INTERCOMPARISON OF PORTABLE RADIATION
MONITORING INSTRUMENT EVALUATIONS

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MASTER

1. INTRODUCTION

The recent growth of nuclear energy as a source of electrical power and the use accelerators and radionuclides for medical and industrial applications has led to a growing interest in the performance of radiation instruments used to measure the radiation hazards associated with the use of these sources. Only after carefully controlled laboratory tests on different designs of instruments can a reasonable assessment of these instruments be formed which can then be used in the proper selection of an instrument for a particular radiation measurement and in estimating the error associated with that measurement.

The calibration facilities at both Berkeley Nuclear Laboratories (BNL) in the United Kingdom and the Pacific Northwest Laboratory of Battelle Memorial Institute (BNW) in the United States have had extensive experience in evaluating radiation protection instruments. Since the evaluation programs and techniques of these two facilities differ, an international intercomparison program was arranged so that results could be compared and deficiencies remedied. This paper briefly describes the evaluation procedures and results on four portable radiation monitoring instruments, as obtained from the two laboratories.

Each laboratory selected two portable monitoring instruments - a neutron survey meter, and a photon survey meter - from the pool of units in current operational use. BNL selected two British designed and built instruments: a low level exposure ratemeter and a neutron DE ratemeter.

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Battelle-Northwest selected two instruments of U.S. origin: a "Cutie Pie" type β -photon survey meter and a neutron DE survey meter. Each of these instrument types has a commercial equivalent, and so the selection is representative of what is available to and used by other facilities. It should be stressed that the instruments were not selected due to any preference or favorable bias, but because they were readily available and in current use in the field.

The instruments selected were calibrated and then run through an evaluation program by the laboratory making the selection. Then, the instruments were exchanged and an evaluation performed by the other laboratory.

Each laboratory selected its own series of evaluation procedures, working within the confines of a rather rigid time schedule. No attempt was made to standardize any techniques or specific tests. In-house facilities were used exclusively by Battelle-Northwest, while BNL made use of facilities at the UK National Physical Laboratory and the GLEEP reactor as well as its own.

2. BRIEF DESCRIPTION OF INSTRUMENTS EVALUATED

The low level exposure ratemeter selected by BNL⁽¹⁾ uses an energy compensated Geiger-Mueller tube as detector and has a usable range of 0.05 to 10 mR/hr spread over 3.5 decades. The instrument is fully transistorized and features a 210° logarithmic meter readout with an effective scale length of 12.7 cm and a temperature compensating circuit. The unit has a plastic case, and weighs approximately 2 kg. A single three position rotary switch is the only external control.

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3. ~~DESCRIPTION OF EVALUATION TESTS PERFORMED AT BNL~~ ^{BNL}

3.1 ~~Energy Response Determinations~~

3.1.1 Beta ^{Photon} ~~Gamma~~ Instruments, ^{Photon} ~~Gamma~~ Response

The energy responses of the two gamma instruments were examined. Below 250keV heavily filtered X-rays were used as the radiation source and the instruments were compared with a Baldwin-Farmer reference chamber which had been cross calibrated against primary standards. Above 250keV, isotope sources were used and the positive ion accelerator was used as a 6MeV source of gamma radiation. The results expressed as instrument reading divided by exposure rate have been normalised to 1.0 for exposure to a ²²⁶Ra ^{10hrs.} source. The filter assemblies, tube operating conditions and data on the resulting spectra used to determine the response below 250keV have been described in an earlier paper. ⁽⁵⁾ ~~(Lavender et al., 1969).~~

For the energy region 0.4MeV to 1.25MeV the following sealed

The β -photon survey meter selected by BNW is the venerable Hanford "Cutie Pie" (CP) ionization chamber.⁽²⁾ The pistol shaped instrument has a cylindrical phenolic plastic ion chamber with an effective volume of 658 cm³ and walls 440 mg/cm² thick. An end cover can be removed to provide a thin (7 mg/cm²) "open window" useful for monitoring beta radiation. Three linear ranges are provided, calibrated in units of 0-50, 0-500 and 0-5000 mR/hr. A zero adjust and rotary range switch are the two external operating controls.

The British neutron DE rate meter is based on a design by Leake⁽³⁾ and utilizes a spherical 3.3 cm diameter ³He proportional counter at the center 20.8 cm diameter polyethylene sphere with an intermediate perforated cadmium layer. The instrument has a range of 0.5 - 1000 mRem/hr with a single 3.5 decade logarithmic meter with an effective scale length of 12.7 cm. The unit was designed to measure DE rate from neutrons with energies from thermal to 7 MeV. It weighs 6.3 kg and is operated by a single, external three position switch.

The American neutron DE ratemeter is based on the original design of Anderson and Braun⁽⁴⁾ and uses a cylindrical BF₃ proportional counter tube as detector. The detector is surrounded by a cylindrical polyethylene moderator 21.5 cm in diameter containing an intermediate perforated borated plastic sleeve. Designed to monitor neutrons over the energy range of thermal to 15 MeV, the instrument has four overlapping linear ranges: Q-2, 0-20, 0-200 and 0-2000 mRem/hr. A five position rotary switch and a battery checkmeter reset switch comprise the external controls. The instrument has a detachable probe for remote operation and weighs approximately 10 kg.

isotope sources were used: ^{198}Au (0.412MeV), ^{137}Cs (0.66MeV), ^{226}Ra (mean 0.84 MeV) and ^{60}Co (mean 1.25MeV). The instruments and sources were placed on relatively scatter-free stands constructed from aluminium and perspex (Lucite). Care was taken to place the instrument and sources well above ground level, and only source to detector distances at which scattered radiation from the floor was negligible were used.

The 6MeV gamma response was determined using the 335keV resonance of the $^{19}\text{F}(p;\alpha\gamma)^{16}\text{O}$ reaction. Standardisation of the 6MeV radiation field is achieved by associated counting techniques of the alpha particles emitted within a well defined solid angle and is cross checked by ionisation measurements using a chamber calibrated by the ~~N.P.L.~~ ^{O.K. National Physical Laboratory (NPL)} at 2MeV.

NA For both the sealed sources and 6MeV tests the sources were not collimated.

Excessive detail
The geometrical centres of the ~~instrumental~~ ^{was} detectors were used as the position for calculating or measuring the ^{"true"} exposure rate. The results obtained for the ~~2601 monitor~~ ^{British and American instruments} are shown in figures 1 and 2. ~~for the G1/P2/P in figure 2.~~ Differences due to irradiating the instrument under different geometries are ^{also} shown.

3.1.2 Neutron Instruments

The energy response of the two rem counters were determined using a range of sealed sources, 2.8MeV and 14MeV neutrons from the B.N.L. positive ion accelerator, and neutrons with energies from 25keV to 1.6MeV produced by the ~~N.P.L.~~ ^{also} 3MeV Van de Graaff. *stet*

The sealed sources, outputs standardised by the manganese bath technique, used were: $\text{Sb/Be}(\gamma, n)$, 0.024MeV; $\text{RdTh/D}_2\text{O}(\gamma, n)$, 0.197MeV; $\text{RdTh/Be}(\gamma, n)$, 0.827MeV; $\text{Ra/Be}(\gamma, n)$, 0.30MeV; $\text{Ra/Be}(\alpha, n)$, 3.9MeV, and $\text{Am/Be}(\alpha, n)$, 4.4MeV.

The $\text{D(D, n)}^3\text{He}$ reaction and the $^3\text{H(D, n)}^4\text{He}$ reaction were used at B.N.L. to produce neutrons at 2.8 and 14MeV respectively. Source to detector distances of 100cm were used and the standardisation of the neutron fields was achieved by means of a calibrated De Pangher long counter, and cross checked by associated particle counting techniques.

Two reactions were used on the N.F.L. 3MeV Van de Graaff; the ${}^7\text{Li}(p,n){}^7\text{Be}$ reaction was used at angles of 40 and 60° to the proton beam to produce neutrons with energies from 30keV to 760keV and the ${}^3\text{H}(p,n){}^3\text{He}$ reaction was used at angles of 60 and 90° to the proton beam to produce neutrons over the energy range from 25keV to 1.8MeV. For both these reactions the rem counters were placed with their geometrical centres at 2 metres from the target and the long counter polythene insert was at the same distance from the target but at the opposite angle.

Calibration at thermal energies was achieved by using the thermal columns of the U.K.A.E.A. reactor GLEEP. A BF_3 counter calibrated in the thermal flux at B.N.L. was used to determine the fluence rate below cadmium cut-off.

Reference

The radiation fields from all the above sources were standardised in terms of fluence rate and these were converted to dose equivalent rates using the dose fluence relationships published by I.C.R.P. (1964).

The results obtained for the ~~4075~~ ^{British neutron} monitor plotted as instrument c/s against neutron energy are shown in figure 3 and measured mrem.h^{-1} have been normalised to 1.0 at 0.219MeV. Response curves for Snoopy are shown in figure 4 for the instrument irradiated from the front and side on; the instrument c/s has been plotted against measured mrem.h^{-1} neutron energy.

why this value?

3.1.3 Beta Response of ~~CP/TP/14~~ ^{the Hanford CP}

The beta response of the ~~CP/TP/14~~ ^{Hanford CP} monitor was determined by exposing the instrument in standardised fields from three ${}^{90}\text{Sr} + {}^{90}\text{Y}$ sources ($E_{\text{max}} = 2.26\text{MeV}$) and a ${}^{204}\text{Th}$ source ($E_{\text{max}} = 0.76\text{MeV}$). The dose distribution above these sources, expressed in rads to tissue, was determined from measurements made with an extrapolation chamber (Thompson et al, 1970).

The ~~CP/TP/14~~ ^{instrument} monitor with its "end cap" ~~on~~ was initially adjusted to read correctly when exposed to the gamma radiation from radium sources ~~with the window closed, and then~~ The instrument with the "end cap" of the ionisation

in open window condition with the
~~chamber removed was~~ then exposed to the beta sources ~~with the~~
central longitudinal axis
of the chamber at right angles to the plane of the sources. Instru-
ment readings in $R.h^{-1}$ were then taken for various source to
chamber distances. The response has been expressed as

$$\frac{\text{instrument reading in } R.h^{-1}}{(\text{rads}.h^{-1}) \text{ tissue as measured by extrapolation chamber}}$$

against source to detector distance and this has been plotted in
three forms in figure 5: curve A corresponds to the tissue dose at
the front face of the ionisation chamber, curve B corresponds to the
tissue dose at the geometrical centre of the ionisation chamber, and
curve C is for the average dose delivered to the position occupied
by the instrument's detector.

3.2 Variations in Instruments Reading with Supply Voltage

The batteries were removed from the instruments and a variable
power pack was fitted to each one. The instruments were then exposed
under fixed irradiation geometry and readings taken for voltages
varied from the maximum battery rating to that corresponding to the
instruments lower battery check position or below. The following
results were obtained.

0075 Neutron Monitor, source used Am/Be(α, n) at two dose
equivalent rates

Voltage	Instrument c/s	Instrument c/s
1.7	0	16.3
1.8	3.50	801.0
1.9	7.51	1135.1, corresponds to $\sim 330 \text{ mRem/hr}$
2.0	7.71	1133.0
2.2	7.66	1139.2
2.4	7.76	1131.4 $\leftarrow 2.35 \text{V}$ corresponds to lower battery check position
2.6	7.56	1130.2
2.8	7.10	1128.8
3.0	7.23	1139.9
3.2	7.85	1127.5
3.3	7.71, corr. to $\sim 2.1 \text{ mrem/hr}$	1131.0 upper battery check position

*There should
be shown
graphically*

Neutron Monitor "Snoopy" - Am/Be(α ,n) source

Volts	Range x1		8.0mrem/hr Range x10		32mrem/hr Range x100	
	Inst.Rdg.	Inst.c/s	Inst.Rdg.	Inst.c/s	Inst.Rdg.	Inst.c/s
2.6	1.2	2.38	9.8	17.05	38	62.34
2.8	-	-	9.8	16.99	38	61.61
3.0	-	-	9.8	17.13	38	61.97
3.2	1.3	2.32	9.8	16.86	38	62.34
3.4	-	-	9.8	16.63	38	63.79
3.6	1.2	2.23	9.8	16.82		
3.8	-	-	9.8	16.86		
4.0	1.3	2.31	9.8	17.46		
4.5	-	2.26	9.8	17.21		

show graphically

2.8 volts corresponds to the lower battery check position.

Low Level Monitor, type 2601

Variations in instrument reading with supply voltage were checked at exposure levels of $100\mu R.h^{-1}$, $0.5mR.h^{-1}$ and $5.0mR.h^{-1}$. Varying the voltage from the lower limit of the battery check (2.0 volts) up to the maximum battery voltage (3.0 volts) did not give any significant change in reading at these three radiation levels.

~~Harford CP~~
~~CP-251 Monitor~~

No tests were made on the instrument since three different battery types are used, i.e. 4 off 22.5V, 2 off 7.5V and 2 off 1.5V.

3.3 Temperature Tests

The instruments in turn were placed in a large environmental test chamber and irradiated under fixed geometry. The temperature was varied from room temperature ($\sim 20^{\circ}C$) up to approximately $+50^{\circ}C$, and then down to $-20^{\circ}C$, and next back up to room temperature, all in $10^{\circ}C$ steps. For these tests the instruments were either fitted with new batteries or a fixed external voltage supply was used instead of batteries. The following results were obtained: Column 1 - 0075 Neutron Monitor, source Am/Be, external 3V supply used; Column 2 - Low Level Monitor, type 2601, source ^{60}Co , two new batteries fitted; Column 3 - Snoopy Neutron Rem Counter, source Am/Be(α ,n), new batteries fitted.

*show in graph form
cut detail*

TYPE 0075		TYPE 2601		SNOOPY	
Temp. °C	Inst. Rdg. mRem.h ⁻¹	Temp. °C	Inst. Rdg. mR.h ⁻¹	Temp °C	Inst. Rdg. mRem/hr
+20	27	+20	5	+20	62
+30	27	+29	5	+28	70
+40	27	+34	5	+40	72
+50	26	+40	5	+50	72
+40	27	+50	5	+40	72
+30	27	+40	4.7	+30	72
+20	27	+30	4.7	+20	73
+ 9	28	+20	5.2	+10	75
0	27	+ 9	5.6	0	72
-10	18	+ 5	5.6	-10	72
-20	10	+ 1	5.3	-20	68
-10	16	- 5	5.4	-10	70
0	21	-10	5.3	0	72
+10	25	-15	4.9	+20	72
+20	27	-20	4.4		
		-22	4.4		
		-10	4.4		
		+ 6	4.5		
		+10	4.9		
		+22	4.7		

These results are shown in figure 6 where the relative response is plotted against temperature.

should
this
be
72?

Hanford CP
CP/TP/1A, on 0-50mR.h⁻¹ range, ⁶⁰Co source used, instrument switched on approximately 2 minutes before each reading and zeroed before taking reading

Temp. °C	Rdg. mR.h ⁻¹	Relative Response	Temp. °C	Rdg. mR.h ⁻¹	Relative Response
+19	22	1	0	23.5	1.068
+30	21	.95	-10	24.5	1.114
+40	20	.91	-20	27	1.227
+50	cannot read as zero drift cannot be compensated for		-10	25	1.136
+40	20	.91	0	24	1.091
+30	21	.95	+10	23.5	1.068
+20	22.5	1.023	+20	23	1.045
+10	23	1.045			

Plot as
Graph

NB: Considerable zero drift had to be corrected for.

These results are shown in figure 7.

3.4 Instrument Accuracy

This test is to check for any non linearities or range change errors in a properly calibrated instrument. The accuracy can be expressed as the ratio of the instrument reading to the calibrated radiation field.

Low Level Monitor, type 2601

Exposure Rate	Instrument Reading	Inst. Reading Exposure Rate
9.0 $\mu\text{R.h}^{-1}$	11 $\mu\text{R.h}^{-1}$	1.222
18.5	20	1.081
26.6	28	1.053
55.9	57	1.020
98.1	100	1.019
.123 mR.h^{-1}	.125 mR.h^{-1}	1.016
.213	.22	1.033
.473	.50	1.057
.938	.95	1.012
2.11	2.1	.995
4.75	4.8	1.012
8.9	8.5	.955
Mean accuracy = 1.040		

*Plot
as
graph*

These results are shown in figure 8.

0075 Neutron Monitor, source D/D 2.5MeV neutrons calibrated against "De Pangher" long counter

Calibrated DE Rate mRem/h	Inst. Reading mRem/h	Inst. Reading DE Rate
1.9	2.0	1.053
7.6	7	.921
11.3	10.7	.947
13.5	13.5	1.00
17.3	16	.925
32.5	28	.862
32.4	30	.926
50.2	47	.936
75.4	73	.968
112	98	.875
115	100	.870
163	150	.920
307	275	.896
620	520	.839
Mean ratio = .924		

*Plot as
graph*

Snoopy Neutron Rem Counter, source D/D 2.5MeV neutrons,
irradiated "end on", calibrated against
"De Pangher" long counter

Range	Calibrated DE Rate mRem/hr	Instrument Reading mRem/hr	Inst. Reading DE Rate
x1	1.09	.95	.868
	1.43	1.35	.944
	1.68	1.8	1.071
x10	4.68	4.5	.962
	12.59	11	.874
	15.94	13.8	.866
	20.63	19	.921
x100	32.1	25	1.080
	56.6	52	.919
	120	110	.917
	163	150	.920
	215	192	.893
x1000	651	630	.968
	902	900	.997
	1182	1130	.956
Mean accuracy = .944			

Graph

CP/TP/1A, source ^{226}Ra , instrument irradiated end on, side on

Range	Exposure Rate	Instrument Reading			Inst.Rdg. Cap On Exp.Rate	
		End On		Side On	End On	Side On
		Cap On	Cap Off			
0-50mR.h ⁻¹	8.9mR.h ⁻¹	9mR.h ⁻¹	10.8mR.h ⁻¹	9mR.h ⁻¹	1.011	1.011
	14.7	14.8	18	15	1.007	1.020
	20	20	24.5	20	1.000	1.000
	28.8	29	35	29	1.007	1.007
	45.1	45	>50	42	.998	.931
0-500mR.h ⁻¹	113	115	139	112	1.018	.991
	203	203	250	192	1.000	.946
	333	335	418	303	1.006	.910
	453	455	>500	400	1.004	.883
0-5R.h ⁻¹	.508R.h ⁻¹	.48R.h ⁻¹	.58R.h ⁻¹	.5R.h ⁻¹	.945	.984
	.902	.88	1.1	.8	.976	.887
	1.30	1.3	1.7	1.1	1.000	.846
	2.03	2.1	2.75	1.75	1.034	.862

The results for the End On, Cap On irradiations are shown in figure 10.

looks as if there were some scatter,
or, perhaps, secondary electrons.
If you are varying distance you might expect
this kind of thing to occur as you move

Graph

Both gamma instruments were checked for fall back effects in radiation fields exceeding the maximum designed exposure rate of each instrument.

The 2601 monitor was tested up to $1,500\text{R.h}^{-1}$, i.e. 150,000 times its full scale reading, and for exposure levels from 10mR.h^{-1} up to this level the meter needle remained at full scale deflection.

The CP/TP/1A was tested up to $1,500\text{R.h}^{-1}$, i.e. 300 times its full scale reading, and showed no signs of fall back.

The testing of neutron instruments in known neutron radiation fields, the levels of which greatly exceed the instrument's design range, is much more difficult due to the difficulties in producing such levels.

Both the 0075 and Snoopy were therefore only tested up to approximately 10Rems.h^{-1} at which level both instruments still had their meter needles at full scale. It should be noted however that, if an external scaler is being used with the 0075, then the appropriate $\text{c/s} / \text{mRem.h}^{-1}$ will be reduced by approximately 35%.

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infra

3.5 Design Features

Other aspects of the evaluation are less experimental and call for subjective views. Such aspects include design features but for simplicity these have been grouped together with comments on such features as instrument true constant.

The design features will all be dealt with in a brief report on each instrument.

Low Level Monitor, type 2601

The instrument is light and easy to handle, weighing approx. 4 lb. of which just over 6 oz. is accounted for by the two 1.5V batteries. The instrument is probably rainproof and should be easy to decontaminate; both batteries are checked by the battery check test. The batteries are easily replaced after removing the four handle retaining screws. Access to the three calibration and EHT variable resistors can be gained by removing a further four screws in the base, which allow the instrument's cover to be removed. This access would be improved by

the use of a small removable cover; this would be of little use to the user but would greatly ease the task of the calibrator. The instrument switch is clearly marked at both ends so that there can be no misunderstanding as to the mode of operation of the instrument, namely "Off", "Battery Check" and "On". Readings should not be taken for at least 10 secs when switching rapidly from "Off", through "Battery Check" to "On". If, however, the instrument is kept at the "Battery Check" position for about 5 secs it can then be switched to the "On" position and used immediately.

The meter needle fluctuations are significantly large particularly at the lowest exposure rate readings. On the instrument tested extreme readings in a constant radiation field were $8\mu\text{R.h}^{-1}$ and $20\mu\text{R.h}^{-1}$ for observations made over a 5 minute period, although the average fluctuations were somewhat less, approximately $\pm 4\mu\text{R.h}^{-1}$. It is perhaps worth noting that although steady meter readings are more desirable the high accuracy attached to such readings can in some cases be false, namely reproducibility should not be confused with accuracy.

The meter display is very clear and the markings are such that it would be difficult to misread the meter indication, apart from the part of the scale where $\mu\text{R.h}^{-1}$ and mR.h^{-1} join; there is also a mechanical zero adjustment to the meter.

The electronic components are clearly marked and the circuit diagram showing the calibration resistors is fixed to the inside of the instrument case. The main electronic board is held by captive screws and the battery compartment is marked to show which way to insert the batteries.

There were no noticeable capacitance effects when this was checked by pressing inwards on the sides of the instrument. No geometry effects were observed when using the instrument on its side.

The 0075 Neutron Monitor

Perhaps the chief advantage to the user of this instrument is its comparative light weight (14.5 lb.) compared with other rem counters which can weigh 30 lb.

The power supplies for the instrument are derived from two 1.5V batteries which can be easily replaced and properly checked by the battery test facility.

Dismantling the instrument is not particularly simple as it requires the removal of six screws but since the calibration resistor can be adjusted from outside and the batteries replaced without removal of the cover, this operation will occur rather infrequently. The two main electronic boards are bolted on and the components are clearly marked.

Scale markings are visually clear on the $3\frac{1}{2}$ decade quasi log scale although confusion may arise in reading the two markings between 1 and 2 mRem/hr, 10 and 20 mRem/hr, and 100 and 200 mRem.h⁻¹. The electronics section etc. is positioned relative to the detector in such a way that in normal use the worst directional response would be used although with a spherical detector any position would have occasioned some undesirable characteristic, such as difficulty in reading the meter.

The gamma discrimination was tested with ⁶⁰Co and ²²⁶Ra. With ⁶⁰Co no reading was obtained when tested up to approx. 4 R.h⁻¹; with ²²⁶Ra at approx. 7 R.h⁻¹ a reading of ~0.6 mRem.h⁻¹ was obtained.

An output socket is provided for negative pulses for a scaler so that the instrument can be read remotely.

There is a mechanical zero adjustment on the meter.

Davidson CP
The CP/TP/1A Survey Meter

This survey meter uses the same basic instrument with two interchangeable ionisation chambers. The Model ~~CP/TP/1A~~ has a cylindrical bakelite chamber of approximately 690cc volume. The inside walls of this chamber (⁴³⁰mg/cm² thick) are coated with graphite and an end cover can be removed leaving an end acetate window ²mg/cm² thick which is sufficiently thin to permit penetration of beta particles. Its normal operational ranges are 0-0.5, 0-5 and 0-50 R.h⁻¹.

no. Model CP/TP1B uses an aluminium walled ionisation chamber, volume 50cc, and will only respond to gamma radiation. Its three ranges are 0-50, 0-500 and 0-5,000 R.h⁻¹.

*NB
This
is
erroneous
in
part*

The instrument tested had neither of the above exposure ranges but had three linear exposure rat ranges of 0-50, 0-500 mR.h⁻¹ and 0-5 R.h⁻¹.

Good features of the instrument are the adjustment resistors, for each range, as well as a zero control. They are conveniently situated on the outside of the instrument's case; it would be well worth fitting protective covers over these to prevent meddling hands from altering the calibration. During the first few minutes after the instrument is switched on the zero drifts and it is therefore necessary whilst the instrument is warming up to reset the zero before taking each reading.

An undesirable feature is the lack of any battery test. This together with the fact that there is no check source provided could lead to dangerous consequences in the case of malfunctioning of the instrument. Battery replacement presents certain difficulties for users in the U.K. Two of the American battery types do have direct British equivalents, but the third American type, Burgess W5BP, of which there are two, does not. The user of this instrument will therefore be forced to modify his instrument to take a more readily available substitute 7½ volt battery. Fitting new batteries into the instrument is not an easy job and it is possible to short the meter terminals with the metal clad U₂ battery.

The instrument is light (6 lb.) and easy to manipulate by its pistol type grip handle. The ionisation chamber is not particularly robust and the existing method of end window fastening could well be improved.

~~Model No. DE Retrometer~~
Snoopy Neutron Rem Counter

"Snoopy" is a rugged rem counter having four linear ranges: 0-2, 0-20, 0-200 and 0-2000 mRem.h⁻¹. The instrument, detector plus electronics, is fairly heavy, ~21½ lb., although the detector weighing 1 lb. can be detached from the electronics and used up to 180cm away from the electronics. A strap can be fitted to the electronics for carrying this part on the body.

The batteries can be adequately checked whilst using the instrument on any of its four ranges and also whilst it is switched

Does this imply that all instruments should have check sources?

This is probably outside the purview of this report, and could be said for virtually any instrument

off by depressing the battery check/meter reset button located below the switch. This button also resets the meter to zero and it is advisable to do this before taking any readings as capacitance effects are occasionally observed when switching ranges on the instrument. Access to the batteries can be gained by undoing four screws in the base of the electronics box and removing a metal flap. A plastic tab can then be pulled to remove the three 1.5V batteries and this is clearly marked with the battery polarity position.

The two main electronics boards are firmly bolted in position and all the components and test points are clearly marked. A BNC output socket is provided for which negative pulses can be used to operate a scaler; this feature is useful for measuring integrated dose equivalent or for improving the accuracy of low dose rate measurements.

A mechanical adjustment is provided for setting the instrument zero reading.

Gamma discrimination was checked by first exposing the instrument to an Am/Be(α ,n) source for which a reading of 300 mRem/hr was obtained. Then whilst still exposing the instrument to this neutron source a 20 Ci ^{60}Co source was also brought into close proximity (exposure rate = 30 R.h^{-1}) and no variation in the neutron response was observed.

When the level of the gamma radiation was increased to 900 R.h^{-1} the response to neutrons fell from 300 mRem.h^{-1} to 200 mRem.h^{-1} .

~~3. THE BNW EVALUATION~~

4. THE BNW EVALUATION

Facilities and evaluation procedures at Battelle-Northwest have been elsewhere described in detail⁽⁸⁻¹⁰⁾ and only brief mention will be made of the more relevant procedures. Results are provided concisely in the form of four evaluation summaries below (4.5 - 4.8).

4.1. Energy Response Determinations

4.1.1. Photon Energy Dependence

The energy dependence of the two photon monitoring instruments was evaluated by comparison with U.S. National Bureau of Standards calibrated R-meters and other laboratory standards such as a free air ionization chamber. Photons with effective energies up to about 100 keV were produced by the wide beam K-fluorescence source of Larson et. al.^(11, 12), effective energies of 60, 78, 98, 120, 155, and 175 keV were produced from heavily filtered X-ray spectra with homogeneity coefficients approaching 1.0, and ^{137}Cs , ^{226}Ra + daughters, and ^{60}Co provided effective energies of 662, 842, and 1250 keV, respectively.

Exposure rates were determined at the geometric center of the detector; however, in all cases, the exposure rate gradient over the volume of the detector was small - less than $\pm 2\%$. Results are plotted in Figures 1 and 2.

4.1.2. Neutron Energy Dependence

Neutron energy response was only checked cursorily with spectra from $^{239}\text{PuF}_4$ ($E_{\text{av}} \sim 1$ MeV) and $^{239}\text{PuBe}$ (4.5 MeV); in both

cases the response was within $\pm 20\%$ of the expected response for each instrument. A more complete evaluation was not done because of the time requirement and the availability of published data for these types of detectors (3, 4, 13).

4.2. Linearity

System linearity was in all cases checked with an external source. Dose or exposure rates were varied by changing source to detector distance, with measurements being made in a semirandom sequence with respect to intensity.

4.3. Reproducibility

Reproducibility, or precision, was determined by placing the instrument in a constant field for one minute, taking a reading, and removing the instrument from the field for one minute before again placing the instrument in the radiation field. This was done a minimum of ten times.

4.4. Temperature Dependence

Temperature dependence was determined by placing the instruments in an environmental test chamber in a fixed irradiation geometry and allowing them to equilibrate for 30 minutes before a reading was made.

4.5. Summary of Evaluation: BNL Low Level Exposure Ratemeter

4.5.1. Physical Construction

In general, the design appears quite good, with smooth, rounded corners. Electronics assembly and layout excellent, design appears good. Does not appear to have good moisture resistance.

4.5.2. Human Factors

Very well designed. Light weight and well balanced and comfortable to hold. Design permits good access for ease and simplicity of maintenance; however, detector location not shown externally. Meter display excellent for logarithmic type. However, unit does not have meter reset capability, nor was location of detector marked on the exterior of the case.

4.5.3. Range

0.005-10 mR/hr in 3.5 decades (5-10 mR/hr, 10 mR/hr-0.1 mR/hr, 0.1-1.0 and 1.0-10 mR/hr).

4.5.4. Linearity (Tracking Error)

Checked only over upper 3 decades. Typically better than $\pm 5\%$, except at levels > 8 mR/hr. (Figure ____)

4.5.5. Reproducibility

Typically within $\pm 10\%$.

4.5.6. Sensitivity

$\leq 1\%$ of full decade reading.

4.5.7. Lower Detection Limit

20 μ R/hr readily detected above background of 20 μ R/hr.

4.5.8. Saturation

None noted at maximum level checked (10 R/hr or $10^3 \times$ upper detection limit).

4.5.9. Geotropism

Negligible.

4.5.10. Beta Response

$\frac{\text{Meter reading in mR/hr}}{\text{Mean } \beta \text{ dose rate}} = 0.01 \text{ (} ^{90}\text{Sr-}\gamma \text{)}$

4.5.11. Neutron Response

Essentially none to $\leq 10^3 \mu/\text{cm}^2/\text{sec}$

4.5.12. Switching Transients

None.

4.5.13. Energy Dependence

$\pm 10\%$, 40 keV - 1.25 MeV (Figure ____).

4.5.14. Temperature Dependence

$\leq 10\%$ change over range 10-140°F

4.5.15. Angular Dependence

$\pm 15\%$ @ 840 keV_{eff} (Figure ____).

4.6. Summary of Evaluation: Hanford CP H-4-2209

4.6.1. Physical Construction

In general, construction appeared satisfactory, except that crevices may serve as foci for contamination, and may also create water integrity problems. Electronic assembly is good, but circuitry is outdated.

4.6.2. Human Factors

In general, fairly well designed; however, instrument somewhat difficult to service, and shield over open window may be inconvenient. Instrument has good balance and convenient grip, but weight and size are greater than comparable units. Has externally accessible calibration pots.

4.6.3. Range

0-5 R/hr in three overlapping decade ranges (0-50, 0-500, 0-5000 mR/hr).

4.6.4. Linearity (Tracking Error)

Typically, $\pm 4\%$ f.s. on X1 range; $\leq \pm 1\%$ f.s. on other ranges. (Figure ____).

4.6.5. Reproducibility

Typically $\leq \pm 5\%$ of reading.

4.6.6. Sensitivity

$\sim 0.5\%$ f.s.

4.6.7. Lower Detection Limit

~ 1 mR/hr

4.6.8. Saturation

None noted at levels to 5 x maximum detection limit.

(Maximum checked.)

4.6.9. Geotropism

$\leq 5\%$ f.s.

4.6.10. Beta Response

$\frac{\text{Meter reading in mR/hr}}{\text{Mean } \beta \text{ dose rate in chamber}} = 0.34 \text{ } (^{90}\text{Sr-Y})$
 $= 0.17 \text{ } (^{147}\text{Pm})$

4.6.11. Neutron Response

None noted at levels to 2×10^3 n/cm²/sec ($^{239}\text{PuBe}$ spectrum)

(Maximum Checked)

4.6.12. Switching Transients

These between ranges; $< 10\%$ f.s. between "Zero" and "X1" positions.

4.6.13. Energy Dependence

$\pm 10\%$ from 30 - 1250 keV with window closed. (Figure ____)

4.6.14. Temperature Dependence

See attached curve.

4.6.15. Angular Dependence

$\pm 10\%$ at 840 keV_{eff}

4.7. Summary of Evaluation: BNL DE Neutron Meter B001

4.7.1. Physical Construction

Generally, a well constructed instrument. Circuitry appears modern, well laid out, and accurately done.

4.7.2. Human Factors

Although the instrument is heavy, it is well balanced and easy to use. Battery changes can be simply accomplished externally and the 210° logarithmic meter is relatively easy to read. There is, however, no meter reset capability, and the calibration pots and other circuitry are somewhat difficult to get at.

4.7.3. Range

0-1 rem/hr in quasilogarithmic meter (3.5 decades).

4.7.4. Linearity (Tracking Error)

Typically within $\pm 2\%$ over entire range. (Figure ____)

4.7.5. Reproducibility

$\pm 10\%$.

4.7.6. Sensitivity

$\sim 10\%$ of reading.

4.7.7. Lower Detection Limit

~ 0.5 mrem/hr.

4.7.8. Saturation

Not measured.

4.7.9. Geotropism

$< 5\%$

4.7.10. Photon Response

1 R/hr (^{226}Ra + daughters) gives response of ~ 0.5 mrem/hr.

Response linear to at least 10 R/hr.

4.7.11. Temperature Dependence

See attached graph.

4.7.12. Angular Dependence

$\leq \pm 15\%$

4.8. Summary of Evaluation: BNW Neutron DE Ratemeter

4.8.1. Physical Construction

Exceptionally well built; extra heavy gauge metal used. Electronics design, layout, and access very good. Waterproofing excellent.

4.8.2. Human Factors

Very heavy (24 pounds). Handles awkward, as is design to separate electronics package from detector. The time constant on the X1 range is excessively long (~ 30 seconds). Meter easy to read, calibration technique simple. Design facilitates electronic maintenance. Accessory recorder plugs a convenience, as is external calibration pot access.

4.8.3. Range

0-2 rem/hr in 4 ranges (0-2, 0-20, 0-200, 0-2000 mrem/hr).

4.8.4. Linearity

(Tracking error) $\leq \pm 10\%$ over entire range.

4.8.5. Reproducibility

$\pm 5\%$

4.8.6. Sensitivity

$\sim 0.5\%$ f.s.

4.8.7. Lower Detection Limit

Not checked; estimated at 0.1 mrem/hr.

4.8.8. Saturation

Not checked.

4.8.9. Geotropism

$\leq 0.5\%$ f.s.

4.8.10. Photon Response

None at maximum level checked (10 R/hr).

4.8.11. Temperature Dependence

$\sim 0.25\%/^{\circ}\text{F}$ over range 30-120°F.

4.8.12. Angular Dependence

$< \pm 15\%$

5. COMPARISON OF EVALUATION

5.1. Design and Human Factors Engineering

The portion of the evaluation is the least objective and it is therefore somewhat surprising that both laboratories reach essentially the same conclusions. In part, this may reflect a similarity in the backgrounds and personal preferences of the evaluators. For all four instruments each laboratory commented on a specific feature that the other did not.

5.2. Linearity (Tracking Error)

5.2.1. Exposure Ratemeters

The comparison of the linearity measurements for the exposure ratemeters (Figures 8 and 10) showed excellent agreement, reflecting in part the relatively good standardization of the roentgen and its measurement for photons in the region of 1 MeV. In addition, the instruments intercompared have relatively simple circuitry, which tends to minimize tracking error.

5.2.2. Neutron DE Meters

Linearity measurements made by BNL and BNW on the British neutron DE meter showed a rather considerable difference (Figure 9). The BNL data show a highly linear response, while the BNW data show an increasing under response with decreasing dose rate. For example, at a dose equivalent rate of 10 mRem.h^{-1} the Berkeley results are 58% higher, at 100 mRem.h^{-1} they are 30% higher, and at 300 mRem.h^{-1} they are 18% higher.

This variation may be explained by the different methods used to obtain the results. At Berkeley a fixed source to detector

distance was used for the 2.5 MeV accelerator produced neutrons. At Battelle a $^{239}\text{PuBe}$ source was used and the source to detector distance varied to give changes in the dose equivalent rate. This also "softened" the neutron energy spectrum somewhat primarily from air scattering and the apparent tracking errors were the result of the pronounced change in energy dependence of the British DE monitor in the 10 keV - 1 MeV region, where the maximum spectral enrichment would be expected. Linearity measurements on the American neutron DE meter did not reveal the same effect, probably due to its reduced energy dependence in this region.

5.3. Reproducibility

This evaluation was made only by BNW, and the results were not unexpected.

5.4. Sensitivity and Lower Detection Limit

Basically, good agreement was noted between the findings of the two laboratories, although methods and reporting techniques were dissimilar.

5.5. Saturation

The maximum level of exposure is generally determined by source availability and convenience of use as well as the use for which the instrument was intended. For example, in the case of the low level exposure ratemeter, which has a maximum full scale reading 10 mR/hr, the saturation characteristics in the kiloroentgen per hour range are not too meaningful when the use for which the instrument was designed is considered. Results obtained by both laboratories were in good agreement.

The testing of neutron instruments in neutron fields which greatly exceed the instrument design range is rendered difficult because of the problems inherent in producing and quantifying such levels. Therefore, only BNL was able to conveniently perform this evaluation.

5.6 Geotropism

Evaluation was performed by both laboratories, and results agreed well.

5.7 Beta Response of Exposure Rate Meters

Techniques, terminology and results of both laboratories varied considerably, and tended to underscore the lack of standardization with regard to external beta dosimetry. About the only area of agreement was the instrument used for standardization, viz., the extrapolation chamber.

Figure 5a shows the results of the Berkeley measurements for a $^{90}\text{Sr} + ^{90}\text{Y}$ source. The data show three ways of expressing the beta dose to the chamber. Since the depth of the Hanford instrument chamber is 16 cm, measurements close to a source could not be made. For $^{90}\text{Sr} + ^{90}\text{Y}$, the Battelle response, expressed in terms of the mean dose rate to the chamber, is 0.34 compared with approximately 0.9 for curve C of the Berkeley result. This very large difference will be investigated but the whole problem of beta dose evaluation is plagued by ambiguities over normalising results, determinations of the standard dose delivered to large size detectors, geometrical considerations as well as the units used.

5.8 Photon Response of Neutron Rate Meters

Both laboratories made this evaluation, and agreement was good.

5.9 Neutron Response of Exposure Rate Meters

(Apparently only done by BNW).

5.10 Energy Dependence

5.10.1 Exposure Rate Meters

Reference to Figures _____ will show apparent difference between the energy response curves obtained for the two instruments at the different laboratories. These differences can be at least partially attributable to the achievable accuracy of the standards used. As has been pointed out elsewhere, the uncertainty implicit in photon dosimetry are on the order of 5-10%⁽¹⁴⁾. Neither the U. S. National Bureau of Standards nor the U. K. National Physical Laboratory routinely achieve a systematic error or uncertainty (as distinct from precision) of less than 2% in the case of the former and 1% for the latter. Moreover, such accuracy is generally provided for only a limited range of photon spectra. Hence, the data generated by both laboratories are probably in reasonable agreement.

Other factors can also play a role. In the case of the Hanford CP, the method used to normalize the results contributed to the differences noted. The instrument was received at Berkeley after the energy determinations had been made at Battelle. Before and after the Berkeley measurements the range used, 0-500 mR/h⁻¹, was checked for linearity against ²²⁶Ra sources, the instrument being exposed end on with window closed. A linearity graph was drawn

and the instrument readings obtained during the other energy measurements were corrected from this graph. This corrected reading was then divided by the measured or calculated exposure rate to obtain the response, the curves in Figure 2a being drawn through the circle points. Now if instead of correcting the instrument reading as above the uncorrected values are used for the cap off results, the triangular points are obtained and these agree reasonably well with the Battelle results.

5.10.2 Neutron Rate Meters

The problems of accuracy are even greater with neutrons than with photons, and need no further comment. BNW performed no neutron energy dependence other than with two sources - $^{239}\text{PuBe}$ and $^{239}\text{PuF}_4$. BNL performed a more extensive evaluation of the energy response of this specific Anderson-Braun type instrument. The results, as shown in Figure ____, were in poor agreement with experimental data reported by Anderson and Braun⁽⁴⁾ and Block⁽¹³⁾.

5.11 Temperature Dependence

The results, as indicated in Figure ____, were in good agreement, with slight differences attributable to experimental error.

5.12 Angular Dependence

Some disagreement was noted in this area, primarily due to the method used for normalizing data.

6. DISCUSSION AND CONCLUSIONS

The intercomparison of instrument characteristics described in this report has shown that the techniques used by both laboratories give roughly the same results and lead to similar opinions. Not surprisingly the largest differences are to be found in the interpretation of beta dose measurements, and in the normalizing of data.

Linearity measurements on the neutron rate meters (Figure 9) clearly show the need to state explicitly the conditions under which the measurements and evaluations were made. Directional dependence of the instrument, its energy response as well as geometrical conditions, will all affect the results obtained.

7. EVALUATION PROGRAM

Unruh⁽⁹⁾ and Zuerner and Kathren⁽¹⁰⁾ have described an evaluation program for portable monitoring instruments which is outlined below.

TYPICAL EVALUATION AREAS FOR PORTABLE RADIATION SURVEY METERS

I. MECHANICAL

- A. Physical Construction
- + B. Shock and Moisture Resistance
- * C. Human Factors Engineering

II. ELECTRONIC

- A. Power Supply
 - 1. Stability
 - 2. Temperature Dependence
 - * 3. Battery Life

- B. Input Sensitivities
- C. Linearity
- D. Electromagnetic Interference
 - 1. Magnetic Fields
 - 2. AC Induced Fields and Transients
 - 3. Radio Frequency
 - 4. Electrostatic Fields
- + E. Switching Transients
- + F. Capacitance Effects
- + G. Geotropic Effects
- * H. Temperature Dependence
- + I. Extracameral Effects
- + J. Sound and Vibration Effects

III. RADIOLOGICAL

- * A. Range
- * B. Sensitivity and Detection Limit
- * C. Accuracy
- * D. Reproducibility
- * E. Saturation
- * F. Energy Dependence
- + G. Temperature and Pressure Dependence
- + H. Angular Dependence
- + I. Response to Unwanted Radiations

The "proof-of-the-pudding" tests are, of course, given in III, the so-called "radiological" tests. These, of course, will vary somewhat according to instrument type, but in the main are applicable to all. Items marked with an asterisk are considered essential, and these form the basic evaluation program. Items marked with a cross are highly desirable but of secondary importance in an evaluation program.

Although the intercomparison showed that, in general, the two laboratories chose the same items to evaluate, and, in general, obtained the same results, there is a need for uniformity, both in terminology and testing procedures. Standards agencies, both international and national are attempting to remedy this deficiency. This process, however, is slow, and perhaps should be supplemented and encouraged by expanded technical intercomparisons.

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Instrument Response

++++
oooo

AAA--

BWD results are end on

END ON

BACK ON

END 013

W 6A

--- CIP 200
 --- CIP 100
 + + + + + Berkeley results
 O O O O O Berkeley 1940

1.2

1.1

1.0

0.9

0.8

0.7

0.6

0 50 100 150 200 250 300 400 500 600 700 800 900 1000 1100 1200 1300

Gold Activity low -
 to be checked.

Photon Energy (kev)

Argon measured at
0.25 MV.

1.47
1.47
1.47

The line should go thru 0.25

Two data points each

1.47
1.47
1.47

Plot of $\log_{10} \frac{V_p}{V_{p0}}$ vs $\log_{10} \frac{V_p}{V_{p0}}$

Fig 4.

Neutron Energy response of Brooks on counter

Fig 5a

BETA RESPONSE HANFORD CP

H-4-2209

(EN) ON

 $^{90}\text{(Sr+Y)}$ source.

INSTRUMENT RESPONSE

distance (cm) } to centre of chamber for Curves B & C
 } to front face for curve A

0-500 MRH⁻¹ Range

INSTRUMENT RESPONSE

1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

+ + + + Tec 2 2000
 B513 (1.2) 90 (Sc+Y)
 □ □ □ □ Sic 2 "
 ○ ○ ○ Sic 1 "

distance (cm) to centre of chamber

0 10 20 30 40 50 60

Fig 6

Temperature dependence of ~~toxicity~~ ^{0.075 d-ration d-ration}

Fig 7 Temperature dependence of CP/TP/1 - Results

Fig 93

Fig 9.

LOG LOGARITHMIC
 46 7440
 MAX IN 0.1
 3 X 3 CYCLES
 KEUFTEL & ESSER CO.

Motor Power, Horsepower

Fig 10

10³

Linearity of γ detector CP 11-1-2009

O X1 Range
 X X10 Range
 A X100 Range

Extrapolated

Note: Red Line $\pm 10\%$ of Scale

O X1 Range
 X X10 Range
 A X100 Range

Extrapolated

EXPOSURE RATE, MC/HR

467400
 LOGARITHMIC
 5 X 3 CYCLES
 KEUFFEL & ESSER CO. TRUIS

METER READING, MC/HR

ENERGY DEPENDENCE OF HANFORD CP H-4-1109

o BLD ON, OPEN WINDOW
x BLD ON, CLOSED WINDOW

R. HANFORD
9/10

~~Figure 3~~ ANGULAR DEPENDENCE OF BNL

~~High Level Exposure~~

LOW LEVEL EXPOSURE METER

R. L. K. 11/8/70