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DRDC Ottawa Participation in the SILENE Accident Dosimetry Intercomparison Exercise

June 10-21, 2002

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Abstract

DRDC Ottawa (and formerly as DREO) has participated in two NATO-sponsored and one TTCP-sponsored dosimetry intercomparisons. The SILENE International Accident Dosimetry Intercomparison Exercise at Valduc, France in June 2002 coincided with DRDC Ottawa work designed to refine its proposed criticality dosimetry system (consisting of Rh foils for neutron dosimetry and the combination of CaF_2:Mn and Al_2O_3 TLDs for gamma-ray dosimetry). In addition, DRDC Ottawa has recently substantially expanded its efforts in radiation dosimetry – and this intercomparison offered a unique opportunity to showcase and quantify these new capabilities.

The results presented herein conclusively show DRDC Ottawa's capabilities to measure accurately criticality fields.

In particular the neutron dosimetric work produced near real-time results – consistent with the target doses. The Rh foils clearly demonstrated their arguably most important feature – near invariability of response for all conceivable fission-like spectra. The gamma-ray dosimeters also showed their efficacy.

The SILENE International Accident Dosimetry Intercomparison Exercise at Valduc, France in June 2002 was implemented to test the international biodosimetry programs. DRDC Ottawa as well as several other countries participated in the international biodosimetry intercomparison. DRDC Ottawa used a Health Canada generated ^{137}Cs dose response curve to convert aberration frequencies into dose estimates.

Résumé

RDDC Ottawa (anciennement CRDO) a participé à trois exercices de comparaison corrélative: 2 organisés par l'OTAN, et un par le Programme technique de coopération (TTCP). L'exercice international de comparaison corrélative de dosimétrie d'accident à SILENE, Valduc, France, en juin 2002 coincidait avec le travail effectué à RDDC Ottawa afin de raffiner son système de dosimétrie de criticalité (des feuillets Rh pour la dosimétrie des neutrons, et une combinaison des dosimètres thermoluminescents CaF_2:Mn et Al_2O_3:C pour la dosimétrie des rayons gamma). De plus, RDDC Ottawa a récemment augmenté considérablement ses efforts en dosimétrie des rayonnements – et cette comparaison présentait une occasion unique de mettre en évidence et de quantifier ces nouvelles capacités.

Les résultats présentés démontrent de façon concluante les capacités de RDDC Ottawa à mesurer avec précision les champs de criticité.

Notamment, le travail de dosimétrie de neutron a produit des résultats proches du temps réel – en harmonie avec les doses ciblées. Les feuillets Rh ont démontré clairement leur caractéristique la plus importante – la quasi-invariabilité de leur réponse à tous les spectres concevables de fission. Les dosimètres gamma ont également démontré leur efficacité.

L'exercice international de comparaison corrélative de dosimétrie d'accident à SILENE, Valduc a aussi été mis en oeuvre afin de vérifier les programmes international de biodosimétrie. RDDC Ottawa ainsi que plusieurs autres pays ont participé à l'intercomparaison internationale de biodosimétrie. RDDC Ottawa a utilisé une courbe de réponse établie par Santé Canada avec une source de 137Cs pour convertir la fréquence d'aberrations en estimations de dose.

Executive summary

DRDC Ottawa participated in the International Accident Dosimetry Intercomparison Exercise at SILENE, Valduc, France in June 2002. The lab fielded neutron gamma-ray and biological dosimetry systems and their performance against many of the world's civilian radiological establishments was examined.

To summarise, DRDC Ottawa performed exceptionally well with all dosimeter types. It was one of the few laboratories capable of providing physical dosimetry data on-site (although this is clearly a necessity for criticality systems). These on-site results were well within errors of the target doses, and agreed with the results from other participating, world-renowned labs. Retrospective biological dosimetry estimates also closely correlated with the doses delivered. Human blood samples were irradiated in vitro and chromosomal aberration frequencies and pre-existing dose response curves were used to estimate the actual doses delivered. The results from physical and biological dosimetry clearly show that DRDC Ottawa, long held as paramount among military dosimetry labs, has now expanded its reputation to the world stage.

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RDDC Ottawa a participé à l'exercice international de comparaison corrélative de dosimétrie d'accident à SILENE, Valduc, France, en juin 2002. Le laboratoire a testé des dosimètres de neutrons et de gamma, ainsi qu'un système de dosimétrie biologique, et leur performance a été comparée à plusieurs établissements radiologiques internationaux civils de première classe.

En résumé, tous les dosimètres de RDDC Ottawa se sont acquittés de façon exceptionnelle. DRDC Ottawa a été un des rares laboratoires capables de fournir les données de dosimétrie physique sur place (ceci est clairement une nécessité en cas de criticalité). Les résultats étaient dans les limites d'erreur des doses visées, et concordaient avec les résultats des autres laboratoires présents. Les données de dosimétrie biologique, obtenus à partir d'échantillons envoyés à nos laboratoires, concordaient de près aux doses livrées. Les échantillons de sang avaient été irradiés *in vitro*, et la fréquence des aberrations chromosomales et les courbes de réponse préétablies ont été utilisées afin d'estimer les doses livrées.

Les résultats de dosimétries physique et biologique démontrent clairement que RDDC Ottawa, longtemps reconnu comme compétence suprême parmi les laboratoires militaires de dosimétrie, a maintenant étendu sa réputation sur l'échiquier mondial.

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1. Background

DRDC Ottawa (and in its former life as DREO) is recognized as a NATO and TTCP leader in radiation dosimetry and spectroscopy. This position has been verified through the laboratory's development of and participation in three international military dosimetry intercomparison exercises – at US Army Aberdeen Proving Ground in 1986 and 1992 and at DEP, ETBS, Bourges, France in 1999. The first two examined nuclear battlefield dosimeters while the last concentrated on the so-called "Low-level" radiation threat – reflecting the new military acquiescence to the vital application of ALARA (As Low as Reasonably Achievable) in the modern reality.

One can note from above that the gap between military and civilian radiation dosimetry – once a yawning gulf – has now dwindled to insignificance. The goals, actions and even equipment used are virtually identical. This has never been so clear as in combined military and civilian efforts on countering radiation terrorism.

Two obvious radiological scenarios attractive to a terrorist are sabotage of a nuclear reactor and construction/detonation of an improvised nuclear device. Both could involve near-simultaneous irradiation of personnel with neutrons and gamma rays – most likely in very fast pulses. Such scenarios are often dubbed as "critical" in the nuclear community – referring to the configuration of the fissile material, and not necessarily the consequences. The terms "criticality dosimetry" and "accident dosimetry" are often used interchangeably.

DRDC Ottawa has been assessing the capabilities of its own criticality dosimetry system over the past few months – with experiments at US Army Aberdeen Proving Ground, US Army White Sands Missile Range and WIS, Germany. Results of these will be reported in a future DRDC report. However the announcement of the Accident Dosimetry Intercomparison at SILENE, France offered an irresistible opportunity. Not only could DRDC Ottawa's system be used in extremely well calibrated fields, but it could be compared against the best such systems that other countries could offer

In addition, DRDC Ottawa's Radiation Effects Group has been augmented over the past year with radiation biology expertise from Health Canada. The SILENE intercomparison also presented an opportunity to evaluate our new capabilities to deploy biological dosimeters in these calibrated fields. (DRDC Ottawa/HC performed similar work at the WIS, Germany facility earlier this year). Accordingly, DRDC Ottawa participated in the intercomparison using both physical and biological dosimeters, and the results are delineated herein.

2. Experiments and Equipment

2.1 The SILENE Facility

The SILENE experimental reactor is a part of the French Commissariat à l'énergie atomique (CEA) facility at Valduc. The reactor is unique in that it has a liquid (uranyl nitrate) core – with power controlled via withdrawal from the core of a control rod. The advantage of using a liquid core is that it mitigates the chances of any local environmental perturbation causing localized melting.

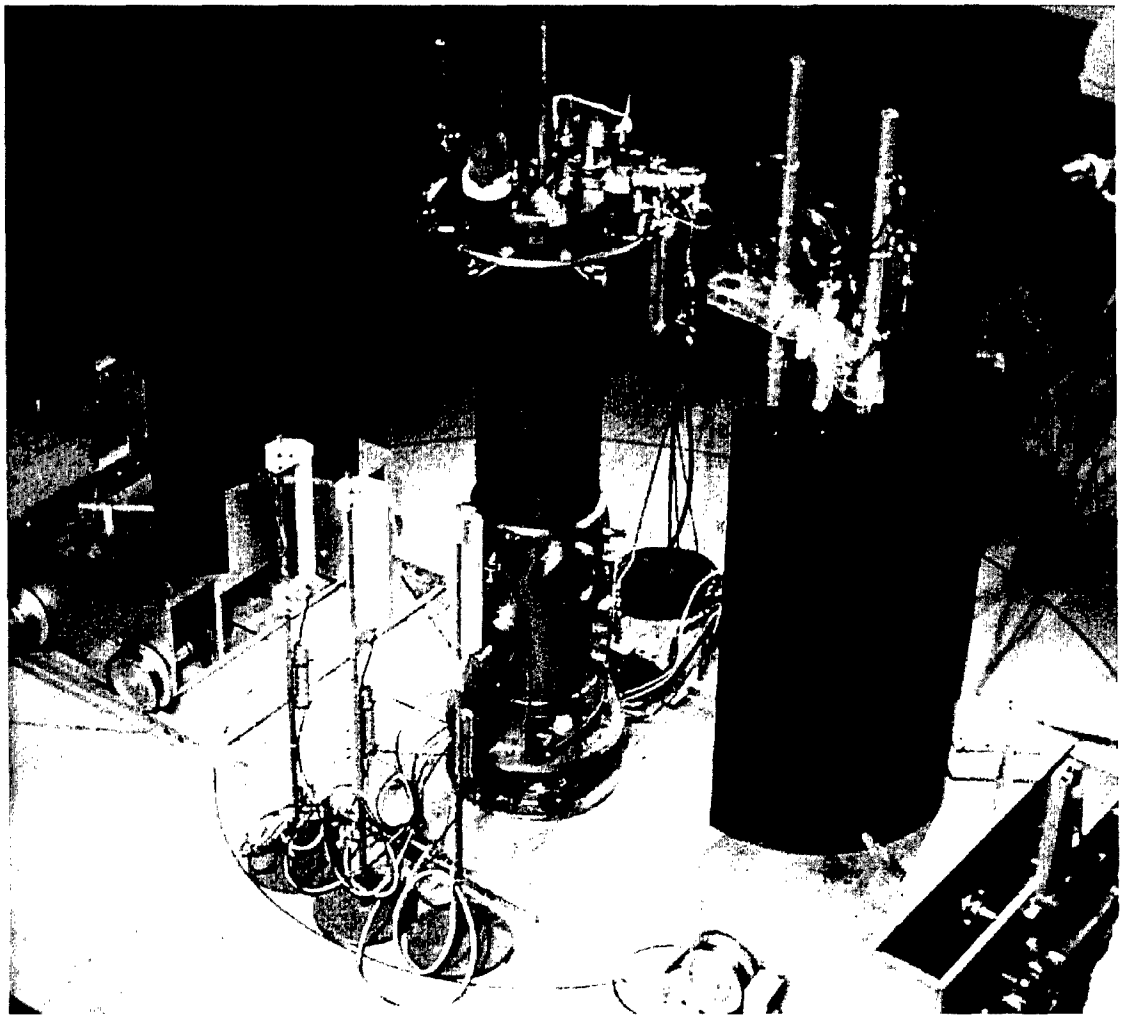

Figure 1. *Silene Reactor*

The facility may be operated in any of three modes:

a. Pulse Mode: a brief high-power excursion for a few ms, induced by rapid ejection of the control rod.

b. Free Evolution Mode: divergence here is typical of a criticality accident, achieved by slow withdrawal of the control rod. (Typically a few minutes long)

c. Steady State Mode: Power Stabilized at a pre-determined level by operation of a control rod. (Typically many minutes or hours long)

The shielding around the reactor may be configured to give various neutron-to-gamma ray ratios as required. The versatility of the reactor is such that doses of up to a few Gray may be obtained at reasonable distances in a few minutes, or – conversely – extremely low dose rates (few microGray/h) may be delivered.

2.2 Specific Radiation Scenarios For This Work

For the 2002 Intercomparison, the following four scenarios (three at SILENE) were decided upon.

Table 1. *Scenarios for SILENE Intercomparison*

Type of Scenario	***Desired Total Dose at 4 m***	***Maximum Dose Rate***	***Type of Irradiation***	***Operating mode***
1. Criticality Accident	4 Gy in < 3 min	4 Gy/s	Mixed (γ/n = 1.2)	Free evolution Bare source
2. Criticality Accident	2 Gy in < 3 min	2 Gy/s	Neutron (γ/n = 0.2)	Free evolution Lead shielded source
3. Reactor in Operation	1 Gy in ~30 min	0.004 Gy/s	Neutron (γ/n = 0.2)	Steady state mode Lead shielded source
4. Shutdown Reactor	1 Gy in ~30 min	1 - 5 Gy/h	Pure γ (^{60}Co)	Gamma Source, **NOT** the SILENE Reactor

A total 23 experimental groups from 15 countries were on site to take part in the intercomparison. Dosimeters from other laboratories that had chosen not to be at Valduc for the exercise had been previously received and were returned after the exercise to each respective laboratory for measurement. The phantoms were ovoid cylinders 20x30 cm by 80 cm tall, on stands placed 4 metres from the centre of the reactor. DRDC Ottawa did not participate in scenario #4.

2.3 DRDC Ottawa Physical Criticality Dosimetry Systems

2.3.1 Neutron Dosimetry

Neutron dosimetry is perhaps the most vexing of all radiation metrological activities. The combination of the indirectly ionizing nature of neutron interactions with matter and the widely varying reaction cross sections (with neutron energy) of many materials have been key factors in limiting the accuracy generally achievable. For criticality dosimetry, the problems are exacerbated by the high dose rates associated with most scenarios – mitigating the use of any real-time electronic dosimeter.

Foils have long been proposed and used for criticality dosimetry (as well as for general monitoring of neutron fields). DRDC Ottawa is in the process of finalizing a comprehensive study on the use of Rhodium foils as criticality dosimeters. Such foils employ the $^{103}Rh(n.n')^{103}Rh$ reaction – producing 20 keV x-rays with a 56 minute half-life. These foils have the following advantages:

a. Nearly energy-independent cross-section when compared to neutron kerma – as shown in Figure 2.

b. Reasonable half-life (about 1 hour) for most scenarios where doses must be measured accurately and quickly. (i.e. Rh foils produce more reaction products in a shorter period of time compared to longer half-life Foils with similar cross sections).

c. Ease of data acquisition analysis. The automated acquisition analysis system that was the prototype of the Microspec suite developed by DRDC Ottawa is shown in Figure 3. It consists of a thin (1/4" x 2" diameter) NaI(Tl) with a thin Be window ideally suited to the measurement of photons in the 10 – 100 keV range.

The data analysis system allows automated conversion of the number of 20 keV photons detected into neutron kerma, fluence or dose equivalent – requiring only knowledge of the incident energy spectrum to increase accuracy.

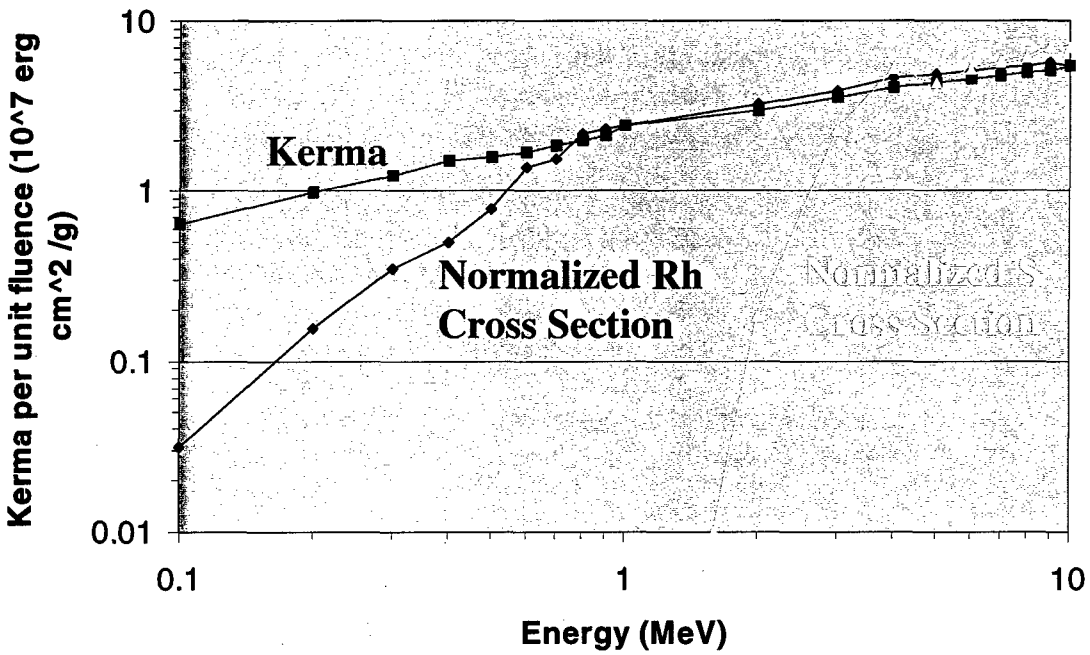

Figure 2. *Rhodium & Sulphur Energy Cross-Sections compared to Tissue Kerma. Sulphur activation is used by many reactor facilities such as US APG and WSMR. The lower threshold of Rh means that it is much more sensitive to changes (usually softening) in neutron spectra.*

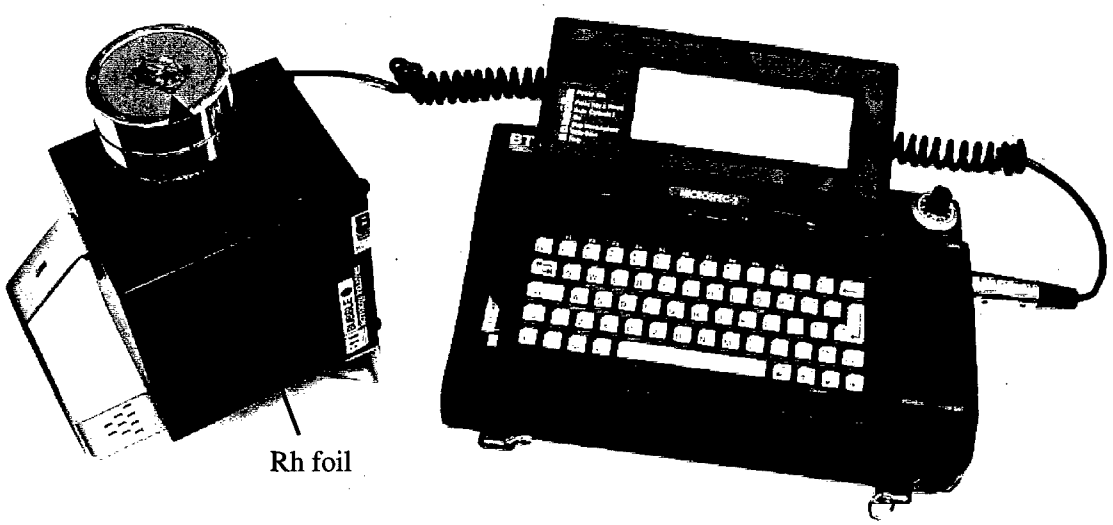

Figure 3. *MicroSpec Rhodium Foil Data Acquisition/Analysis System*

2.3.2 Gamma-ray Dosimetry

DRDC Ottawa offers a number (over five) of various thermoluminescence dosimetry (TLD) systems. The choice of any particular TLD depends upon mission details.

For this work, the necessity of neutron-insensitivity pointed to the use of either Al_2O_3:C or CaF_2:Mn TLDs. Normally, DRDC Ottawa would prescribe Al_2O_3:C for doses below about 100 Rad and CaF_2:Mn for doses above 10 Rad. Since the gamma-ray kermas anticipated here span these ranges, it was decided to deploy both.

DRDC Ottawa's TLD systems offer the following advantages over many others.

a. Individual calibration. The batch mode of TLD calibration by its very definition leads to increased errors owing to individual variations of TLD sensitivity.

b. Energy dependence. Wrapping of the TLDs in thin tin (approximately 0.018") flattens their over-response at low energies as in Figure 4 and Figure 5.

c. Linearity. Figure 6 shows the measured response of CaF_2:Mn and Al_20_3:C over the dose ranges required here.

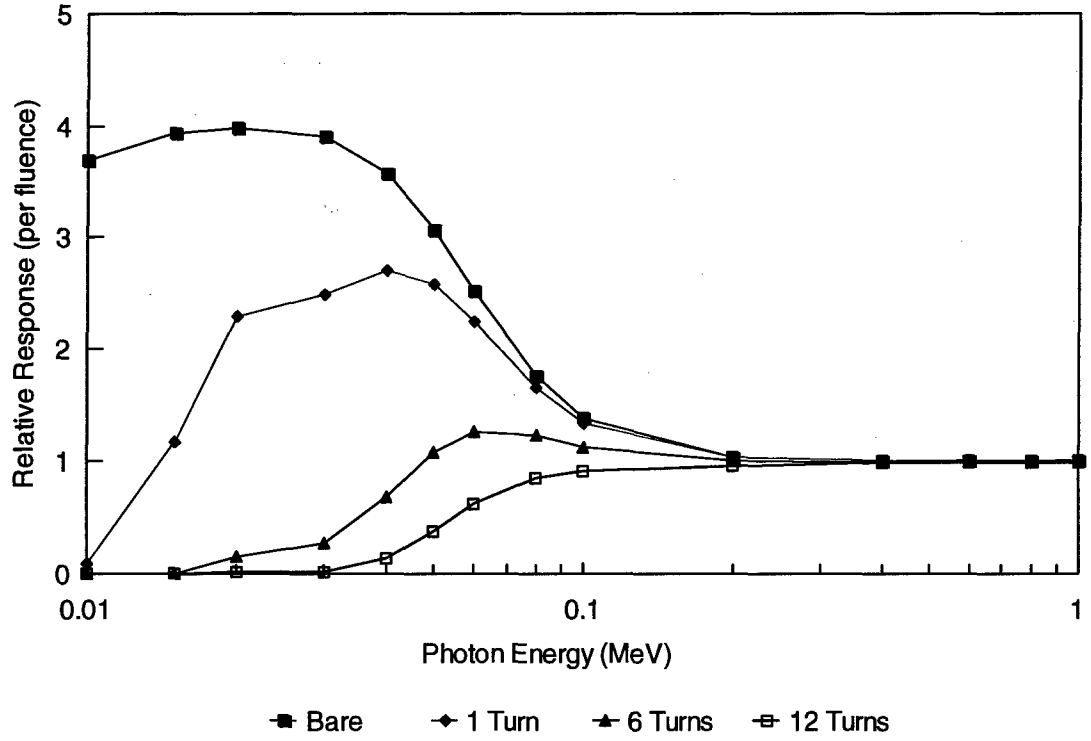

Figure 4. *Measured Al_2O_3 Energy Response With Tin Wrapping (Note that one "turn" of tin is equal to 0.0015")*

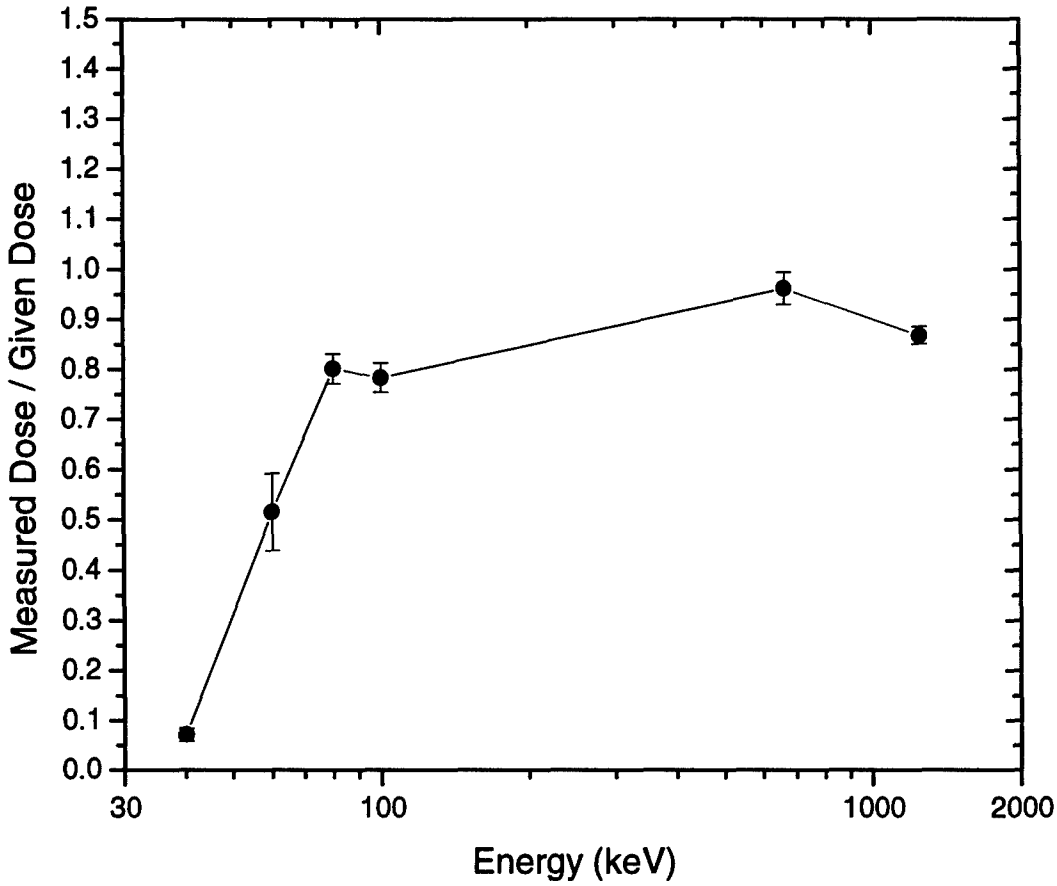

Figure 5. *Measured Al_2O_3 Energy Response*

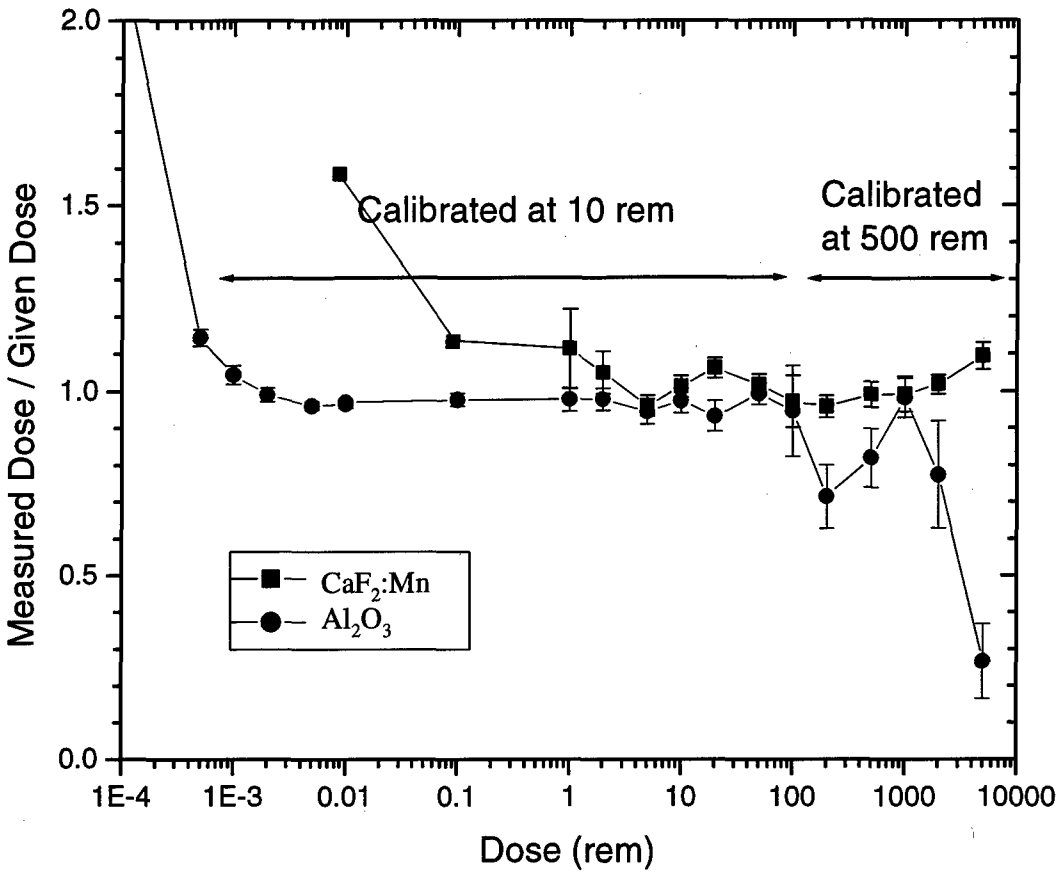

Figure 6. *Measured TLD Dose-Linearity Response*

2.3.3 Biological Dosimetry

Wide usage of radioactive sources for medical, industrial, agricultural, research and military purposes increases the risk of overexposure of radiation workers, and members of the military and general public. When individuals are accidentally or belligerently exposed to ionizing radiations, follow-up investigations may include dose assessment by cytogenetics. Scoring (physically counting) of chromosome aberrations (damaged genetic material) in peripheral blood lymphocytes is presently accepted as the most specific method for estimating the exposure dose. The dicentric assay has been used for estimating radiation doses in hundreds of suspected or verified overexposure over the past 40 years. It has been accepted as the International Standard for biological dosimetry providing a very important input into the compendia of information needed for assessment of radiological accidents.

Many studies have demonstrated a good correlation between the results obtained *in vivo* and *in vitro*, so that *in vitro* established dose-effect relationships from irradiated blood samples can be used as calibration curves for accidental exposures. DRDC Ottawa as well as several other ISO member states (ISO TC85/SC2 WG18) participated in this exercise. *In vitro* irradiated blood samples, cultured for chromosomal aberrations, were distributed to participants for analysis and dose estimates.

3. Results

3.1 Physical Dosimetry

3.1.1 Neutron Dosimetry

Table 2 gives the initial results from DRDC Ottawa's neutron dosimetry system, calculated on-site at SILENE – within minutes of radiation exposure. In this table, the neutron energy spectrum from US Aberdeen Pulse Reactor Facility was used as input (this spectrum is resident in the analysis software). It was anticipated that the APRF spectrum should be similar enough to SILENE (Watt-like above about an MeV, with significant down scatter contributions below this) that these values should be extremely close to reality. As mentioned previously, this is the beauty of using Rh foils.

The activation C (counts/min/g) produced by a 1-rad neutron kerma at the end of an irradiation that is short compared to the half-life of the activity produced is:

$$C = \varepsilon \times \frac{0.602}{A} \times \frac{\sigma}{\kappa} \times \frac{0.693}{T_{1/2}}$$

where

ε is the detection efficiency (counts/disintegration),

A is the atomic weight,

$\frac{\sigma}{\kappa}$ is the ratio of the of the cross section (barn) to the dose or kerma (rads per neutron/cm^2) either at a particular energy or averaged over the neutron spectrum,

and

$T_{1/2}$ is the half-life (min).

This formula would apply to scenarios 1 and 2, Table 2. For scenario 3, the above equation must be modified via consideration of buildup (1-

exp(-.693*t/$T_{1/2}$)) and decay (exp(-.693*t/$T_{1/2}$)) during irradiation using standard techniques.

Table 2. *Measured Neutron Kerma Using APRF Input Spectrum*

Run # (scenario/date)	***Measured Kerma Free-in-air (Rads) (3)***	***Measured Kerma Font of Phantom (Rads)***	***Measured Kerma Back of Phantom (Rads)***	***Target Free-in-Air Kerma (Rads) (1,4)***
1 (Criticality Accident/June 12)	178 ± 5	176 ± 14	22 ± 6	182
2 (Criticality Accident/ June 19)	177 ± 7	182 ± 1	17 ± 1	167
3 (Reactor in Operation/ June 18)	80 ± 7	71 ± 10	4.7 ± 0.1	84

Notes :

1. At the time of writing there was no official data from SILENE dosimetry
2. Preliminary comparisons with other groups look favourable, as does the comparison with the anticipated dose
3. Means and Standard deviations here are simply ascertained by examination of Rh foil-measured kerma. Two foils were used at each position, and sometimes multiple (time-spaced) readings were made for any one particular foil. Even using an acknowledged incorrect spectrum (although felt to be a reasonable approximation) the free-field kermas differ from those anticipated by only 2%, 6% and 5% for the three runs, respectively.
4. The "target" Kerma comes from Table 1.

Following return to DRDC Ottawa, an attempt was made to modify the analysis software specifically for SILENE. In order to do this, published neutron spectra of SILENE (appearing in Figure 7) at 3 and 6 m were used to parameterize the software.

Clearly the spectral shapes are extremely similar above about 50 keV. Thus the Rh foils will exhibit only minor sensitivity to the use of any of the three as an input parameter. As most of the kerma is from neutrons having energies above the Rh threshold, one may expect that the APRF results would be good. This is borne out below.

The actual experiments took place @ 4 m from the core, and no data at this position was available. So the kermas were re-evaluated using both the 3 m and 6 m spectra as input, yielding the values in Table 3. Here the tabulated values are the arithmetic mean of the two evaluated kerma values. The measured values at 6m are about 10% higher than at 3 m.

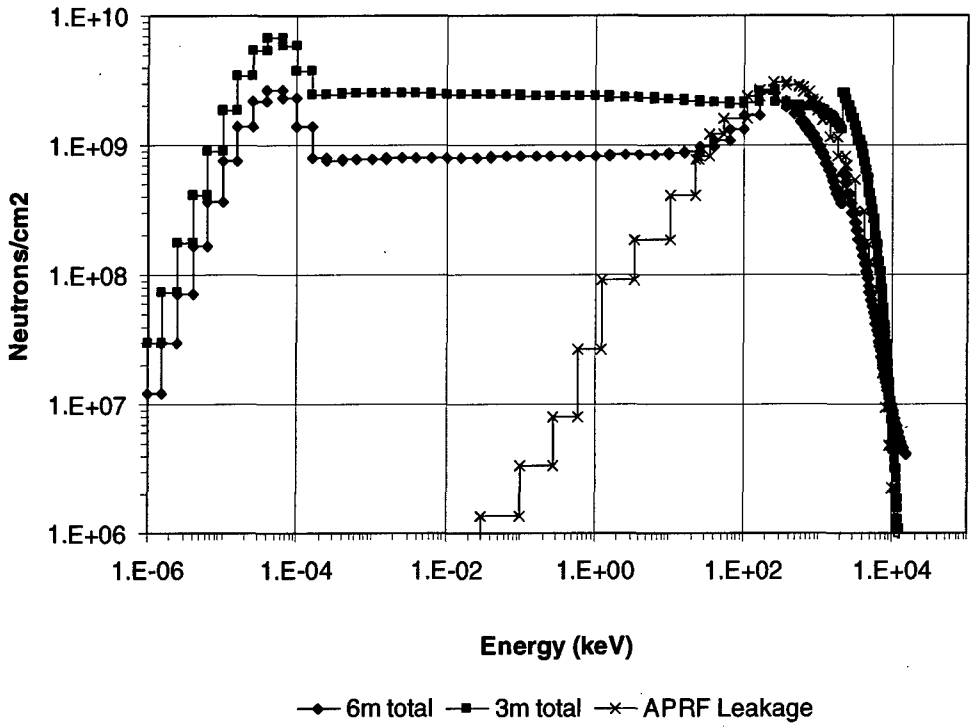

Figure 7. *Silene 3m and 6m and APRF Leakage Spectra. Note that above about 50 keV the shapes are nearly identical.*

Table 3. *Measured Neutron Kerma Using SILENE Input Spectrum*

Run # (scenario/date)	***Measured Kerma Free-in-air (Rads)***	***Measured Kerma Font of Phantom (Rads)***	***Measured Kerma Back of Phantom (Rads)***	***Target Free-in-Air Kerma (Rads)***
1 (Criticality Accident/June 12)	183	172	23.4	182
2 (Criticality Accident/ June 19)	170	185	22.5	167
3 (Reactor in Operation/ June 18)	79	77	7.5	84

The mean of the 3m and 6 m measured kermas differ from the anticipated by 1%, 2% and 6% for the three cases respectively. It will indeed be interesting to compare when final dosimetry is obtained from SILENE.

The values in Table 3, with an associated error of around 10 % constitute the official DRDC Ottawa values for the SILENE intercomparison. This uncertainty is derived from errors associated with counting statistics, peak fitting and tabulated cross sections.

3.1.2 Gamma-ray Dosimetry

The measured gamma-ray kermas for each TLD type yielded results in Table 4 and Table 5. Here again, as for the Rh foils, results were produced on-site within minutes of exposure. It must be noted that DRDC Ottawa was one of the few groups to attain this goal.

Table 4. *CaF_2:Mn TLDs Gamma Ray Results*

Run # (scenario/date)	***Measured Kerma Free-in-air (Rads)***	***Measured Kerma Font of Phantom (Rads)***	***Measured Kerma Back of Phantom (Rads)***	***Target Free-in-Air Kerma (Rads)***
1 (Criticality Accident/June 12)	241 ± 9	301 ± 37	140 ± 7	218
2 (Criticality Accident/ June 19)	41 ± 0.3	80 ± 1	46 ± 0.3	32
3 (Reactor in Operation/ June 18)	22 ± 1	39 ± 1	22 ± 1	16

Table 5. *Al_2O_3:C TLDs Gamma Ray Results*

Run # (scenario/date)	***Measured Kerma Free-in-air (Rads)***	***Measured Kerma Font of Phantom (Rads)***	***Measured Kerma Back of Phantom (Rads)***	***Target Free-in-Air Kerma (Rads)***
1 (Criticality Accident/June 12)	259 ± 53	281 ± 13	151 ± 1	218
2 (Criticality Accident/ June 19)	45 ± 5	77 ± 5	55 ± 4	32
3 (Reactor in Operation/ June 18)	27 ± 1	50 ± 3	26 ± 1	16

The uncertainties here represent deviations from the mean of two TLDs of each type at each position.

Table 6 gives ratios of the measured CaF_2:Mn results to those from Al_2O_3:C.

Table 6. Ratios of Measured TLD Kermas			
Run # (scenario/date)	***Ratio of CaF_2:Mn/Al_2O_3:C Free-field***	***Ratio of CaF_2:Mn/Al_2O_3:C Front of Phantom***	***Ratio of CaF2:Mn/Al203:C Back of Phantom***
1 (Criticality Accident/June 12)	0.93	1.07	0.93
2 (Criticality Accident/ June 19)	0.91	1.04	0.84
3 (Reactor in Operation/ June 18)	0.81	0.78	0.85

The ratios are generally within the range of what one would expect from employing TLDs with a (DRDC Ottawa quoted) error of ± 5%. However, there are some – especially for scenario #3 – in which there is clearly a bias. Upon receipt of SILENE results, this may be examined further.

These values are presented as ratios to the free-field targets, as in Table 7 below.

Table 7. Ratios of Measured Free-field Targets		
Run # (scenario/date)	***Ratio of Measured Al_2O_3 Results to "Target" Value***	***Ratio of Measured CaF_2:Mn Results to "Target" Value***
1 (Criticality Accident/June 12)	1.19 ± .24	1.11 ± .04
2 (Criticality Accident/ June 19)	1.40 ± .16	1.28 ± .01
3 (Reactor in Operation/ June 18)	1.69 ± .06	1.38 ± .06

In all cases, both TLDs indicate more dose than that targeted. It will be interesting to see if this is a real effect of scatter when the final SILENE results roll in. For now, the best TLD results for DRDC Ottawa are listed below in Table 8 as the mean of the two TLDs, with the errors either being 10 % or the arithmetic mean of the two values, whichever is greater.

Table 8. DRDC Ottawa Measured TLD Kermas			
Run # (scenario/date)	***DRDC Ottawa Measured TLD Kerma***		
	Free-in-Air (Rads)	***Front of Phantom (Rads)***	***Back of Phantom (Rads)***
1 (Criticality Accident/June 12)	250 +/- 50	291 +/- 32	146 +/- 15
2 (Criticality Accident/ June 19)	43+/- 5	79 +/- 8	51 +/- 5
3 (Reactor in Operation/ June 18)	25 +/- 3	44 +/- 7	25 +/- 4

Again, the SILENE results here will be interesting.

3.2 Biological Dosimetry

The expected background of chromosomal aberrations in a normal (unexposed population) is generally accepted to be in the order of 1 dicentric per 1000 metaphase spreads scored. For practical purposes, 1000 chromosomal spreads are scored allowing detection of doses as low as 0.10 to 0.15 Gy. Theoretically, it is possible to detect doses lower than this, but because of statistical power the number of chromosome spreads that need to be scored becomes too large making this very low dose detection impractical. However, this threshold of detection at 0.10 to 0.15 Gy is sufficient under most circumstances.

DRDC Ottawa analyzed the samples received from the SILENE intercomparison exercise and used a Health Canada generated ^{137}Cs dose response curve to convert aberration frequencies into dose estimates. The protocols followed were in compliance with the IAEA recommendations (ref 1). For practical purposes, the accepted recommendation was that the number of scored metaphases for each sample should be 500 or 100 observed dicentrics. This data is presented in Table 9.

Table 9. *DRDC Ottawa Measured Biological Dosimetry*

	Dose	Total # cells scored	Normal	Dicentrics + Rings	Aberrations per cell	0 Dicentric	1 Dicentric	2 Dicentrics	3 Dicentrics	4 Dicentrics	Estimated Dose (Gy) based on ^{137}Cs $y=0.0021+0.039+0.0733\,x^2$	95% confidence limits (Gy)	
												Lower	Upper
Control	1 Gy γ	251	247	1	0.00	247	1	0	0	0	0.1		
	1 Gy η	500	491	1	0.00	491	1	0	0	0	0.0		
	2 Gy η	500	497	1	0.00	497	1	0	0	0	0.0		
	4 Gy mixed	500	492	0	0.00	492	0	0	0	0	0.0		
Irradiated	1 Gy γ	430	276	110	0.26	276	89	9	0	0	1.6	1.4	1.8
	1 Gy η	175	58	132	0.75	58	80	20	4	0	2.9	2.6	3.3
	2 Gy η	92	13	119	1.29	13	43	21	10	1	3.9	3.5	4.5
	4 Gy mixed	111	6	129	1.16	6	57	21	10	0	3.7	3.3	4.2

Table 10 below compares the estimated dose from biological dosimetry to the total kerma from DRDC Ottawa's physical dosimetry.

Table 10. *Comparison of Biological Dosimetry to DRDC Ottawa's Kerma*				
Run # (scenario/date)	***Neutron Kerma (Rads)***	***Gamma-ray Kerma (Rads)***	***Total Kerma (Rads)***	***Biodosimetry (Rems)***
1 (Criticality Accident/June 12)	183	250	433	290 ± 40
2 (Criticality Accident/ June 19)	170	43	213	390 ± 60
3 (Reactor in Operation/ June 18)	79	25	104	370 ± 50

As one can see, while the biodosimetry yielded reasonable approximations to the measured values, there are significant differences. For run number 2 and 3 perhaps they can be explained by assigning quality factors to the neutrons.

However, this only makes sense for runs 2 and 3 where the neutron quality factors would be about 2 and 4 respectively. Run number 1 is not explainable by this method.

It will be interesting to compare these results to biological dosimetry from other labs.

4. References

1. IAEA:2001, Cytogenetic Analysis for Radiation Dose Assessment, A Manual – Technical Reports Series N°405

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research and Development Canada
IAEA	International Atomic Energy Agency
DEP	Décontamination et Études de Protection
ETBS	Etablissement Technique de Bourges

Glossary

Technical term	Explanation of term
acentric	terminal or interstitial chromosome fragment of varying size. When it is formed independently of a dicentric or centric ring chromosome aberration, it is usually referred to as an excess acentric
centric ring	aberrant circular chromosome resulting from the joining of two breaks on separate arms of the same chromosome (generally accompanied by an acentric fragment)
centromere	specialized constricted region of a chromosome that appears during mitosis joining together the chromatid pair
chromosome	46 of these structures that carry genetic information are normally contained in the human cell nucleus. During nuclear division they condense to form characteristically shaped bodies
cytogenetics	the study of chromosomes, the visible carriers of DNA, the hereditary material. Cytogenetics is a fusion science due to joining of cytology (the study of cells) with genetics (the study of inherited variation).
dicentric	chromosome aberration resulting from annealing of the centromeric pieces of two broken chromosomes (accompanied by an acentric fragment)
metaphase	the stage of cell division when chromosomes are aligned at the cell center prior to separation. A "metaphase spread" refers to the view of a cell's chromosomes in the metaphase stage on a slide.

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DRDC Ottawa (and formerly as DREO) has participated in two NATO-sponsored and one TTCP-sponsored dosimetry intercomparisons. The SILENE International Accident Dosimetry Intercomparison Exercise at Valduc, France in June 2002 coincided with DRDC Ottawa work designed to refine its proposed criticality dosimetry system (consisting of Rh foils for neutron dosimetry and the combination of CaF2:Mn and Al2O3 TLDs for gamma-ray dosimetry). In addition, DRDC Ottawa has recently substantially expanded its efforts in radiation dosimetry – and this intercomparison offered a unique opportunity to showcase and quantify these new capabilities.

The results presented herein conclusively show DRDC Ottawa's capabilities to measure accurately criticality fields.

In particular the neutron dosimetric work produced near real-time results – consistent with the target doses. The Rh foils clearly demonstrated their arguably most important feature – near invariability of response for all conceivable fission-like spectra. The gamma-ray dosimeters also showed their efficacy.

The SILENE International Accident Dosimetry Intercomparison Exercise at Valduc, France in June 2002 was implemented to test the international biodosimetry programs. DRDC Ottawa as well as several other countries participated in the international biodosimetry intercomparison. DRDC Ottawa used a Health Canada generated 137Cs dose response curve to convert aberration frequencies into dose estimates

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SILENE, Intercomparison, Criticality, Dosimetry, Neuton, Rhodium foils, Thermoluminescent Dosimeter, Reactor