ISSN 1411 - 3481

CALORIMETRIC MEASUREMENT OF ^{192}Ir BRACHYTHERAPY SOURCES

T. Genka[1] and M. Sayad[2]

[1]Technical Coordinator of JAERI at Pusat Pengembangan Radioisotop dan Radiofarmaka- BATAN

[2] Pusat Pengembangan Radioisotop dan Radiofarmaka- BATAN

ABSTRACT

CALORIMETRIC MEASUREMENT OF ^{192}Ir BRACHYTHERAPY SOURCES. Radioactivities of ^{192}Ir metallic sources of "single pin" and "hairpin" types for the low dose rate brachytherapy for cancer treatment were determined with a microcalorimeter. In order to convert the complete decay energy evolved from the source into thermal energy, a radiation absorber made of tungsten was used. Measurements of the sources with an ionization chamber gave 9% smaller values of radioactivity than those from microcalorimetry mainly because of the self absorption effect in ionization chamber measurement. It was considered that the calorimetric method which is free from the self absorption effect could provide a standard for radioactivity measurements of the brachytherapy sources.

Key words: calorimetry, radioactivity measurement, ^{192}Ir brachytherapy source

ABSTRAK

PENGUKURAN SUMBER BRAKITERAPI ^{192}Ir SECARA KALORIMETRI. Radioaktivitas sumber brakiterapi ^{192}Ir yang berupa *single pin* dan *hairpin* dosis rendah yang digunakan dalam terapi kanker ditentukan dengan mikrokalorimeter. Untuk mengkonversi seluruh energi yang dipancarkan dari sumber ^{192}Ir menjadi energi panas, digunakan penyerap radiasi yang terbuat dari wolfram. Pengukuran sumber radiasi dengan kamar pengion (*ionization chamber*) memberikan radioaktivitas 10% lebih rendah dibandingkan pengukuran dengan kalorimetri, yang terutama disebabkan oleh efek *self absorpsi* pada pengukuran dengan *ionization chamber*. Metode kalorimetri yang bebas dari efek *self absorpsi* dapat digunakan sebagai metode standar dalam pengukuran radioaktivitas sumber brakiterapi.

Kata kunci : kalorimetri, pengukuran radioaktivitas, sumber brakiterapi ^{192}Ir

Jurnal Sains dan Teknologi Nuklir Indonesia
Indonesian Journal of Nuclear Science and Technology
Vol.1, No. 2, Agustus 2000 : 59 - 69

ISSN 1411 - 3481

1. INTRODUCTION

Establishment of the treaceability of radiation and radioactivity measurements for medical sources is of great importance. In radiotherapy of cancer treatment, the more radiation dose results the better local control of cancer, but at the same time the more complication might occur. Therefore optimization of total dose requires accurate information about quantities of radiation output or radioactivity of the source as much as possible. For the teletherapy, uncertainty of the dose estimation of 5% at the point of exposure is recommended by ICRU [1]. It is also suggested for the brachytherapy source that the specification must be within an uncertainty around 2% [2]. Standardization for exposure rate (air kerma rate) calibration has been well established [3] but not those for radioactivity calibration, mainly because of error due to self absorption of radiation by metallic source itself. For the routine assay of low dose rate (LDR) brachytherapy sources, ionization chamber measurement is the most simple and practical way if the standard source of identical shape of the brachytherapy source is available. Japan Atomic Energy Research Institute (JAERI) has developed a radiocalorimetric method for determining absolute radioactivity of various metallic sources without being influenced by self absorption [4,5]. Recently a calorimeter system was installed in the laboratory of the Centre for Development of Radioisotopes and Radiopharmaceuticals (P2RR)-BATAN in Serpong. The system is to be used for the calibration of ionization chambers for process control and quality control in P2RR-BATAN [6].

2. THEORY

The radioactivity A can be calculated from the thermal power P knowing average energy E_{av} of disintegration by

$$A = P/E_{av} . \quad (1)$$

Assuming the Newton's law of cooling, the following equation can be applied to heat-flow calorimetry [7].

$$T_c - T_e = (P/k)(1 - e^{-kt/C}) \quad (2)$$

where, T_c : Temperature of a calorimetric body

T_e : Temperature of environment (aluminium heat sink)

k : Heat transfer coefficient of the thermomodule

P : Power dissipated in the cell

C : Total heat capacity (sample + cell)

As can be seen from the equation (2), the right side second term approaches zero when t elapses a sufficient time so that

$$P = k(T_c - T_e). \quad (3)$$

Thus one can measure the thermal power independent to the heat capacity C after sufficient time to reach the equilibrium state. Accordingly, any kind of materials with large heat capacities to absorb the radiations from the sample in it is acceptable in principle. In the present experiment, a tungsten radiation absorber having enough thickness to convert whole radiation energy into thermal energy was used.

3. PROCEDURES

3.1. Description of the brachytherapy sources

Physical constructions and dimensions of these sources of single pin and hairpin are shown in Fig. 1. Both sources have a core of 25%

ISSN 1411 - 3481

Physical constructions and dimensions of these sources of single pin and hairpin are shown in Fig. 1. Both sources have a core of 25% iridiated platinum of 0.45 mm diameter with a sheath of pure platinum of 0.1 mm thick. The outer diameter is 0.65 mm for both sources and the total length is 47.6 mm and 93.0 mm for the single pin and hairpin, respectively. They were irradiated in the reactor MPR-30 at a thermal neutron flux of 3×10^{13} n cm^{-2} s^{-1} for 120 min on 15 November 1999. The target materials were supplied by JAERI.

3.2. Microcalorimeter

A twin-cup heat-flow microcalorimeter was used in the present experiment. Construction and operating principles of this microcalorimeter were described elsewhere [8]. A calorimetric assembly is immersed in a thermostatic air bath. Two identical cells are fitted with thermomodules in the calorimetric assembly, with their outputs connected in opposing polarities. A radioactive sample is set in one cell and a dummy, an exact physical replica of the sample is set in the other cell for the sake of balancing heat capacities of both sides. Thus the common response due to factors such as environmental temperature fluctuations can be cancelled out. The thermomodules are made of compound semiconductors through which the thermal energy from the cells flows into a surrounding mass of aluminium heat sink embedded in 30 mm thick styroform. A high-sensitive chopper amplifier is also immersed in the thermostatic bath to improve its performance characteristics.

ISSN 1411 - 3481

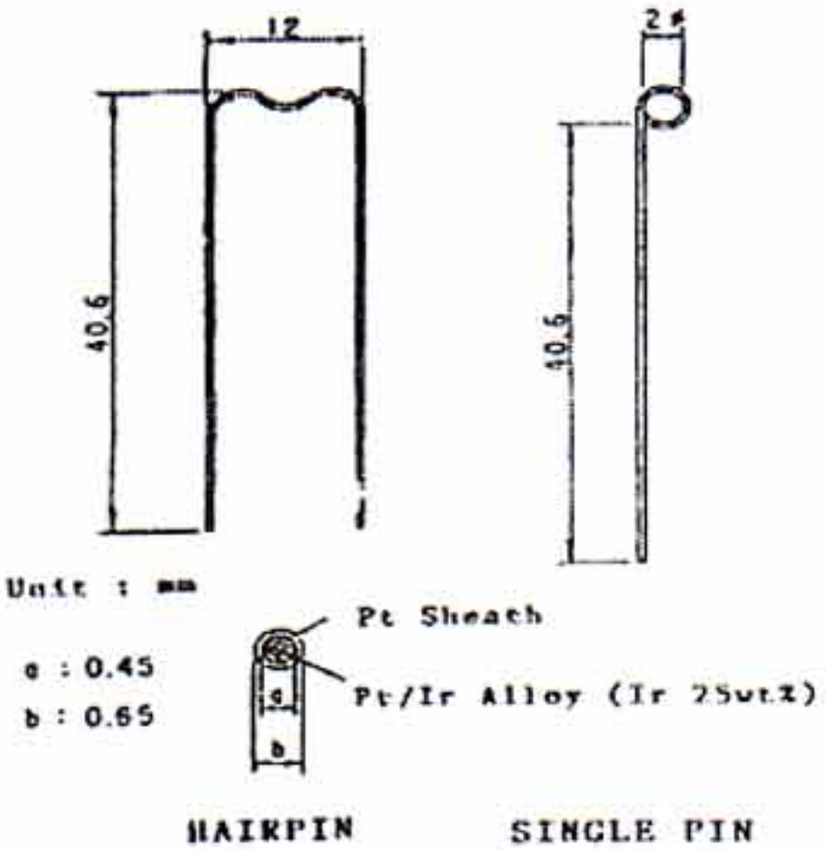

Fig. 1. Physical constructions and dimensions of hairpin and single pin sources

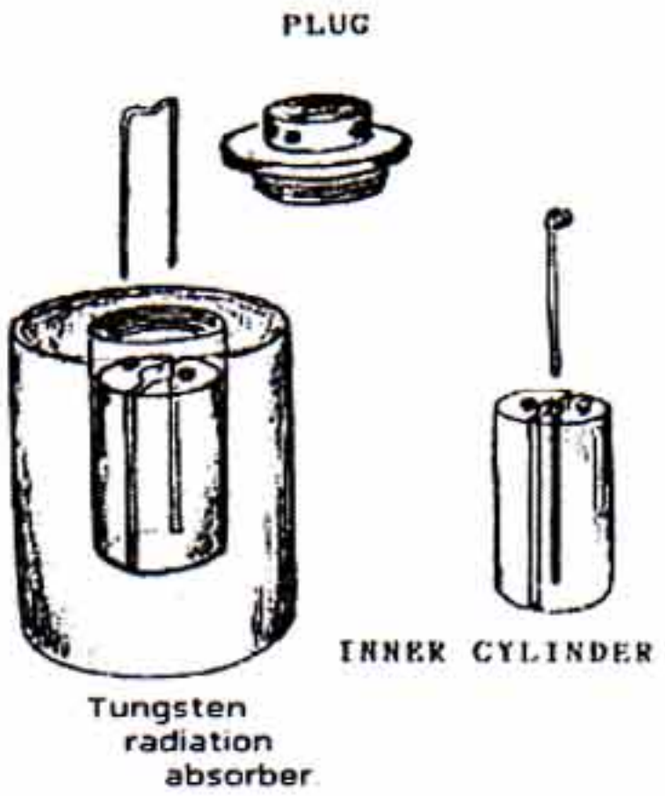

Fig.2. Tungsten radiation absorber and its inner cylinder.

3.3. Thermal energy emission from the source

The radioactivity of the ^{192}Ir sources can be determined by absorbing all radiations within the microcalorimeter to be converted into thermal power. Iridium-192 decays through the processes of β^- (95.4%) and electron capture (4.6%) with a half-life of 78.831 d. Average energies of radiations per disintegration of ^{192}Ir are 813 keV for photons, 45.2 keV for atomic electrons, 171 keV for beta-rays and 0.123 keV for internal bremsstrahlung, totally 1029.3 keV [9]. Accordingly, 1.65×10^{-7} (=1029.3 $\times 10^3$ eV$\times$1.602$\times 10^{-19}$ J/eV)μJ of thermal energy is dissipated per disintegration or thermal power of 6.10 μW is generated per 37 MBq (1 mCi).

3.4. Radiation absorber

The radiation absorber is a cylinder made of solid tungsten as shown in Fig. 2. The external dimensions of the absorber are 45 mm diameter and 80 mm height. It accommodates the removable inner

ISSN 1411 - 3481

diameter and 80 mm height. It accommodates the removable inner cylinder made also of tungsten. The inner cylinder has a hole into which the single pin source is inserted and slits along which the hairpin source is inserted.

3.5. Calibration of thermal power

The electric current in the coils of manganin wires embedded in the wall of each cell serves to inject heat as the reference thermal power. Both coils are adjusted to realize an electric resistance of 100.0 ±0.1Ω each. Fig. 3 shows a calibration curve measured over ranges from 9μW up to 290μW. Calibration of thermal power was done by comparing input Joule power versus output of the thermomodule. The calibration factors for around 40μW region for single pin and 100μW region for hairpin were determined to be 0.140 and 0.142μV/μW, respectively.

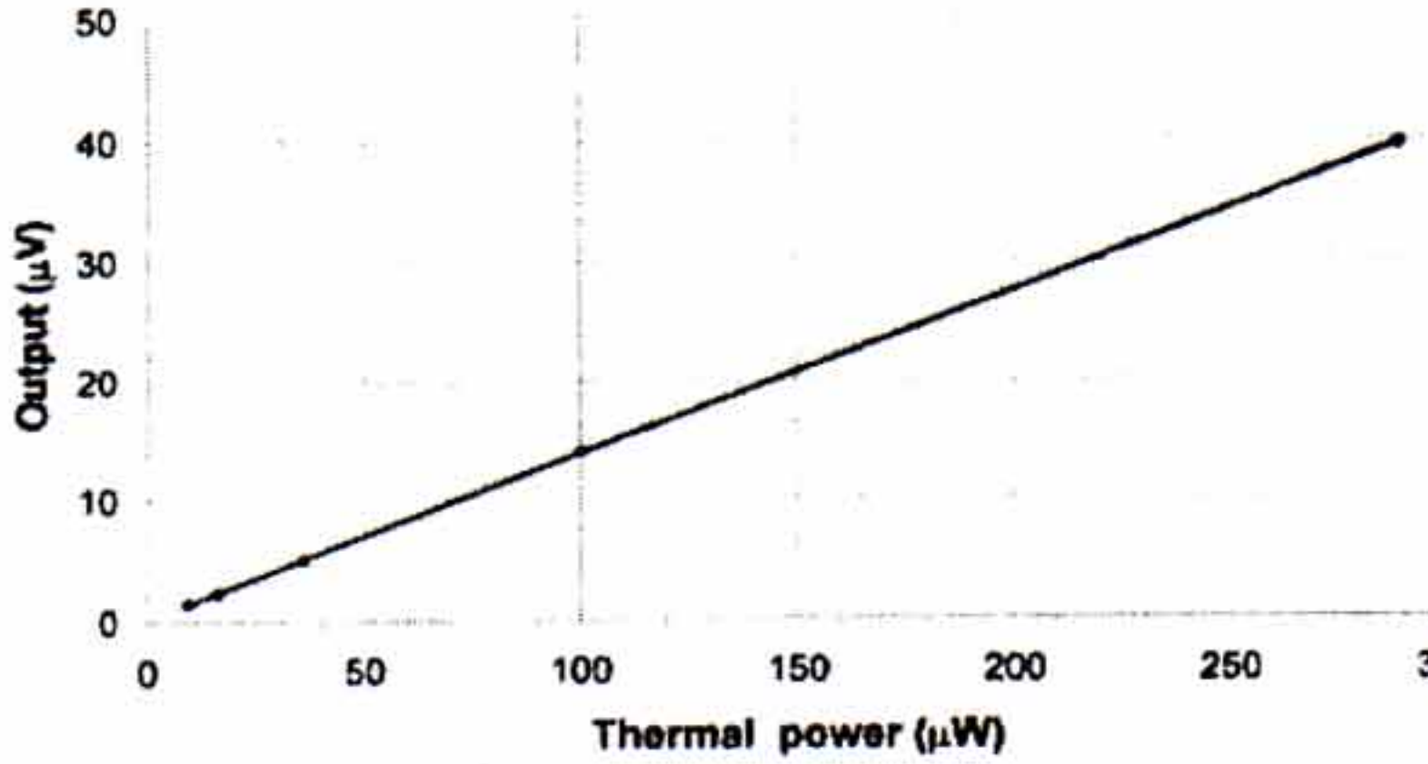

Fig. 3. Calibration curve for the thermal power measurement

ISSN 1411 - 3481

4. RESULTS AND DISCUSSION

4.1. Measurement with the microcalorimeter

The results of the thermal power measurements, corrected to the reference time, are summarized in Table 1. Correction for radionuclidic impurity of ^{194}Ir (half-life 19.15 h) was ignored because the measurements were done after a sufficient cooling time (less than 0.1% after 1 week cooling) and impurities due to abundance of platinum isotopes were also negligibly small.

The measurements were carried out in two different methods referred to as the methods I and II. Method I is the measurement in that output voltage of amplifier is converted into μW using the calibration factors, whereas the method II is a reverse Joule method to supply just enough Joule power on the dummy side to cancel out the thermal power generated from the sample. In latter case the cancellation process is no other than the calibration process. The results of the both methods were summarized in Table 1.

Table 1. Results of microcalorimatric measurements

Source	Radioactivity	
Hairpin	Method I	14.2_4 mCi ± 1.8%
	Method II	14.3_7 mCi ± 3.6%
Single pin	Method I	7.1_1 mCi ± 2.1%
	Method II	7.0_4 mCi ± 4.2%

Reference Time: 10:00 May 11, 2000

4.2 Measurement with an ionization chamber

Activities were also measured with a dose calibrator (Atomlab 100 plus Dose Calibrator, Biodex Medical Systems Inc.,U.S.A.[10]). This is a re-entrant well-type ionization chamber filled with pressurized

ISSN 1411 - 3481

argon gas. Dimension of well opening is 64 mm and well depth is 260 mm. It is surrounded by a 6.4 mm thick lead with top well opening. Calibration was based on the directly traceable standards to the National Institute of Standards and Technology, USA. According to the operation manual of this instrument, overall accuracy of activity determination is claimed as within 3% for "solution samples".

Table 2. The results of measurements with microcalorimeter and ionization chamber

	Microcalorimeter	Ionization Chamber	Difference
Hairpin	14.3 mCi ± 2%	13.1 mCi ±3%	9%
Single pin	7.1 mCi ± 2%	6.5 mCi ± 3%	9%
Ratio(H/S)	2.01	2.01	

Reference Time: 10:00 May 11, 2000

4.3 Discussion

The results of measurements with microcalorimeter and ionization chamber are summarized in Table 2. Differences of both measurements are also shown. Relative ratio of activities of hairpin and single pin were compared to verify the quality of measurement.

The results of the ionization chamber measurements were lower than those from the microcalorimeter by 9%. In the calorimetric measurement, effect of self absorption does not exist. On the other hand, ionization chamber measurement is affected by self absorption effect mainly due to the difference of absorption of photons in the metallic wire and in the solution if the ionization chamber is calibrated by standard solution source. This is understood by the analytical calculation done by Uritani et al. [11].

ISSN 1411 - 3481

Uncertainties quoted for the microcalorimetric measurements (Method I and II) are statistical ones estimated from fluctuation of the output voltage. The uncertainties quoted for the Method II are rather larger than the Method I mainly because difficulty in the process of Joule power adjustment to cancel the thermal power from the sources. The final result of each hairpin and single pin by microcalorimatric measurement was given as an average of the Methods I and II.

5. SUMMARY

A method of measuring radioactivity of ^{192}Ir brachytherapy sources in a fully nondestructive way was tested. The radioactivity obtained with the ionization chamber must be corrected for self absorption effect by 9% to get the true radioactivity of the brachytherapy sources in the present case. It is, however, noteworthy that, if the different ionization chamber is used, the correction for self absorption is not necessarily 9%, because it depends on the response characteristics of each ionization chamber.

ACKNOWLEGEMENT

This experiment was carried out in the course of developing the brachytherapy sources in Indonesia under guidance by Dr. A. Mutalib and Ms. Wayan Rediatning. The authors are grateful for their support and valuable discussions throughout in this work.