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# **Evaluation of the DOS1600 Personal Dosimeter**

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and Linda K. Killoran**

**UNITED STATES DEPARTMENT OF THE INTERIOR  
Bruce Babbitt, Secretary**

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This report has been technically reviewed, but it has not been copy edited because of the closure of the agency.

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## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Bq/m <sup>3</sup>	Becquerel per cubic meter
°C	degree Celsius
h	hour
in H <sub>2</sub> O	inches of water
km	kilometer
kPa	kilopascal
L	liter
L/min	liter per minute
µm	micrometer
min	minute
mm	millimeter
part/cm <sup>3</sup>	particle per cubic centimeter
mSv	millisievert
%	percent
pCi	picocurie
pCi/L	picocurie per liter
rem	roentgen equivalent man
r/min	revolution per minute
s	second
MR	TLD reader response
WL	working level
WL·h/MR	working level hour per MR

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Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

# EVALUATION OF THE DOSI600 PERSONAL DOSIMETER

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## ABSTRACT

The U.S. Bureau of Mines (USBM) has tested a personal dosimeter for measuring radon decay products that is manufactured by Tom Scurry Associates. The tests were made to determine the accuracy of the dosimeter system for record keeping of radiation exposures to radon decay products encountered in mining. The radioactivity-detecting head is based on a design developed by the USBM, and the associated air pump was developed by the manufacturer. The dosimeter system was tested in the USBM radon chamber. The detecting head uses CaF:Dy thermoluminescent phosphors and is mounted on a self-regulating air pump. Batteries supply power sufficient for an 8-h shift. The dosimeter system is worn on the miner's belt. Dosimeter calibration tests were performed by the USBM. In addition, the pumps were tested and evaluated under continuous flow conditions. The results of these tests indicate that the Tom Scurry Associates Model DOSI600 dosimeter is suitable for general use in mines where record keeping for natural radiation exposure is required.

## INTRODUCTION

Radium ( $^{226}\text{Ra}$ ) is widely distributed in nature and is a minor component in all rocks, sand, and soil. Radium transforms through radioactive decay into radon ( $^{222}\text{Rn}$ ). Because all rock and soil are porous to a degree, some radon diffuses out of any exposed rock or soil surface. There are four short-lived decay products from radon:  $^{218}\text{Po}$ ,  $^{214}\text{Pb}$ ,  $^{214}\text{Bi}$ , and  $^{214}\text{Po}$ , each of which has a half-life of less than 30 min. Thoron ( $^{220}\text{Rn}$ ) is present in the thorium series and has four short-lived decay products:  $^{216}\text{Po}$ ,  $^{212}\text{Pb}$ ,  $^{212}\text{Bi}$ , and  $^{212}\text{Po}$ . Each of the short-lived decay products emits alpha, beta, and/or gamma radiation. If radon or thoron decay products are inhaled, they may be deposited in the upper respiratory system. As further decay occurs, an alpha dose to the upper lung tissue may cause tissue damage that is associated with an increased risk of lung cancer.

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Underground uranium miners have a lung cancer incidence five times higher than the general population (1).<sup>4</sup> From 1971 to 1980, over 150 uranium miners are known to have died of radiogenic lung cancer. Over the decade, the fatality rate was 21.9 per 10,000 miners. This rate is three times the rate for all coal mine accident fatalities. Underground miners represent less than 1% of the more than 300,000 workers exposed to ionizing radiation, but their radiation dose is more than four times higher than the average dose received by the other 99% of all other workers exposed to radiation. Compared to other radiation workers, uranium miners have about 10 to 15 times the lifetime risks of premature death due to radiogenic cancer.<sup>5</sup>

The regulations of the Mine Safety and Health Administration (MSHA), 30 CFR 57.5040 (2), require that individual exposures to radon decay products of all noncoal mines underground personnel shall be measured and recorded (record keeping is required if 0.1 WL is exceeded). Radon and thoron decay products generally enter the miner's lung via the inhalation of particles.<sup>6</sup>

One goal of the USBM is to improve the health and safety of miners. For over 20 years, the USBM has had a program that evaluates the accuracy of methods for measuring exposure to radon decay products. This work was done primarily for MSHA to aid their exposure enforcement program. Grab sampling, continuous Working Level detectors, and personal dosimeters were evaluated using USBM facilities. This report covers the results of the evaluation of one of the personal dosimeter systems made under this program.

## BACKGROUND

It has been recognized for many years that there is a need to improve the accuracy of measuring the exposure of miners to radon decay products (3). Most of the exposure measurements in the past were based on area grab sampling. The exposure is calculated by radiation protection personnel from records of where and how long the individual miners were underground and at what radioactivity concentration (4).

The distribution of radon decay products in an underground mine atmosphere varies significantly over short distances. This makes grab sampling a rather poor

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<sup>4</sup>Italic numbers in parentheses refer to items in the list of references at the end of this report.

<sup>5</sup>Private communication from R. C. Bates, USBM (retired), 1983.

<sup>6</sup>Schiager, K. J., T. B. Borak, and J. A. Johnson. Radiation Monitoring for Uranium Miners: Evaluation and Optimization. USBM Contract J0295026, ALARA Inc., Ft. Collins, CO, 1981, 132 pp.

measurement of the worker's actual exposure to the hazard. Accordingly, considerable effort has been made over the past 25 years to develop a more accurate method than existing ones of measuring worker exposure. The personal dosimeter offers the best chance to meet this goal.

The results of tests of the original (Model 8H) USBM-developed active (equipped with a vacuum pump) personal thermoluminescent dosimeter (TLD) were reported by Drouillard (5-6). The Model 8H dosimeter system consists of two major components: a detector head and an air pump. The detector head is threaded onto the air pump. A commercial air pump was used on this system developed by the USBM in the late 1970's.

A field evaluation of the Model 8H dosimeter was conducted by a contractor in active uranium mine environments. The results showed that this dosimeter performed the best of several dosimeters tested.<sup>7</sup> It measures both alpha and gamma exposure using two  $\text{CaF}_2:\text{Dy}$  phosphors in a plastic matrix with a diameter of 12 mm and separated by a beta shield. The long-lived alpha contribution collected on the filter is also measured later in the laboratory using a second exposure to the phosphor or by gross alpha counting of the filter. Alpha spectroscopy or radio-chemical methods provide additional information on exposure (7).

Even though the USBM TLD cannot distinguish between the radon and thoron decay products, it is not a serious disadvantage if one realizes that the error is on the safe side with about a 60% overestimation of the thoron decay products contribution, and that most of the exposure to alpha radiation comes from the radon decay products. Alpha particles from thoron decay products are less dangerous because of their longer half-life (about 10 h), which allows for more efficient lung clearance compared to radon decay products with their less than an hour combined half-life. However, it should be noted that it only takes approximately 8 to 9 pCi of thoron in equilibrium with its short-lived decay products to make an exposure of 1 WL, whereas approximately 101 pCi of radon are required.

The decline of the domestic uranium mining industry in the early 1980's (from 10,000 miners to nearly zero at present) has made it appear that radiation protection is no longer a significant problem in mining. Several years ago, however, new attitudes on radiation safety emerged worldwide when (1) the 1990 recommendations of the International Commission on Radiation Protection (ICRP) (8) lowered the exposure standards for radiation workers from 50 mSv (5 rem) to 20 mSv (2 rem); (2) it was acknowledged that exposure from radon and thoron decay products for the general population and work force other than traditional radiation workers is several times

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<sup>7</sup>Dodge, W. D., and V. B. Parr. Radon Daughter Dosimeter Tests in Active Uranium Mines. USBM OFR 71-80, 1980, 109 pp.

higher than the previously accepted value of 1 mSv (0.1 rem) a year; (3) a recent publication by the ICRP (9) recommends an exposure range of 500 to 1,500 Bq/m<sup>3</sup> (0.035 to 0.1 WL) for miners, whereas existing U.S. regulations allow an average exposure of 0.33 WL (an increase of 3 to 10 times over the ICRP values); and (4) the increased awareness of real or imagined threats to longevity and health on the part of the public and regulatory agencies. The most telling example of this is perhaps the National Emission Standard for Hazardous Air Pollutants (NESHAP) for radon emissions from uranium mines (10), which allows only 0.1 mSv (0.01 rem) additional exposure for the public ("receptors") within an 80-km radius of the mine air exhaust. This roughly translates into 2 Bq/m<sup>3</sup> (0.05 pCi/L) above background (about 10 Bq/m<sup>3</sup>).

The most widely used personal dosimeter carried by thousands of miners over a period of more than 10 years is one developed by the Commissariat à l'Énergie Atomique (CEA) in France (11). It is based on four nuclear track detectors equipped with various filters to resolve the various radon and thoron decay products. The air pump uses a high r/min propeller. The air flow through the collection filter is determined by measuring the flow at the beginning and at the end of exposure. There is no continuous flow control during sampling, the assumption being that the volume sampled is given by interpolation between the measured initial and the measured final flow. In addition to the problems of not knowing the sampled volume, the high r/min propeller tends to wear out its bearings due to precession. As far as the assumption of constancy of the sampling flow, it was found by Dodge and Parr,<sup>8</sup> for instance, that the flow was significantly decreased when the filter got wet during a shift. After it dried, the flow resumed its previous value. The Canadian Institute for Radiation Safety uses the CEA dosimeters, but they replace the propeller pump with an aquarium pump, which is very bulky and impractical for a personal dosimeter.<sup>9</sup> Nevertheless, the instrument is useful as an area monitor.

Reliable air flow measurements remain a problem. As late as 1989, during an international intercomparison of measuring methods for radon and radon decay products conducted in a CEA uranium mine (12), the main source of error appeared to be the air flow (total volume) determination. This problem is usually compounded by the lack of understanding on the part of the practitioners of the difference between a volumetric flow measuring device (independent of air density) and a mass flow measuring device (dependent on air density). Air density dependent devices usually are a source of experimental error.

The most extensive evaluation of several radon decay product dosimeters

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<sup>8</sup>Work cited in footnote 6.

<sup>9</sup>Private communication from K. Kaletsch, Canadian Institute for Radiation Safety, Ottawa, Canada, 1992.

compared side-by-side was done by Bigu et al (13), and the results were essentially in agreement with the above statements. One of the additional problems he found with the CEA dosimeter was that uranium-containing dust got into the detector and caused undesired tracks that had nothing to do with the short-lived radon decay products tracks. The last group of personal dosimeters, also evaluated by Bigu et al (13), uses various ruggedized solid state detectors (14-15). The alpha counts measured by the detectors are stored electronically and read out at the end of shift. Although these detectors performed satisfactorily, they have never been tested side-by-side with the USBM detector, and it is not clear if their extra cost results in improved ruggedness and reliability. In addition, no gamma exposure information is provided.

## DOSI600 PERSONAL DOSIMETER

### Specifications

Figure 1 shows the prototype of the Model DOSI600 personal dosimeter manufactured by Tom Scurry Associates. The only significant difference from the Model 8H dosimeter system developed by the USBM is the newly designed self-regulating air pump, which provides accurately controlled volumetric air flow through the filter located in the detector head.

The air flow system is composed of a diaphragm pump and an electronic flow controller and is powered by rechargeable batteries. The controller consists of a flow restrictor on the upstream side of the pump that causes a pressure drop proportional to the volumetric flow through it. It should be noted that this arrangement measures the flow independently of altitude, a clear advantage in view of the fact that mines range in elevation from sea level to thousands of meters. The upstream pressure is sensed and kept constant by a closed-loop electronic controller that controls the speed of the pump motor to keep the pressure across the restrictor constant. The pumping system will maintain a constant flow up to a vacuum of about 13 kPa (50 in H<sub>2</sub>O). When the vacuum approaches the upper limit, a warning light is turned on so that corrective action can be taken.

### Testing Procedures

Two tests were conducted using the DOSI600 personal dosimeters. The dosimeter calibration tests were conducted to evaluate the dosimeter detector. The second test was performed to evaluate the self-regulating pumps under continuous flow conditions.

#### Dosimeter Calibration Tests

Evaluation of the Model DOSI600 personal dosimeter was conducted in the USBM radon chamber over a range of radon decay products concentrations of 0.9 to

2.5 WL, with a condensation nuclei level of approximately 100,000 part/cm<sup>3</sup> having an average diameter of about 0.07 μm. The humidity ranged from 10% to 30%, and the temperature was approximately 20 °C. The radon decay products levels in the chamber were measured by means of a continuous WL detector developed by the USBM (16). These detectors measure beta activity collected on a filter to determine the total alpha activity. The calibration of the continuous WL detectors was checked by means of the modified Tsivoglou method (17) three to five times a day. Three tests were performed that ranged in duration from 5 to 12 days.

Two of the three tests were made using 10 detector heads (no pump) on a USBM-devised air system that provides a steady air flow for the detectors for the duration of the test. The system splits a given flow into 10 flows by means of a 3-L steel cylinder with 10 inlets, which also serves as a buffer to even out small variations in the individual flows through the detectors. The flow of each of 10 detector heads is adjusted individually to 0.1 L/min using a mechanical flow controller and a laminar flowmeter. The flow was measured at the beginning and end of the test.

During the third test, three of the Model DOSI600 personal dosimeters were tested (detector with air pump) in the USBM radon chamber (18). This test used the self-regulating air pump manufactured by Tom Scurry Associates as the source of flow. An air pump flow rate of 0.05 L/min was used.

#### Pump Continuous Flow Tests

The three self-regulating pumps used in the third dosimeter calibration test were tested, with filters in place, for rate accuracy. The flow was set at a nominal value of 0.05 L/min and was checked using a bubble-tube flowmeter. The input air flow to the filter was also intermittently measured with a continuous air flow measuring instrument over most of the duration of the 17-day test during which the pumps were continuously running. The bubble-tube flowmeter is a volumetric flow measuring device where the time it takes a bubble to go from the initial to the final markings on a cylinder is electronically timed. The advantage over other available flow-measuring instruments is the ease with which many repeated measurements can be taken.

### Analysis and Results

#### Dosimeter Calibration Tests

The readout of the TLD phosphors, both for the alpha and gamma exposure was done by an independent laboratory. The measurements were within ±15% of the test chamber activity levels. This kind of accuracy will give much more accurate exposures than existing grab sampling methods. These data (TLD response) are listed in table 1, along with computed calibration factors for each of the three tests.

Table 1.--Results of DOSI600 dosimeter calibration tests

Test	Number of dosimeters tested	Flow, L/min	Exposure, WL·h	TLD response, MR	Calibration factor, WL·h/MR
1 ....	10	0.1	46.7	644.7 ±5.7%	0.0725
2 ....	10	0.1	102.8	1,402.6 ±4.6%	0.0714
3 ....	3	0.05	191.3	1,496.0 ±3.8%	0.0635

Figure 2 presents the results of the dosimeter calibration tests. The first two points are the calibration factor determined using the DOSI600 detector and the USBM air system. The third point in figure 2 is from a test where three complete personal dosimeters (as shown in figure 1) were put into the chamber to test the instrument as a system. The air pump operates at flow rates that are lower than the flow rates used in the USBM chamber so that the results plotted in figure 2 were normalized to the same flow. Unfortunately, only three instruments were available for the third test so that the error bars are based on only three measurements. The error bars of the first two points, however, are based on 10 test data points corresponding to the 10 flow-controlled ports in the USBM chamber (18). The fourth point is the average of the three preceding points and is the final accepted calibration factor, which is equal to 0.07015 WL·hrs/MR, for the Model DOSI600 dosimeters. The results of the dosimeter calibration tests were within the 95% confidence interval. This is within MSHA requirements, which state that the annual exposure shall have an error no greater than 50% at the 95% confidence level.<sup>10</sup>

#### Pump Continuous Flow Tests

Figure 3 shows the results of testing the self-regulating pumps under continuous flow conditions to evaluate rate accuracy. The USBM automated system was used to continuously measure the flow. These continuous measurements, presented in figure 3, are intermittent, with three distinct breaks in the data. During these tests, the USBM automated system had an improper impedance match, which resulted in elevated flow readings. These erroneous flows have been omitted from figure 3 and have no direct relationship to the operation of the DOSI600. The continuous flow data presented in figure 3 have a variation of 6.7%.

Individual (discrete) points in figure 3 indicate bubble-tube flowmeter measurements used to confirm the continuous data. These measurements (one set for each pump tested) show a 2.0% to 6.0% variation during the 17-day test. This is a

<sup>10</sup>Private communication from W. E. Cooper, MSHA, 1993.

very satisfactory result in comparison to the 38% to 92% flow variability in CEA dosimeters reported by Bigu (19). The average value for all three pumps, based on the bubble-tube flowmeter measurements, was 0.0513 L/min.

## CONCLUSIONS

The results of the USBM tests shown in figures 2 and 3, and in table 1 indicate that the Tom Scurry Associates Model DOSI600 dosimeter for measuring radon decay products is a reliable instrument with an overall error of about  $\pm 5\%$ , with some additional uncertainty caused by the pump that, over the period of 17 days, shows a small variation in flow of a few percent. The test of a basically identical dosimeter, the Model 8H, in actual uranium mines was successfully passed in 1980.<sup>11</sup> It is concluded, therefore, that this personal dosimeter provides the radiation protection community in mining with a viable alternative to existing personal dosimeters for measuring exposures to radon decay products in mine environments.

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<sup>11</sup>Work cited in footnote 6.

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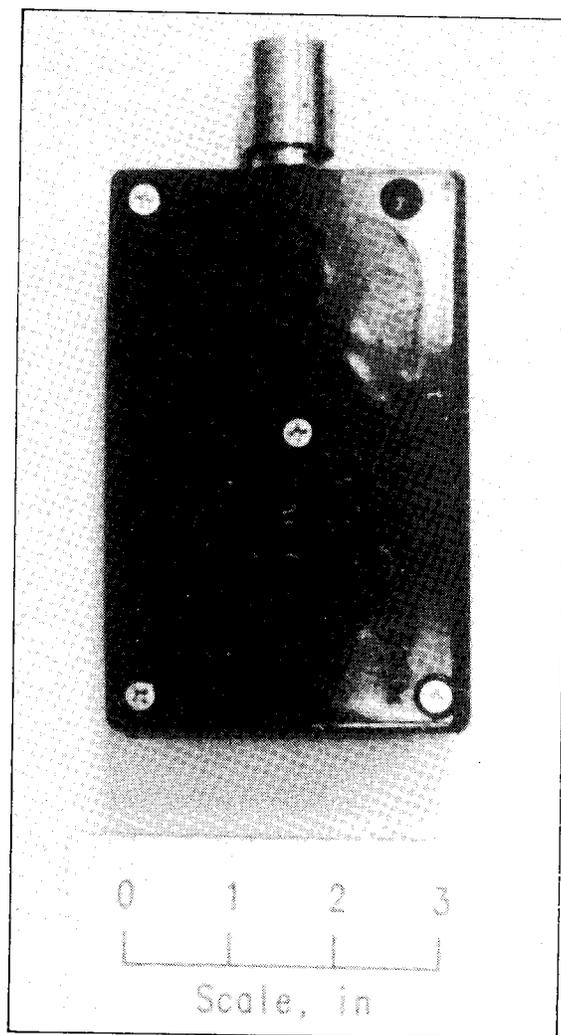


Figure 1. Prototype of Tom Scurry Associates Model DOS1600 Personal thermo-luminescent dosimeter (TLD). Design is identical to one developed by USBM, except for self-regulating air pump system.

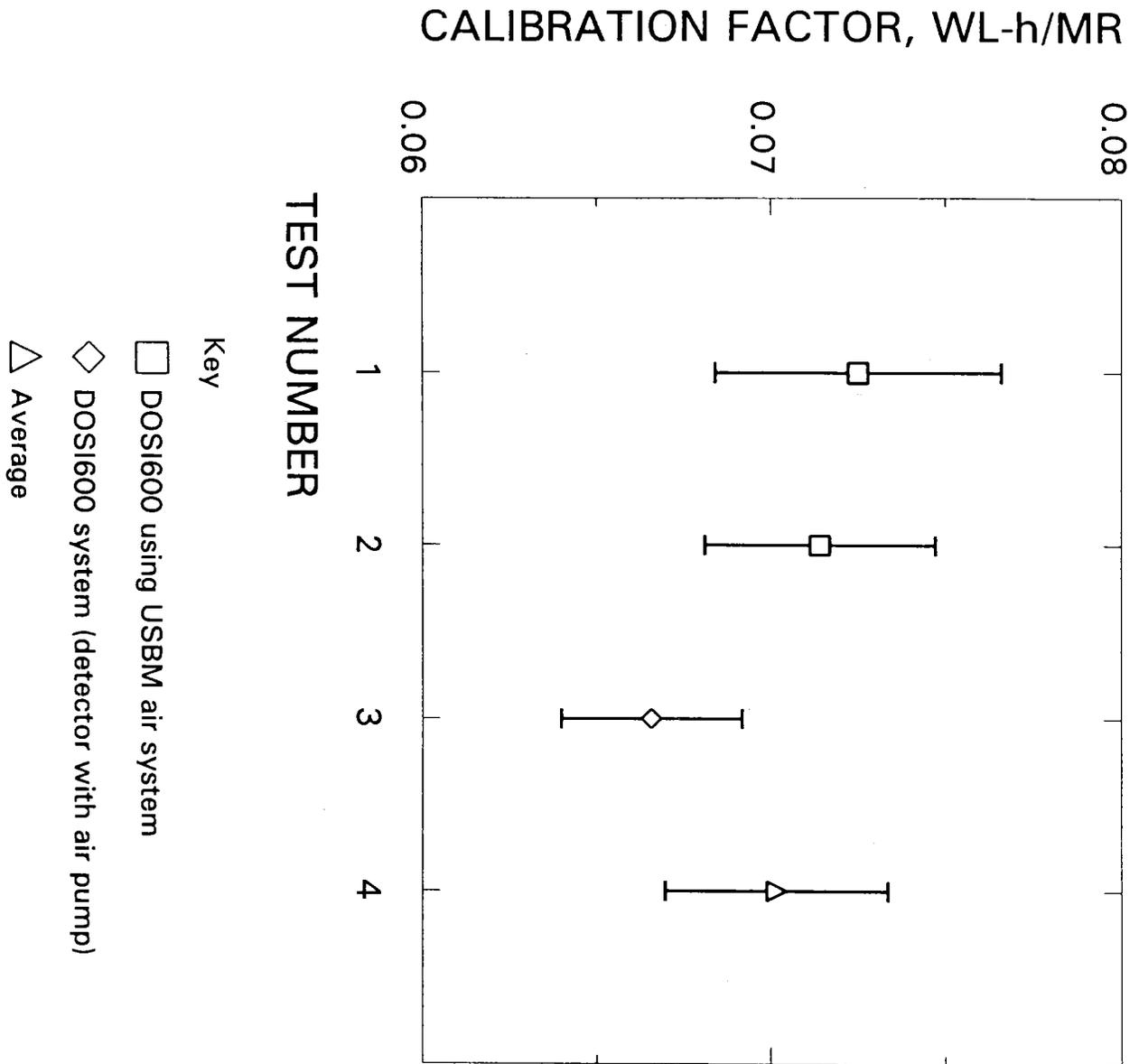


Figure 2. Results of DOSI600 dosimeter calibration tests performed in USBM test chamber. First two data points used USBM air system and third point used DOSI600 self-regulating air pump. Fourth point is final (average) calibration coefficient based on three preceding test data points.

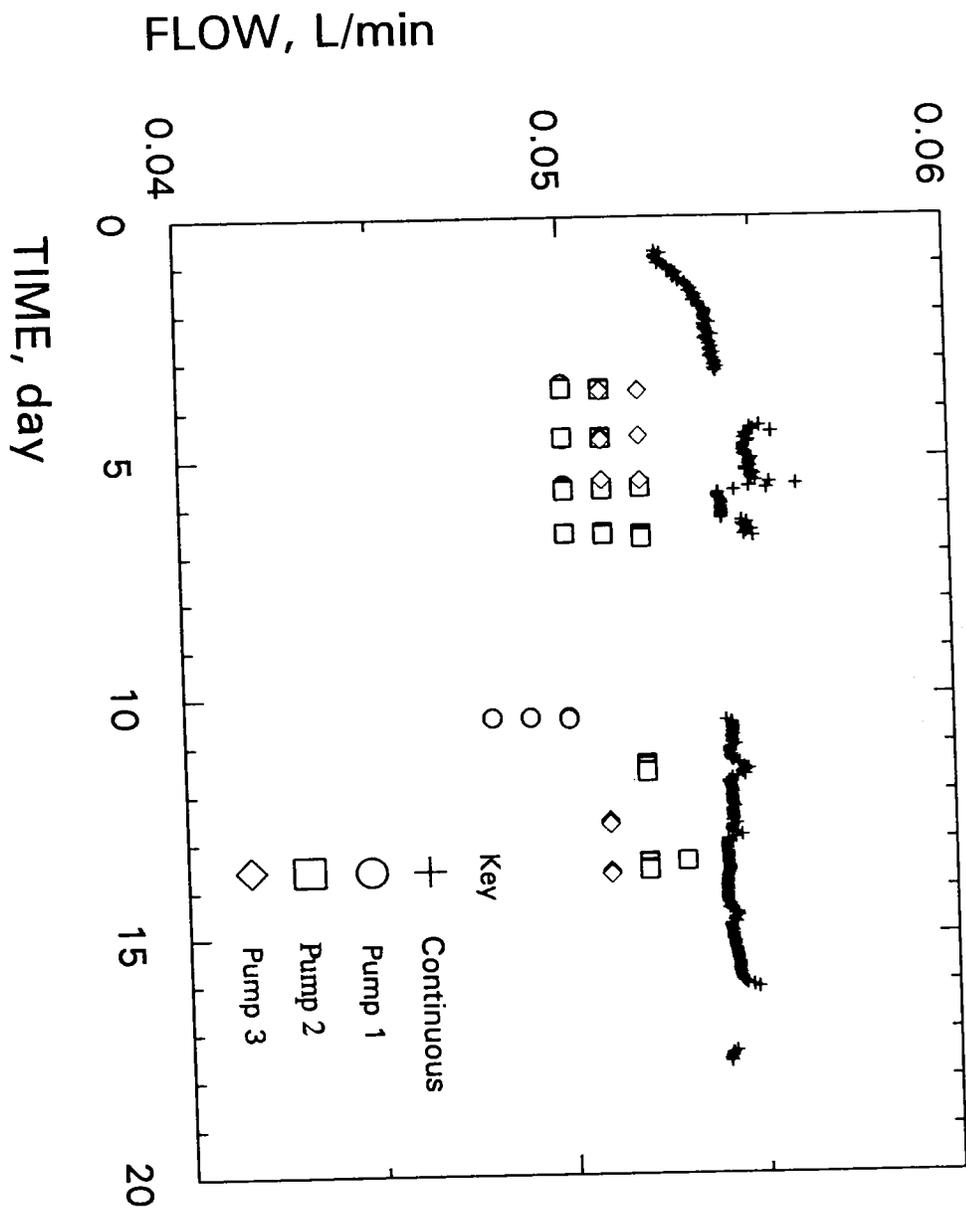


Figure 3. Result of pump continuous flow tests. Continuous line presents constant-interval measurements using USBM automated system. Individual points indicate bubble-tube flowmeter data used to confirm continuous and constant flow.