Comparison of ^{192}Ir brachytherapy source measurements in UK hospitals, 2000

D K Modna, M Baker, M J Woods

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D K Modna, M Baker, G A Bass and M J Woods
Centre for Ionising Radiation Metrology
National Physical Laboratory
Teddington
Middlesex TW11 0LW
United Kingdom

ABSTRACT

The second comparison of measurements of ^{192}Ir brachytherapy sources has been completed and the results show an overall improvement when compared with the results of the previous comparison. Hairpins were included in this exercise and these results, too, indicate a reasonable level of performance.

As in the previous exercise there are still some areas of concern: the reporting of uncertainty budgets; the in-house determination of calibration figures; the realisation that calibration figures are only applicable to a specific measurement geometry; the need for calibration checks to be carried out on all chambers.

(It is recommended that the exercise be repeated, with both thin wires and hairpins.)

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1 INTRODUCTION

Brachytherapy sources are used in the treatment of cancer because they can deliver a high absorbed photon dose to the tumour both in a relatively short period of time and in a localised manner. These sources are generally divided into two categories, low dose rate (LDR) and high dose rate (HDR). The LDR sources have been in use for the longest period of time and are manipulated manually whereas the HDR sources, because of their extremely high dose rates, require remote handling and delivery systems. ^{192}Ir is used for such sources with the (LDR) versions being manufactured as either wires or hairpins. These comprise an inner core of platinum and iridium alloy, with an outer coating of platinum. The wires are activated to ^{192}Ir by irradiation in a neutron flux, and relatively high specific activities can be achieved. This irradiation also produces some other activation products of iridium and platinum but these are insignificant in terms of patient dose. Any particulate emissions are absorbed in the platinum coating and the sources are simply administered to and removed from the patient. There is very little waste generated by this procedure.

For therapeutic applications, it is necessary to know the air kerma rate (AKR) from the sources and this can either be obtained from the manufacturer or be measured using in-house equipment. The manufacturer states the AKR in μGy h^{-1} @ 1 m: however, the thin wires are irradiated as 500 mm coils and uniformity cannot be guaranteed. Since each hospital will cut predetermined lengths from these wires to suit the particular treatment plan, it is not possible to guarantee that the AKR per unit length from any particular offcut will be the same as that quoted for the total coil, which must be merely some average value.

These problems have been recognised by the user community and guidelines for the control of dosimetry using brachytherapy sources have been published by the BIR/IPEM(2). These recommendations include the need to determine, in-house, the AKR for individual cut lengths prior to administration and for the results of those measurements to be traceable to national standards.

A wide variety of radioactive materials are used in UK hospitals for therapy, diagnosis or research purposes. It is essential for all of these sources, not just those used for brachytherapy, that either the activities of, or the dose rates from, these radionuclides are accurately determined prior to their being administered to the patient. For radioactivity measurements, the most common instrument of choice for this purpose is the radionuclide calibrator. Radionuclide calibrators are based on high pressure, re-entrant ionisation chambers. Their operation is relatively simple and, if used in accordance with a quality assurance system, they can ensure the desired level of accuracy needed for the administered activities. A protocol for a quality assurance system for such instruments has been recommended for use in UK hospitals.(1)

These ionisation chambers are also suited to the measurement of the AKR for these types of LDR brachytherapy sources. This is recognised in the guidelines mentioned above and specific guidance is given on measurements using radionuclide calibrators. It should be noted that the derivation of calibration factors for brachytherapy sources is more complex than for solutions. Calibration factors have been measured for the NPL secondary standard ionisation chamber and are published in the open literature(3): these factors are traceable to national primary standards of AKR and activity. The traceability of calibration figures to other chambers is not known to the authors.

In 1997, a comparison was carried out by NPL in order to determine the current level of performance for measurements of these ^{192}Ir LDR sources[(4)]. In general, the results of that exercise indicated that there were no major measurement problems. However, several areas were highlighted where there was some potential for improvement and it was recommended that the comparison be repeated. This present exercise looks at those points raised previously and includes, at the recommendation of the participants, the measurement of hairpins (thick wires).

2 PARTICIPANTS

As in the previous exercise, participation was open to all UK hospitals and the comparison was advertised via the NPL newsletter and its mailing lists. A total of 16 hospitals in the UK elected to take part in this comparison and, in addition, one overseas hospital asked to participate. One participant requested the hairpin only, but the remainder received all of the sources. A list of participants is given in Appendix 1.

3 COMPARISON SAMPLES

Following the previous comparison, there was a request that ^{192}Ir hairpins should be included in future exercises. Therefore, these thick wire sources (hairpins with an outer diameter of 0.6 mm) were included in the exercise as well as the thin wires cut from coils (outer diameter 0.3 mm). Both the hairpins (product code ICW.3090) and the coils (product code ICW.1090) were obtained from Nycomed-Amersham. The coils were supplied in 500 mm lengths and were sub-divided at NPL into three nominal lengths of 10, 30 and 100 mm. Several wires and hairpins were retained at NPL for reference purposes. The samples were made available to the participants from 17th July 2000 with a request that results be reported within two months.

4 CONFIDENTIALITY

Each hospital was given an identifier and the results are tabulated against these identifiers. The correlation between the code and participant is known only to NPL.

5 MEASUREMENTS AT NPL

A perspex jig[(3)] had been designed for measuring these types of brachytherapy sources in the NPL secondary standard ionisation chamber: this ensures reproducibility of the positioning of the sources. The 10 mm wires and the hairpins are measured in a central vertical position, whilst the 30 and 100 mm wires are measured in the trough that is cut into the jig. The chamber had been previously calibrated for these. The calibration factors, in terms of response per unit AKR, are directly traceable to AKR measurements made by the NPL Dosimetry Group in their scatter-free facility. The corresponding calibration factors, in terms of response per unit activity, were determined by dissolving individual wires and assaying the solution activity. The specific details of these measurements and the resultant factors have been published in the open literature[(3)].

All of the ^{192}Ir sources used in this exercise were assayed in the NPL secondary standard re-entrant ionisation chamber[(3)] and the AKR values, in μGy h^{-1} at a distance of 1 m, were calculated using the responses obtained from the ionisation chamber measurements together with the calibration factors mentioned above. Several of these sources were also measured by

NPL's Dosimetry group using a protection level secondary standard system. The AKR was determined at 1 m focal distance from each source and corrected to free space conditions. The results showed very good agreement with the previously determined calibration factors, thus confirming the published values[(2)]. These calibration factors are given in Table 1.

6 RESULTS

Of the 17 participants, two failed to report results whilst several others only reported measurements for some of the samples, but not all. Tables 2 to 5 show the reported results for the different wires: these have been decayed to the NPL reference time of 12:00 GMT on 1st July 2000. Figures 1 to 4 show the individual source results graphically, while Figure 5 represents all the results. The graphs show all uncertainties at the 68 % confidence level, which corresponds to a coverage factor, k=1. The horizontal bars represent the NPL standard uncertainty.

Table 6 gives details of the different instruments and techniques used by the participants together with other relevant data.

7 DATA ANALYSIS

Data reporting forms were prepared (Appendix 2) and distributed with the samples. The reported results were used in conjunction with the NPL data to calculate two main parameters.

The deviation from the NPL value was calculated as a percentage:

$$Deviation\,(\%) = \left(\frac{Analyst's\ result - NPL\ value}{NPL\ value}\right)\times 100$$

To determine whether the results are statistically different from the NPL result, the uncertainties also need to be considered. A u-test[(5)] is commonly used for this purpose:

$$u - test = \frac{(Analyst's\ result - NPL\ result)}{\sqrt{(Analyst's\ uncertainty^2 + NPL\ uncertainty^2)}}$$

The interpretation of the u-test is given in Table 7. It can be seen from this table that any data with a u-value above 3.29 is clearly discrepant. However, as in the previous intercomparison, any data with a u-test above 1.64 will be regarded as needing closer consideration. The reason for this approach is the sensitivity of the general public to radioactivity and, in particular, the incorrect administration of radiotherapy to patients.

8 DISCUSSION

The results indicate that there has been a general improvement when a comparison is made with the results of the previous exercise, which was carried out in 1997. Eight participants took part in both intercomparisons, although only six returned results. A comparison for these cases is shown in Figure 6.

Of the results reported, the majority appear to be in general agreement with the NPL data when the u-values are considered. As in the previous exercise, the 30 mm sources gave no discrepant results. The 100 mm sources had one discrepant result and the 10 mm and the hairpin sources had two and three respectively.

Four participants provided additional information about the positioning of the sources, whilst one participant also reported a correction had been made for non-standard geometry.

Participant 5 measured the hairpin source in two ionisation chambers, an ISOCAL III and a Keithley therapy dosemeter. The hairpins were measured both straight and coiled: the results shown in the tables and graphs are for the straight format only. The results for the hairpin obtained from both chambers are in agreement with each other but they differ from the NPL value by approximately 7 %. It should be noted that the ISOCAL III used by this participant is not of the same construction as the NPL secondary standard (ISOCAL IV). Although the ISOCAL III result is not discrepant according to the u-test, there is some concern about the large percentage difference. By discussing these results with the participant, it was realised that the calibration figure derivation for the ISOCAL III was based on thin wire measurements. Since the diameter of the hairpin is twice that of the wire, the self-attenuation produced by the hairpins will be larger than for the thin wire. This means that the calibration figure for the hairpins should be lower than that for thin wires. If this is not taken into account, the indicated AKR will be lower than the true value. The measurement for the Keithley chamber was based on HDR calibration factors and no data is available to judge the difference that may be produced by the different source corrections. It should be noted that this hospital does not normally use hairpins.

8.1 Instrumentation.

The instruments of choice for this intercomparison were ionisation chambers. Although one participant did not give details of his instrument, it can be reasonably assumed that an ionisation chamber was also used. However, there is insufficient evidence to make any assumptions about the quality of results relating to instrument type. Participant 5 used two ionisation chambers and one instrument definitely shows discrepant results. It should be noted that this instrument is not normally used for patient radiotherapy.

8.2 AKR Constants

In contrast to the previous intercomparisons, the majority of participants used an AKR constant of ~ 0.11 μGy h^{-1}MBq^{-1} m^{2}. Participant 5 derived the LDR calibration factor by using an HDR conversion factor. This does not seem to have affected the results for the wire but, as explained earlier, the hairpin was result was approximately 12 % away from the true value.

8.3 Uncertainties.

There has been an overall improvement in the reporting of uncertainties. Many participants attempted to construct an uncertainty budget, including sources of uncertainty such as those arising from the calibration factor, positioning, temperature, pressure, and length of wire. However, in several cases, there still appears to be some underestimation of the overall uncertainties, possibly due to incomplete uncertainty budgets.

The NPL uncertainties were derived in accordance with the current ISO recommendations[6]. Since these are dominated by the uncertainty on the original, primary AKR measurements, it is reasonable to assume that any secondary measurements would have uncertainties which are not less than these. It is notable that some reported uncertainties are still lower than those for the NPL value: indeed, it is clear that participant 10 has an unrealistically low uncertainty. If the uncertainty is underestimated, the u-test value will be increased and may show that the result is discrepant, when this may not be the case. A more careful consideration of the uncertainties may show a truer picture of the measurements taken.

Participant 13 made a very detailed uncertainty analysis. However, it is acknowledged that such a detailed examination is not a practical option for sources measured daily. The uncertainty budget does not need to be re-evaluated for each measurement. Such an examination should be carried out once, since the main components will remain the same, unless the method of measurement changes. Since an uncertainty of a few percent is acceptable in delivering patient dose, it is not justifiable to spend a significant amount of time reducing the uncertainty by a small amount. Nevertheless, the reporting of uncertainties is recommended since it allows a good assessment of the performance of the participant to be estimated.

8.4 Calibration.

The reporting of individual calibrations was variable. Two participants stated that the manufacturers settings were used (participants 2 and 12). Four participants stated details of how they calibrated their chambers. The results of the participants who gave these details, cannot be said to be better or worse than the other results.

8.5 Reference data.

Most sources are routinely measured just before being administered to the patient and therefore decay is not significant. However, should this not be the case then the correct half life data must be used and a reference time be given. All participants gave a reference time of their measurements. The results were decayed to the NPL reference time, using a half-life of 73.831 ± 0.008 days[6]. It is encouraging to note that more participants are now using the recommended AKR constants, although not all.

There is some concern that some participants are not using the specified geometry for all measurements. For example, the calibration figures supplied for the NPL ISOCAL IV are only valid in the specified geometry[2], which in this case means within the holders supplied with the chamber. The importance of placing the sources in the geometry specified cannot be overstated since any variation to this will introduce an error and an additional uncertainty and the activity that is given to the patient may be different to the reading obtained.

It should also be noted that there is a large difference between the calibration figures for the ISOCAL IV for thin wires and hairpins. This will undoubtedly be the case too for other ionisation chamber systems and participants should be aware of the dangers of trying to derive one from the other.

9 CONCLUSIONS

This intercomparison has shown a general improvement in the performance of measuring brachytherapy sources. However, there are still areas of concern regarding these measurements:

i) care must be taken when trying to determine calibration figures for hairpins from wires or vice versa. Any differences in the structure of these sources will have a large effect on any calibration figure;

ii) although the uncertainty budgets have improved on the whole, there are still some users who do not appear to have included all of the significant uncertainties. The calibration factor uncertainties are not always taken into account;

iii) although there is a wide range of ionisation chambers used, there does not appear to be a significant difference in their performance;

iv) the NPL calibration factors are specific for a particular chamber (ISOCAL IV) and for a particular geometry and when these factors are used the sources must be placed in the correct geometry for all measurements;

v) a re-calibration should be carried out on the ionisation chambers whenever the measurement conditions change e.g. change of container, geometry etc;

10 WORKSHOP REPORT

A one-day workshop was held at NPL on the 4th April 2001. Thirteen UK participants and one overseas participant attended the workshop. There were four formal presentations, three from the NPL and one from a participant:

ARK measurements – Graham Bass (NPL)
^{192}Ir LDR Brachytherapy Intercomparison Results – Dagmara Modna (NPL)
^{192}Ir HDR measurements – Thorsten Sander (NPL)
A hospital experience with LDR measurements – Steve Locks (Newcastle General Hospital)

The presentations were followed by a general discussion. Visits for participants were arranged around the dosimetry and radioactivity groups in the afternoon.

The workshop concurred with the conclusions previously found in the report. From the discussions, it became evident that there was interest in future intercomparisons with ^{125}I prostrate seeds and there was also some interest in having a brachytherapy intercomparison with ^{137}Cs.

The participants found the workshop valuable and of interest and they welcomed the opportunity to be able to discuss brachytherapy issues with their counterparts.

11 ACKNOWLEDGEMENTS

The participants are thanked for the time and effort they have put into this exercise.

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Table 1. Published Calibration Figures for the NPL secondary standard radionuclide calibrator (ISOCAL IV)

Parameter	**Wire length**	**Value**	**Standard Uncertainty (k=1)**
pA MBq^{-1}	10 mm	7.83	± 1.1 %
	30 mm	8.36	± 2.8 %
	100 mm	8.36	± 2.8 %
	Hairpin	7.08	± 2.7 %
μGyh^{-1} MBq^{-1}@1 m	10 mm	0.104	± 1.6 %
	30 mm	0.104	± 1.6 %
	100 mm	0.104	± 1.6 %
	Hairpin	0.098	± 1.6 %
pA $\mu Gy^{-1}h^{-1}$@ 1 m	10 mm	75.2	± 1.1 %
	30 mm	80.3	± 2.8 %
	100 mm	80.3	± 2.8 %
	Hairpin	72.2	± 2.7 %

Table 2 Results for 10 mm wires.
(Results are at the NPL reference date: 1 July 2000)

Code	NPL AKR (μGy h^{-1} @ 1 m)		Hospital AKR (μGy h^{-1} @ 1 m)		Deviation %	u-value
	Value	Standard uncertainty	Value	Standard uncertainty		
1	2.48	0.03	2.54	0.11	2.42	0.53
2	2.46	0.03	2.55	0.18	3.66	0.49
3	2.08	0.03	2.11	0.03	1.44	0.71
4	2.74	0.03	2.87	0.13	4.74	0.97
5a	2.14	0.03	2.12	0.11	-0.93	0.18
5b	2.14	0.03	2.26	0.06	5.61	1.79
6	2.26	0.03	2.21	0.13	-2.21	0.37
7	2.45	0.03	2.55	0.19	4.08	0.52
8	2.92	0.04	2.74	0.03	-6.16	3.6
9	2.61	0.03	2.62	0.13	0.38	0.07
10	2.37	0.03	2.41	0.002	1.69	1.33
11	-	-	-	-	-	-
12	3.18	0.04	3.40	0.17	6.92	1.26
13	3.26	0.04	3.29	0.09	0.92	1.12
14	2.77	0.03	2.87	0.09	3.61	1.05
15	2.80	0.03	2.83	0.16	1.07	0.18
16	2.74	0.03	-	-	-	-
17	2.76	0.03	-	-	-	-

Table 3 Results for 30 mm wires.
(Results are at the NPL reference date: 1 July 2000)

Code	**NPL AKR (μGy h^{-1} @ 1 m)**		**Hospital AKR (μGy h^{-1} @ 1 m)**		**Deviation %**	**u-value**
	Value	**Standard uncertainty**	**Value**	**Standard uncertainty**		
1	6.30	0.18	6.58	0.28	4.44	0.84
2	5.99	0.17	5.96	0.42	-0.50	0.07
3	6.07	0.17	6.09	0.17	033	0.08
4	6.05	0.17	6.38	0.25	5.45	1.09
5a	7.53	0.21	7.53	0.38	0	0
5b	7.53	0.21	7.96	0.35	5.71	1.05
6	6.81	0.19	6.75	0.37	-1.03	0.12
7	7.06	0.20	7.26	0.16	2.83	0.78
8	7.16	0.20	6.93	0.07	-3.21	1.09
9	7.40	0.21	7.39	0.41	-0.14	0.02
10	6.40	0.18	6.57	0.004	2.66	0.45
11	-	-	-	-	-	-
12	6.52	0.19	6.82	2.27	4.60	0.13
13	6.88	0.20	6.97	0.21	1.31	0.31
14	6.70	0.19	6.94	0.18	3.58	0.92
15	8.10	0.23	8.15	0.42	0.62	0.10
16	6.17	0.18	-	-	-	-
17	6.90	0.20	-	-	-	-

Table 4 Results for 100 mm wires.
(Results are at the NPL reference date: 1 July 2000)

Code	NPL AKR (μGy h^{-1} @ 1 m)		Hospital AKR (μGy h^{-1} @ 1 m)		Deviation %	u-value
	Value	Standard uncertainty	Value	Standard uncertainty		
1	23.25	0.65	24.64	1.18	5.98	0.42
2	23.98	0.67	24.25	1.70	1.13	0.15
3	22.52	0.63	22.62	0.63	0.44	0.11
4	23.34	0.66	24.37	0.97	4.41	0.88
5a	23.34	0.66	23.43	1.18	0.39	0.07
5b	23.34	0.66	24.82	0.53	6.34	1.75
6	23.79	0.67	22.93	1.24	-3.61	0.61
7	21.94	0.62	22.68	0.14	3.37	1.16
8	23.36	0.66	22.66	0.23	-3.0	1.0
9	24.32	0.68	24.41	1.29	0.37	0.06
10	22.77	0.64	23.16	0.005	1.71	0.61
11	-	-	-	-	-	-
12	23.86	0.67	23.23	1.16	-2.64	0.47
13	24.28	0.68	24.48	0.76	0.83	0.20
14	23.60	0.66	24.64	0.67	4.41	1.11
15	24.86	0.70	25.11	1.26	1.01	0.17
16	23.49	0.66	-	-	-	-
17	22.86	0.65	-	-	-	-

Table 5 Results for hairpin.
(Results are at the NPL reference date: 1 July 2000)

Code	NPL AKR (μGy h^{-1} @ 1 m)		Hospital AKR (μGy h^{-1} @ 1 m)		Deviation %	u-value
	Value	Standard uncertainty	Value	Standard uncertainty		
1	30.07	0.81	29.67	1.31	-1.33	0.26
2	32.15	0.87	30.63	2.14	-4.73	0.66
3	31.79	0.86	32.10	0.78	0.98	0.27
4	31.55	0.86	31.53	1.26	-0.06	0.01
5a	32.01	0.87	29.78	1.45	-6.97	1.32
5b	32.01	0.87	29.67	0.63	7.31	2.18
6	32.83	0.89	30.88	1.67	-5.94	1.03
7	32.84	0.89	32.46	0.14	-1.46	0.43
8	31.58	0.86	29.10	0.18	-7.85	2.82
9	32.59	0.88	32.67	1.64	0.24	0.04
10	32.15	0.87	31.47	0.007	-0.02	0.78
11	31.84	0.86	32.74	.95	2.83	0.70
12	31.72	0.86	30.86	1.55	-2.71	0.49
13	32.58	0.88	-	-	-	-
14	33.55	0.91	30.84	0.82	-8.08	2.21
15	31.10	0.84	30.74	1.54	-0.01	0.21
16	31.27	0.85	-	-	-	-
17	31.55	0.86	-	-	-	-

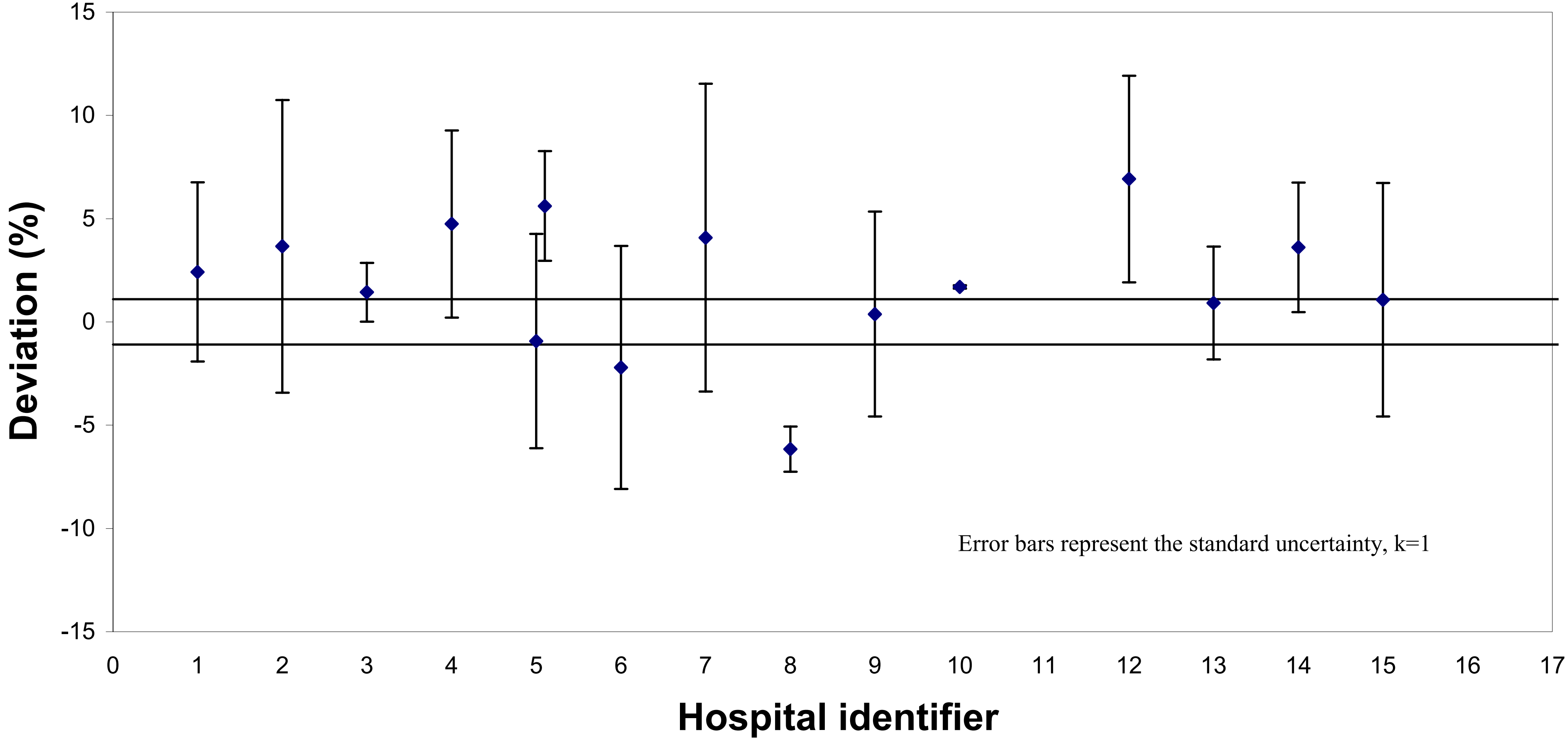
Table 6 Other reported data

Code	Instrument	Manufacturer	Type	Comments
1	Re-entrant ionisation chamber	Capintec	CRC-15β	AKR constant = 0.111μGy h^{-1} MBq^{-1} m^2
2	Well-chamber	Capintec	CRC-12	Capintec factor used - 408 AKR constant = 113 μGy $h^{-1}GBq^{-1}$ m^2
3	Pressurised well-ionisation chamber	NE Technology	ISOCAL-IV	Background subtracted from reading AKR = pA/(chamber calibration x Calibration factor)
4	Re-entrant ionisation chamber	Capintec	CRC 15R	Calibration factor based on previous calibrations measured in a coil. Sources received were coiled. Hairpin is usually measured with the foil. No correction was made for the absence of the foil. 2 sets of measurements taken to correct for non-standard geometry. Sources measured in plastic container in the measurement jig.
5a 5b	Ionisation chamber	ISOCAL III HDR 1000 - (standard imaging). Keithley –35040 therapy dosemeter		LDR derived from HDR AKR calibration factor. LDR factor not available – possible error of 6 %. Standard temperature and pressure. 10 –30 mm wire were lowered into well chamber. 100 mm wires were coiled. Hairpin was measured as received then coiled. The hairpin was lowered into the chamber.
6	Well chamber	PRIT Well counter	WC2 / WCC2	Corrected for temperature and pressure. AKR constant = 133 $\mu Gym^2GBq^{-1}h^{-1}$
7	Well Chamber			Measurement taken in ion chamber against a Cs source of known activity. Geometry factor applied.
8	Ionisation chamber	VINTEN		AKR constant = 0.1104
9	Ionisation chamber	ISOCAL IV		NPL jig used. Wire length was estimated.
10	Ionisation chamber	CAPINTEC	CRC-15R	AKR constant = 0.113 $\mu Gyh^{-1}MBq$ m^2 Hairpin measured 10 times. Repositioned in jig and holder each time.
11	Ionisation chamber	ISOCAL IV		AKR = calibrator reading x 1/72. Hairpin only measured.
12	Ionisation chamber	SIEL	BIC -1 DCAL -1	AKR constant = 0.1132 $\mu Gyh^{-1}MBq$ Siel standard holder used. Dial setting 447. No difference with hairpin in holder or without.
13	Ionisation chamber	Connected to Keithley 610c electrometer and a digital multimeter		Measurement carried out on large IC, due to low activity. This increased the activity.
14	Ionisation chamber	CAPINTEC	CRC-10 R	AKR factor = 0.1097 Half-life = 73.813 days 10 mm wires are not normally measured. Wire suspended in centre of chamber, so it touches the base of holder, hairpin mounted in jig, then placed in standard calibrator insert.
15	Ionisation chamber	CAPINTEC	CRC – 5B	Re-measured previously supplied sources with their quoted AKR from certificate. NPL and old sources of similar sizes and measured in identical geometry in chamber. Ratio'd activities and scaled old source cert for NPL sources. AKR=(Act (NPL)/act old) x old AKR x decay factor
16				Did not return results
17				Did not return results

Table 7 u-test interpretation

Value	**Conclusion**
$u < 1.64$	The values do not differ significantly
$1.64 < u < 1.96$	The values probably do not differ significantly but more data are required to confirm this
$1.96 < u < 2.58$	One cannot say whether there is a significant difference without further data
$2.58 < u < 3.29$	The values probably differ significantly but more data are required to confirm this
$3.29 < u$	The values differ significantly

Figure 1 - AKR measurements of Ir-192 (10 mm wires)



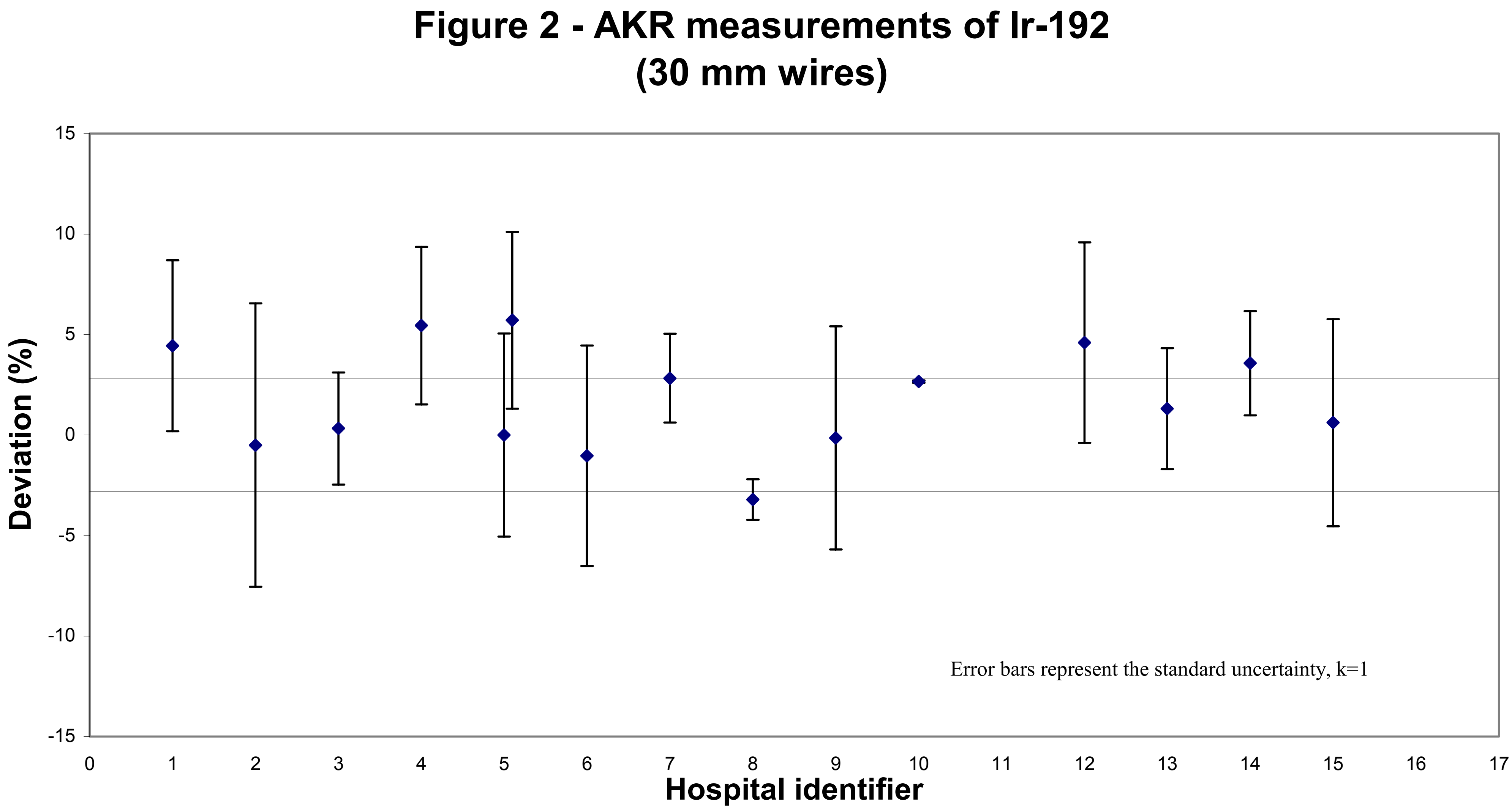


Figure 2 - AKR measurements of Ir-192
(30 mm wires)
Deviation (%)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Hospital identifier
Error bars represent the standard uncertainty, k=1

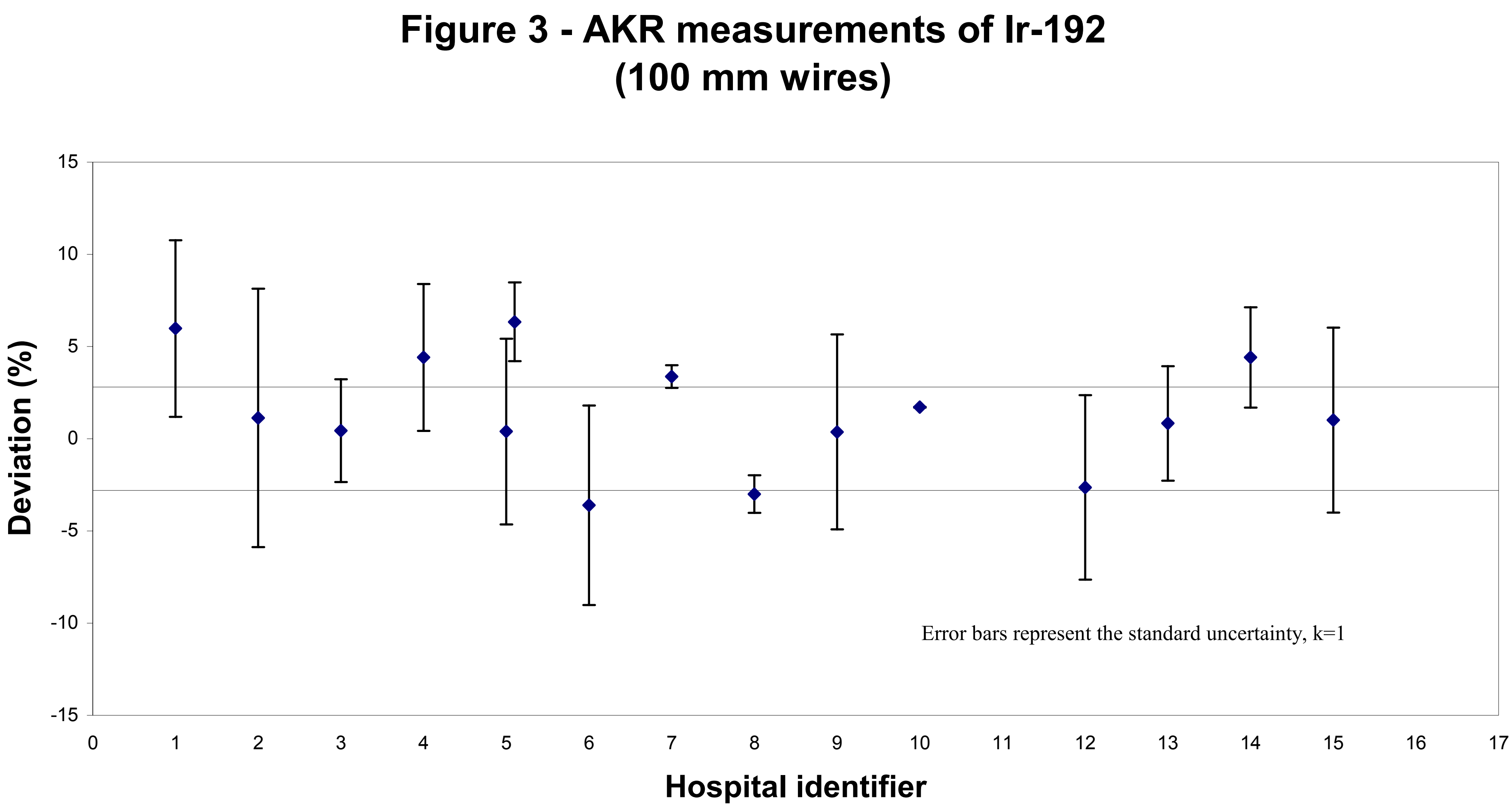
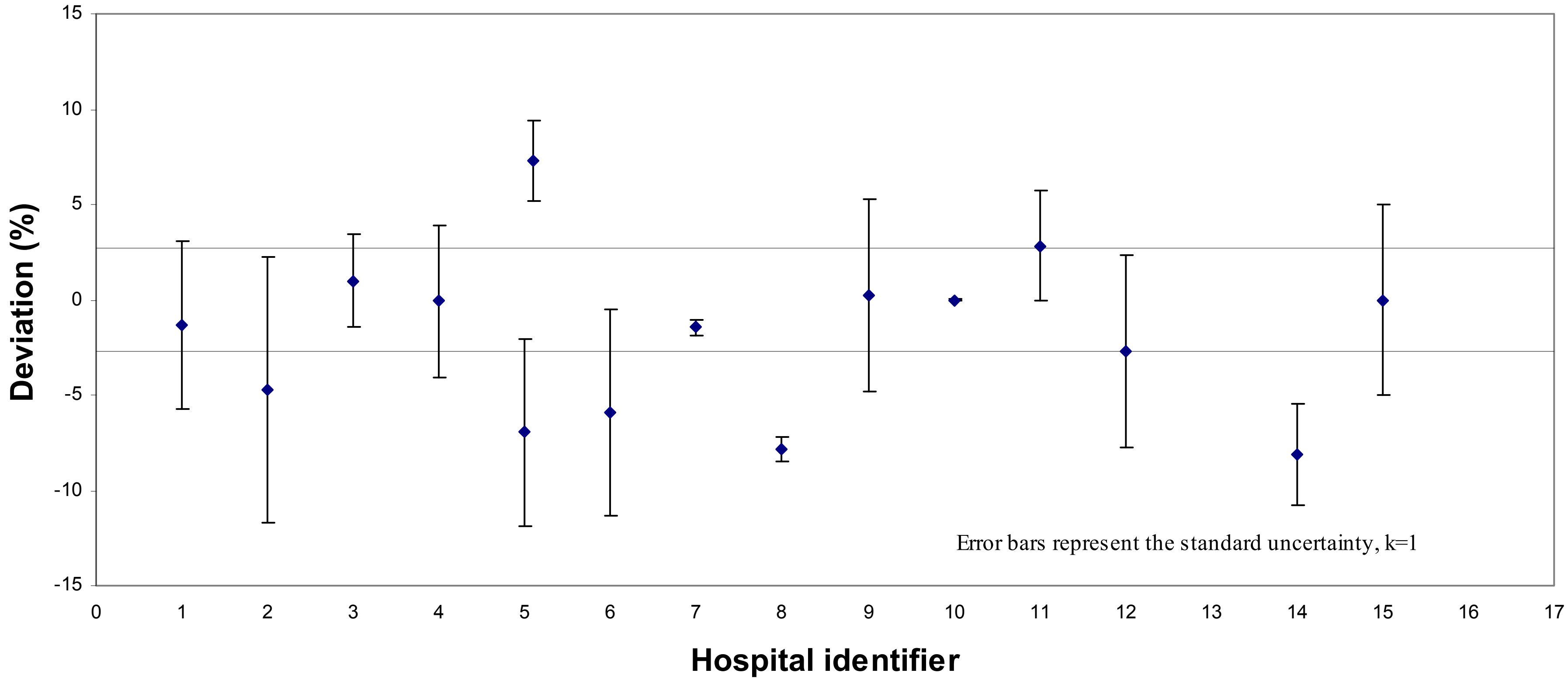


Figure 3 - AKR measurements of Ir-192
(100 mm wires)
Deviation (%)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Hospital identifier
Error bars represent the standard uncertainty, k=1

Figure 4 - AKR measurements of Ir-192 (Hairpins)



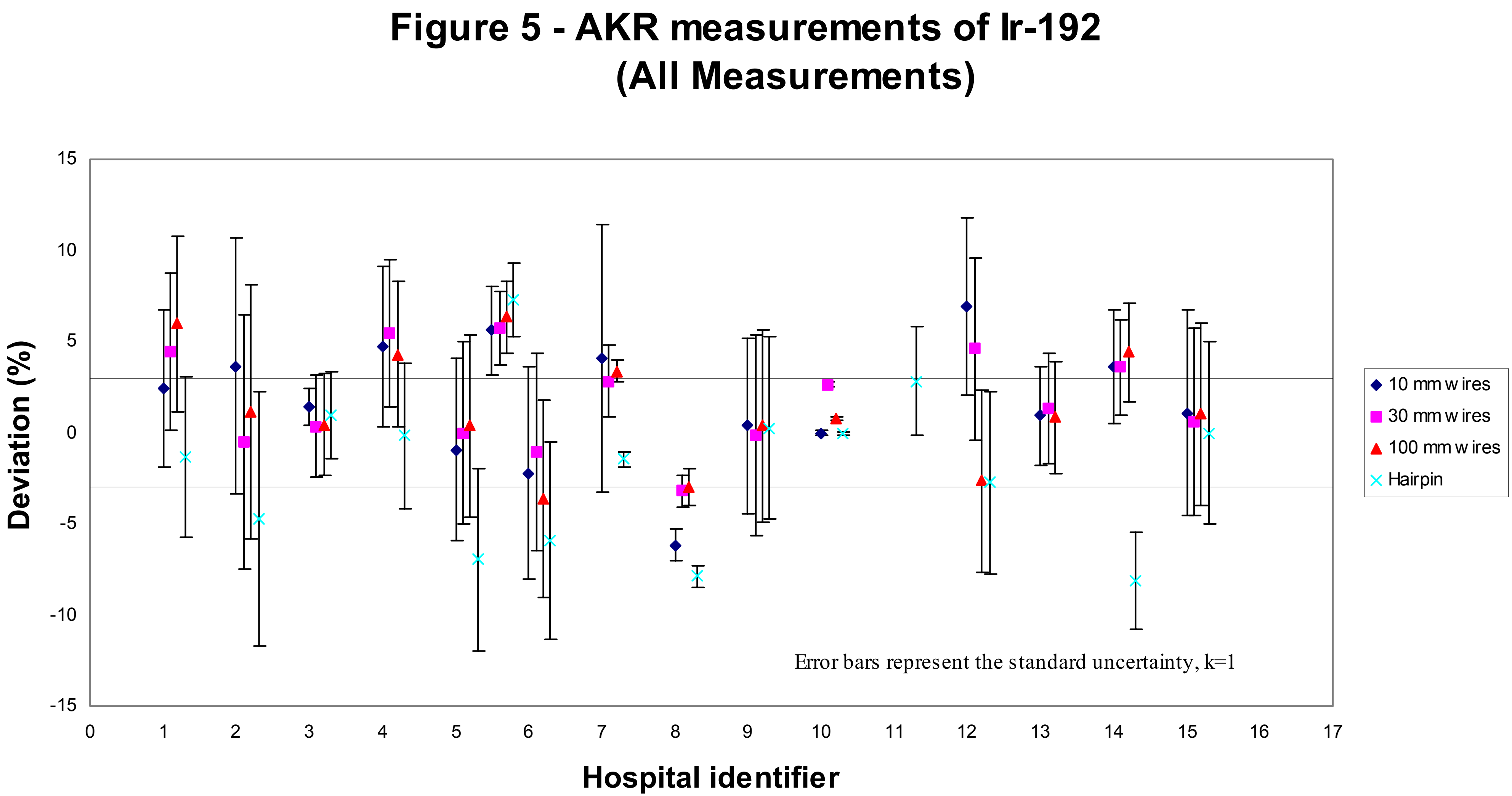


Figure 5 - AKR measurements of Ir-192
(All Measurements)
Deviation (%)
15
10
5
0
-5
-10
-15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Hospital identifier
10 mm w ires
30 mm w ires
100 mm w ires
Hairpin
Error bars represent the standard uncertainty, k=1

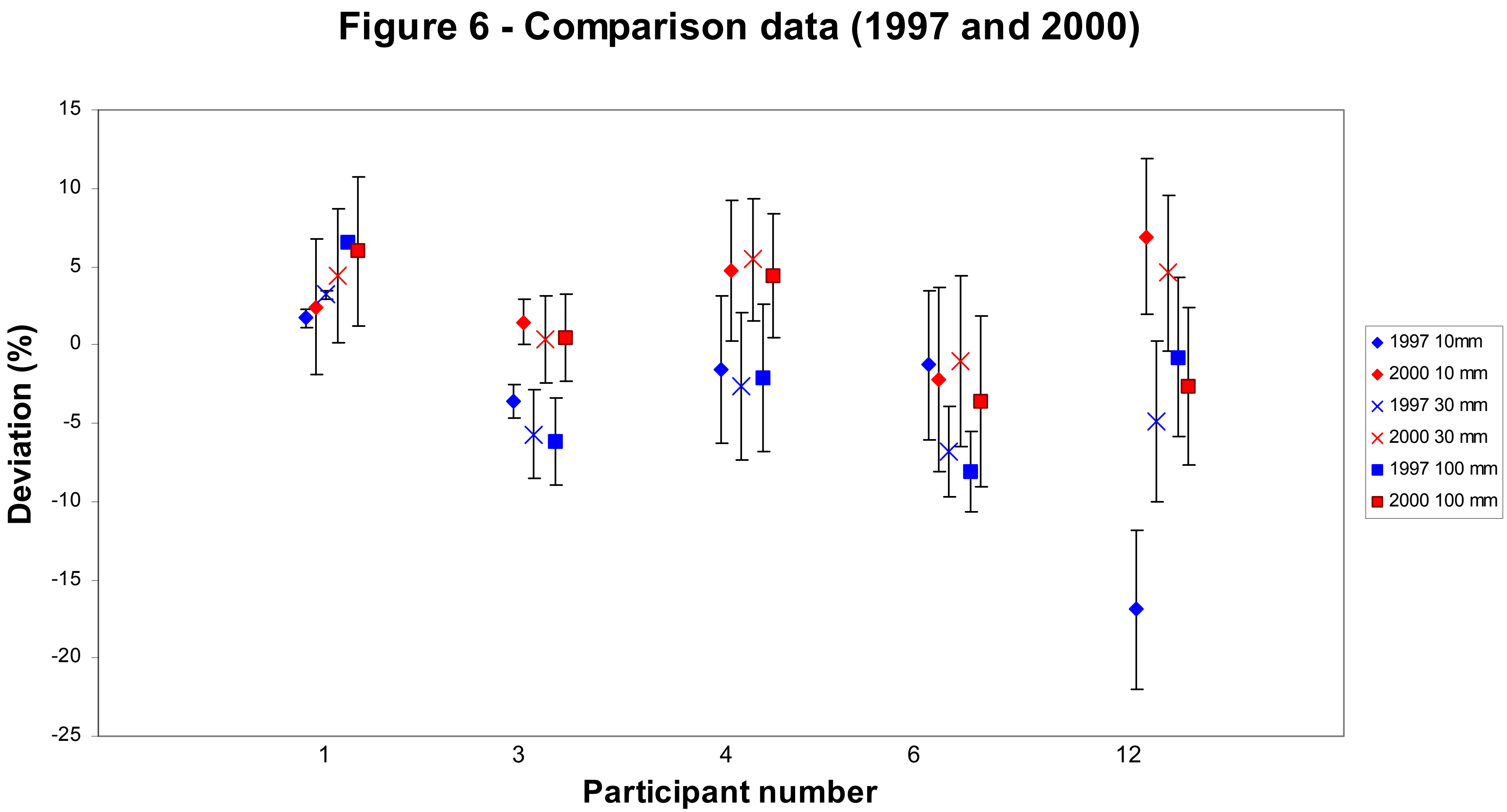


Figure 6 - Comparison data (1997 and 2000)
15
10
5
0
-5
-10
-15
-20
-25
Deviation (%)
1
3
4
6
12
Participant number
1997 10mm
2000 10 mm
1997 30 mm
2000 30 mm
1997 100 mm
2000 100 mm

APPENDIX 1 - PARTICIPANTS

Ms C Barber
Medical Physics
Churchill Hospital
Old Road
Headington
Oxford
OX3 7LJ

Mr I Coles
Department of Radiation Physics
Charing Cross Hospital
Fulham Palace Road
London
W6 8RF

Mrs M Filby
Nuclear Medicine Department
Ground Floor
New Guy's House
Guy's Hospital
St Thomas' Street
London
SE1 7EH

Mr A Flynn
Cookridge Hospital
Medical Physics Unit
Hospital Lane
Leeds
LS16 6QB

Dr M Ford
Radiotherapy Physics
Western Infirmary
Beaston Oncology Centre
Glasgow
G11 6NT

Mr A Garton
Radiotherapy Physicist
Department of Physics
Fulham Road
SW3 6JJ

Mr C Lee
Medical Physics Department
Clatterbridge Centre for Oncology
Clatterbridge Road
Bebington
Wirral
CH65 4JY

Mr S Locks
Department of Medical Physics
Newcastle General Hospital
Regional Medical Physics Department
Westgate Road
Newcastle Upon Tyne
NE4 6BE

Ms J Lord
Physics Department
Royal Berkshire Hospital
London Road
Reading
RG1 5AN

Mr A Poynter
Medical Physics
Woolverstone Wing
Ipswich Hospital
Heath Road
Ipswich
IP4 5PD

Miss A Welsh
Isotope Department
Oncology Centre
Cheltenham General Hospital
Sandfort Road
Cheltenham
GL53 7AN

Ms D Whitney
Department of Medical Physics
Addenbrooke's Hospital
Hills Road
Cambridge
CB2 2QQ

Ms A Ratcliffe
Walsgrave Hospital
Clifford Bridge Road
Walsgrave
Coventry
CV2 2DX
Fax: 024 76 538998

Mrs F Morris
Medical Physics Dept
St Mary's Hospital
Milton Road
Portsmouth
PO3 6AD

Mr N Pettersson
Centrala Isotopintaget
Att. MFT Ter. Radfys
Sahlgrenska
Universitetssjukhuset
41345 Goteborg
Sweden

T Kehoe
Oncology Physics
DCO LUHNT
Western General Hospital
Crewe Road
Edinburgh
EH4 2XU

Ms R Wyatt
Radiotherapy Physics Department
Queen Elizabeth Hospital
Edgbasten
Birmingham
B15 2TH

NPL Iridium-192 Brachytherapy Measurement Intercomparison		
1) Result 10 mm wire		
Value		μGy/hr @ 1 metre
Uncertainty (quote at 1 σ - the 68 % confidence interval)		μGy/hr @ 1 metre
Reference time and date		
2) Uncertainties		
Component of uncertainty	Uncertainty (quote at 1 σ - the 68 % confidence interval) [μGy/hr @ 1 metre]	Degrees of freedom
3) Method employed		
4) Equipment used		
5) Corrections/calculations used		
6) Software used		
7) Other information		