancies which demand emissions such as from Cf-252 for successful treatment.

REFERENCES

1. S. G. Thompson, K. Street, Jr., A. Ghiroso, G. T. Seaborg The new element californium (atomic number 98), Phys. Rev. 80, 790-796, 1950.

2. P. R. Fields, et al. Transplutonium elements in thermonuclear test debris, Phys. Rev. 102, 180-182, 1956.

3. I. W. Osborne-Lee, C. W. Alexander Californium-252: A remarkable versatile isotope, ORNL/TM-12706, Oak Ridge National Laboratory, 1995.

4. J. B. Knauer, Jr., R. C. Martin Californium-252 production and neutron source fabrication, In: Californium-252: Isotope for 21st Century Radiotherapy, Ed. J. G. Wierzbicki, Kluwer Academic Publishers, Printed in the Netherlands, 7-24, 1997.

5. J. G. Wierzbicki, M. J. Rivard, W. A. Roberts Physics and dosimetry of clinical ^{252}Cf sources, ibid, 25-53, 1997.

6. C. S. Schlea, D. H. Stoddard Californium isotopes proposed for interstitial and intracavitary radiation therapy with neutrons, Nature 206, 1058, 1965.

7. W. Mannhart Evaluation of the ^{252}Cf fission neutron spectrum between 0 MeV and 20 MeV, Proc. Advisory Group Mtg Properties of Neutron Sources, IAEA-TECDOC-410, 158, 1987.

8. J. R. Parrington, H. D. Knox, S. L. Breneman, E. M. Baum, F. Feiner Nuclides and Isotopes, General Electric Co. and KAPL, Inc. of Lockheed Martin, 1996.

9. E. J. Hall Linear energy transfer and relative biological effectiveness, In: Radiobiology for the Radiologist, J.B. Lippincott Co., Philadelphia, 153-164, 1994.

10. R. D. Colvett, H. H. Rossi, V. Krishnaswamy Californium-252 dose distributions, Phys. Med. Biol. 17, 356-364, 1972.

11. M. J. Rivard, J. G. Wierzbicki, F. Van den Heuvel, R. C. Martin Neutron dosimetry for low dose rate Cf-252 sources and adherence to recent clinical dosimetry protocol for brachytherapy, American Nuclear Society RPS Division Topical Conf., Nashville, TN, (these proceedings), 1998.

12. R. C. Martin, R. R. Laxson, J. H. Miller, J. G. Wierzbicki, M. J. Rivard, D. L. Marsh Development of high-activity Cf-252 sources for neutron brachytherapy, 3rd Topical Mtg. on Industrial Radiation and Radioisotope Measurements and Applications, Ed. C. W. Alexander, Raleigh NC, 1996.

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