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THE EFFECT OF PROPYLENE GLYCOL ON ETHANOL CONCENTRATIONS DETERMINED BY DENSITY MEASUREMENT

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Abstract.—The effect of propylene glycol on the densities of ethanol-water-propylene glycol solutions has been determined. From the data, and from tables of density of ethanol-water solutions, the effect of propylene glycol on indicated ethanol concentrations, obtained through measurements of density, was determined. For most purposes this effect is thought to be small enough to be neglected in all but the most exacting work.

An important variable in maintaining fluid-preserved collections is the composition of the fluid-preservative. Seventy to ninety % volume/volume (% v/v) ethanol seems to be an ideal fluid composition (Levi, 1966). On occasion other chemicals have been added to the ethanol to reduce brittleness of specimens and ameliorate the consequences of complete drying out of specimens. Glycerol had been added to the 75% v/v ethanol used to preserve the Crustacea collection at the Canadian Museum of Nature. In 1981 it was decided to switch over to the addition of propylene glycol (P.G.) (1,2-propanediol) to the ethanol.

There are various reasons why glycerol is not recommended. Specimens become slippery and thus difficult to handle when preserved in this fluid. As well, if the ethanol in the vials or jars evaporates, the concentration of glycerol increases to the point of clearing the specimens. Evaporation of pure ethanol leaves one with a dried up specimen, whereas evaporation of ethanol from a glycerol mixture leaves a glycerol-water medium that encourages the growth of molds and bacteria (Levi, 1966). For these reasons propylene glycol is now used in preference to glycerol.

P.G. is a humectant and even if solutions containing this reagent evaporate over time the specimens will never dry out completely. It has other properties as well which make it a more suitable additive to ethanol. It too has a softening effect and 2–5% added to alcohol will reduce the rigidity of arthropod appendages. Unlike glycerol, which is a medium for mold growth, P.G. is an inhibitor of molds (Harris, 1978).

Measurement of density is the most convenient and common method of determining alcohol concentrations in simple alcohol-water solutions (SPNHC-CC, 1990). The purpose of this work was to determine the extent to which various amounts of P.G. in an ethanol-water solution would affect ethanol concentration determinations based on measurements of density. P.G. is added to solutions at 2% by volume. However, since the vapour pressure of P.G. is very low (0.01 KPa at 20°C) (Hawley, 1971) in comparison with both ethanol (5.8 KPa at 20°C) (Dean, 1979) and water (2.3 KPa at 20°C) (Weast, 1988) it is expected to become more concentrated as solutions evaporate over time. In addition, an ethanol solution containing 2% v/v P.G. has been used to top up the collection which was already stored in ethanol-water-P.G. Thus, even jars which are full may contain

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Table 1. Required volumes and weights of propylene glycol and ethanol for solutions.

	Propylene glycol		Ethanol	
Solution	ml	g	ml	g
0/0	0.000	0.000	0.000	0.000
0/20	0.000	0.000	5.000	4.250
0/40	0.000	0.000	10.000	8.484
0/60	0.000	0.000	15.000	12.750
0/75	0.000	0.000	18.750	15.950
0/80	0.000	0.000	20.000	17.008
2/0	0.500	0.517	0.000	0.000
2/20	0.500	0.517	5.000	4.250
2/40	0.500	0.517	10.000	8.484
2/60	0.500	0.517	15.000	12.750
2/75	0.500	0.517	18.750	15.950
2/80	0.500	0.517	20.000	17.008
4/0	1.000	1.034	0.000	0.000
4/20	1.000	1.034	5.000	4.250
4/40	1.000	1.034	10.000	8.484
4/60	1.000	1.034	15.000	12.750
4/75	1.000	1.034	18.750	15.950
4/80	1.000	1.034	20.000	17.008
8/0	2.000	2.068	0.000	0.000
8/20	2.000	2.068	5.000	4.250
8/40	2.000	2.068	10.000	8.484
8/60	2.000	2.068	15.000	12.750
8/75	2.000	2.068	18.750	15.950
8/80	2.000	2.068	20.000	17.008
16/0	4.000	4.136	0.000	0.000
16/20	4.000	4.136	5.000	4.250
16/40	4.000	4.136	10.000	8.484
16/60	4.000	4.136	15.000	12.750
16/75	4.000	4.136	18.750	15.950
16/80	4.000	4.136	20.000	17.008

more than 2% v/v P.G. if they have been topped up. Consequently, this work considered the effect of P.G. concentrations greater than 2% v/v on densities of ethanol-water-P.G. solutions.

MATERIALS AND METHODS

A series of solutions containing 0, 2, 4, 8 and 16% v/v P.G. and 0, 20, 40, 60, 75 and 80% v/v ethanol were prepared. This resulted in 30 different solutions. To assess the repeatability of measurements four additional samples of each of the 2% v/v P.G., 20% v/v ethanol solution; the 8% v/v P.G., 60% v/v ethanol solution; and the 16% v/v P.G., 80% v/v ethanol solution were also made. All of the samples, including replicates, were made and measured in a random order (see Table 2).

The first step in preparing the mixtures was to convert the required volumes of P.G. and ethanol into weights (milliliters to grams). Gram weights were determined by multiplying the required volumes of the different components by their known densities. The density of P.G. is 1.0361 g/ml at 20°C (Weast, 1988). The density of P.G. was measured at room temperature and was found to be 1.034 g/ml at 24°C. The density of ethanol is 0.808 g/ml and deionized water 0.997 g/ml at room temperature. Given that 95% v/v ethanol was used, an additional conversion factor of 100/95 was used in these calculations (see Table 1).

Once these calculations had been recorded, the test solutions were made. Into a 25 milliliter volumetric flask the propylene glycol was measured by weight to the nearest 0.001 g. A 1 milliliter syringe

Table 2. Order of solution preparation and actual quantities of components added.

Order prepared	Solution	P.G. (g)	Actual P.G. (g)	Ethanol (g)	Actual Eth. (g)
1	0/0	0.000	0.000	0.000	0.000
27	0/20	0.000	0.000	4.250	4.250
23	0/40	0.000	0.000	8.484	8.480
21	0/60	0.000	0.000	12.750	12.755
24	0/75	0.000	0.000	15.950	15.950
38	0/80	0.000	0.000	17.008	17.008
4	2/0	0.517	0.516	0.000	0.000
12	2/20	0.517	0.517	4.250	4.251
10	2/20	0.517	0.517	4.250	4.250
20	2/20	0.517	0.517	4.250	4.253
22	2/20	0.517	0.517	4.250	4.250
32	2/20	0.517	0.517	4.250	4.250
15	2/40	0.517	0.517	8.484	8.485
9	2/60	0.517	0.517	12.750	12.755
19	2/75	0.517	0.517	15.950	15.954
6	2/80	0.517	0.517	17.008	17.008
5	4/0	1.034	1.034	0.000	0.000
42	4/20	1.034	1.034	4.250	4.250
34	4/40	1.034	1.034	8.484	8.484
16	4/60	1.034	1.034	12.750	12.770
17	4/75	1.034	1.034	15.950	15.951
18	4/80	1.034	1.034	17.008	17.009
25	8/0	2.068	2.069	0.000	0.000
2	8/20	2.068	2.068	4.250	4.253
39	8/40	2.068	2.068	8.484	8.485
8	8/60	2.068	2.068	12.750	12.750
14	8/60	2.068	2.068	12.750	12.750
28	8/60	2.068	2.068	12.750	12.746
33	8/60	2.068	2.068	12.750	12.746
36	8/60	2.068	2.068	12.750	12.749
37	8/75	2.068	2.068	15.950	15.951
3	8/80	2.068	2.066	17.008	17.008
30	16/0	4.136	4.136	0.000	0.000
11	16/20	4.136	4.136	4.250	4.250
29	16/40	4.136	4.136	8.484	8.484
31	16/60	4.136	4.136	12.750	12.753
40	16/75	4.136	4.136	15.950	15.959
35	16/80	4.136	4.136	17.008	17.008
13	16/80	4.136	4.136	17.008	17.008
26	16/80	4.136	4.136	17.008	17.008
7	16/80	4.136	4.137	17.008	17.008
41	16/80	4.136	4.136	17.008	17.008

with a 27 gauge needle was used in order to deliver the required amount. Ethanol was then measured into the flask, in a similar manner, to the nearest 0.01 g. The actual weights were recorded for each solution using a Mettler AT 400 balance (see Table 2). Deionized water was then added to bring the level close to the 25 ml mark. Solutions were slowly agitated and left to stand for a few minutes before finally making up to the 25 ml mark. They were then transferred into test tubes and left for a period of two days before any densities were measured and recorded. Before measuring the densities the closed samples were immersed in a water bath at 30°C, long enough for them to warm to that temperature (15–20 min).

A Paar DMA 35 density meter was used to measure the densities. It was calibrated, using deionized

Table 3. Results of density readings for solutions prepared in replicate.

Solution	Density 1	Density 2	Density 3	Average	
2/20	0.974	0.974	0.974	0.974	
2/20	0.973	0.974	0.974	0.974	
2/20	0.974	0.974	0.974	0.974	
2/20	0.972	0.965	0.974	0.970	
2/20	0.974	0.974	0.974	0.974	Avg. 0.973
8/60	0.905	0.906	0.906	0.906	
8/60	0.898	0.901	0.901	0.900	
8/60	0.904	0.904	0.905	0.904	
8/60	0.904	0.904	0.904	0.904	
8/60	0.906	0.906	0.906	0.906	Avg. 0.904
16/80	0.840	0.840	0.840	0.840	
16/80	0.847	0.847	0.847	0.847	
16/80	0.845	0.845	0.846	0.845	
16/80	0.846	0.847	0.847	0.847	
16/80	0.811	0.812	0.811	0.811	Avg. 0.838

Table 4. Measured and average densities of solutions.

Solution	Density 1	Density 2	Density 3	Average
0/0	0.997	0.997	0.997	0.997
0/20	0.972	0.972	0.972	0.972
0/40	0.945	0.945	0.945	0.945
0/60	0.905	0.906	0.906	0.906
0/75	0.867	0.867	0.867	0.867
0/80	0.854	0.854	0.854	0.854
2/0	0.998	0.998	0.998	0.998
2/20	0.974	0.974	0.974	0.974
2/40	0.946	0.946	0.946	0.946
2/60	0.905	0.905	0.905	0.905
2/75	0.869	0.869	0.868	0.869
2/80	0.854	0.855	0.855	0.855
4/0	1.000	1.000	1.000	1.000
4/20	0.970	0.976	0.970	0.972
4/40	0.943	0.946	0.947	0.945
4/60	0.904	0.904	0.905	0.904
4/75	0.865	0.865	0.866	0.865
4/80	0.850	0.852	0.850	0.851
8/0	0.995	1.003	1.003	1.003
8/20	0.975	0.979	0.978	0.977
8/40	0.943	0.944	0.944	0.944
8/60	0.906	0.906	0.906	0.906
8/75	0.865	0.865	0.865	0.865
8/80	0.854	0.855	0.855	0.855
16/0	1.009	1.009	1.009	1.009
16/20	0.980	0.985	0.985	0.983
16/40	0.952	0.953	0.953	0.953
16/60	0.897	0.901	0.902	0.900
16/75	0.859	0.860	0.860	0.860
16/80	0.845	0.845	0.845	0.845

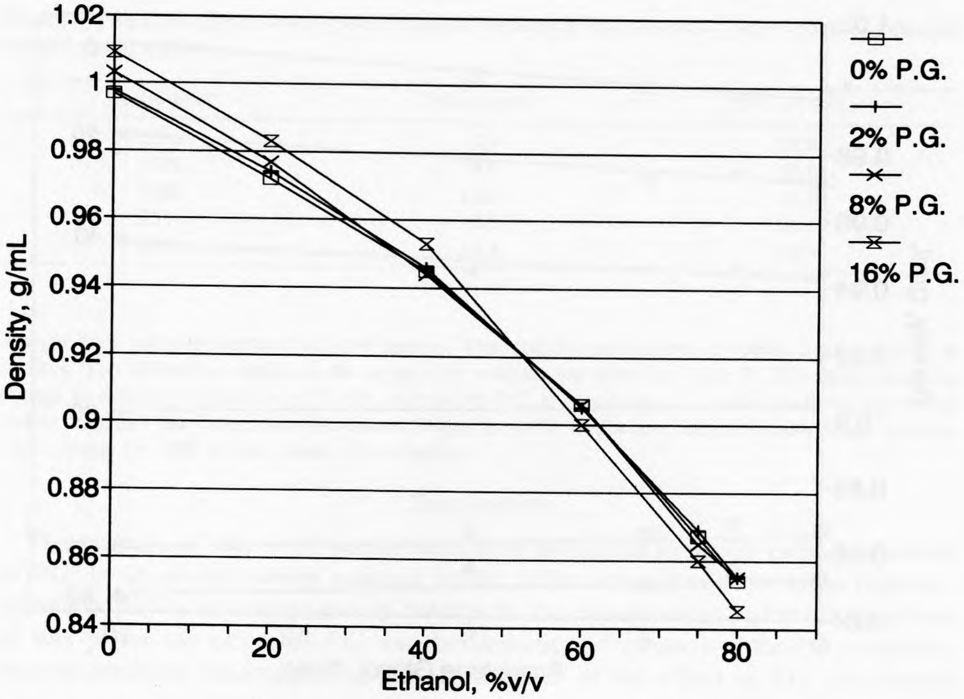

Figure 1. Densities of solutions as a function of ethanol concentration for solutions containing 0, 2, 8 and 16% v/v propylene glycol. Data for solutions containing 4% v/v propylene glycol are not shown as they are practically identical to the data for solutions containing 8% v/v propylene glycol.

water, to 0.997 g/ml at 25°C. A 2 milliliter syringe was used to insert the samples into the density meter. The density of each solution was measured five times, each time at the moment the sample temperature reached 25°C. Three satisfactory measurements and their average were recorded for each test sample. The first attempted measurement was not used since it would, in some cases, be affected by traces of the previously measured solution. Any subsequent measurements where air-bubbles could be seen in the sample tube of the density meter were also not used. The measured densities for the three sets of solutions for which four replicates were made are given in Table 3.

In Table 3 there was an anomaly in the data for the fifth 16/80 solution. Upon examination of these data it was decided to do a Q Test to determine whether or not the data could be discarded. A Q Test involves taking the difference between the questionable result and its nearest neighbour and dividing it by the spread of the entire set. The resulting ratio, Q, is then compared with rejection values that are critical for a particular degree of confidence. The critical value of Q at the 90% confidence level for an observation of five measurements is 0.64. Rejection of data is possible if the result of the Q Test is greater than 0.64 (Skoog and West, 1963). The questionable readings were 0.811, 0.812, 0.811, and their average 0.8113. The nearest average density to this was 0.8400, and the spread of the entire set was 0.8470 to 0.8113. The following equation shows the results:

$$\frac{(0.8400 - 0.8113)}{(0.8470 - 0.8113)} = \frac{0.0287}{0.0357} = 0.8040$$

The resulting ratio is 0.8040. Therefore these data can be rejected. The readings for the fifth 16/80 solution in Table 3 were then replaced with the mean readings of the other four 16/80 solutions.

The data in Table 3 can also be used to compare the relative precision of density measurements and of solution preparation procedures. The standard deviation associated with the preparation of the 15 solutions, calculated from measured densities, is 0.0090 with 36 degrees of freedom. After rejecting the deviant result for the 16/80 series of solution the standard deviation reduces to 0.0027 with 33

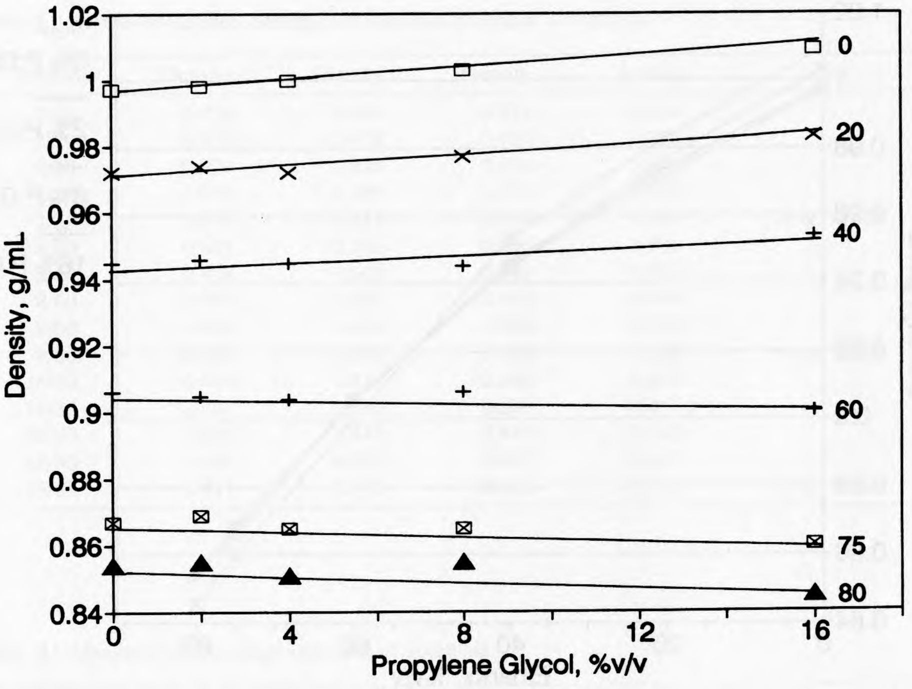

Figure 2. Densities of solutions as a function of propylene glycol concentration for solutions containing 0, 20, 40, 60, 75 and 80% v/v ethanol.

degrees of freedom. The standard deviation associated with the measurement of densities for each of the 15 replicated solutions is 0.0014 with 30 degrees of freedom. Comparison of these standard deviations shows that, even after rejection of the deviant results, density measurements are considerably more precise than the preparation of solutions. This is in spite of the fact that great care was taken in preparing the solutions.

Density measurements for each of the series of solutions are given in Table 4. The mean densities for each of these solutions are shown in Figures 1 and 2. Figure 1 indicates that for a given concentration of propylene glycol, changing the concentration of ethanol (i.e., from 0–80% v/v) had a marked effect on the densities of the test solutions. In contrast, Figure 2 indicates that for a given concentration of ethanol, changing the concentration of propylene glycol (i.e., 0–16% v/v) had a very minor effect on density.

It is evident from Figure 2 that the effect of P.G. concentration on solution density for each of the ethanol concentrations studied is approximately linear. Because of this, the data was modelled by

Table 5. Results of linear regression of density (g/ml) against % v/v propylene glycol (degrees of freedom = 3).

% Ethanol	Constant	Std. dev. constant	Slope	Std. dev. of slope	90% C.T. around slope
0%	0.9968	0.0002	0.00076	0.00002	±0.000020
20%	0.9714	0.0015	0.00070	0.00012	±0.000125
40%	0.9438	0.0025	0.00046	0.00020	±0.000209
60%	0.9062	0.0016	−0.00032	0.00013	±0.000130
75%	0.8681	0.0015	−0.00049	0.00012	±0.000125
80%	0.8552	0.0029	−0.00054	0.00023	±0.000244

Table 6. Propylene glycol concentration required to cause a 2% v/v and a 5% v/v error in indicated ethanol concentration.

% Ethanol	2% v/v error	5% v/v error
20%	3.1	36.6
40%	6.9	16.9
60%	13.8	35.6
75%	10.8	28.1
80%	10.4	26.7

straight lines using the method of least squares. The straight lines shown in Figure 2 are fit by least squares. The numerical results of the regression analysis are given in Table 5. The slopes indicate change in density in g/ml for a 1% v/v increase in P.G. concentration. It can be seen that all of the slopes are small but statistically significant. Slopes for 40% v/v, or less, ethanol solutions are positive while slopes for 60% v/v, or greater, are negative.

DISCUSSION

The purpose of this work was to determine the extent to which various amounts of P.G. in an ethanol-water solution would affect ethanol concentration determinations based on measurements of density. In the experimental and results sections of this paper the effect of P.G. on the densities of ethanol-water-P.G. solutions was determined. Understanding the significance of the effect of P.G. on ethanol

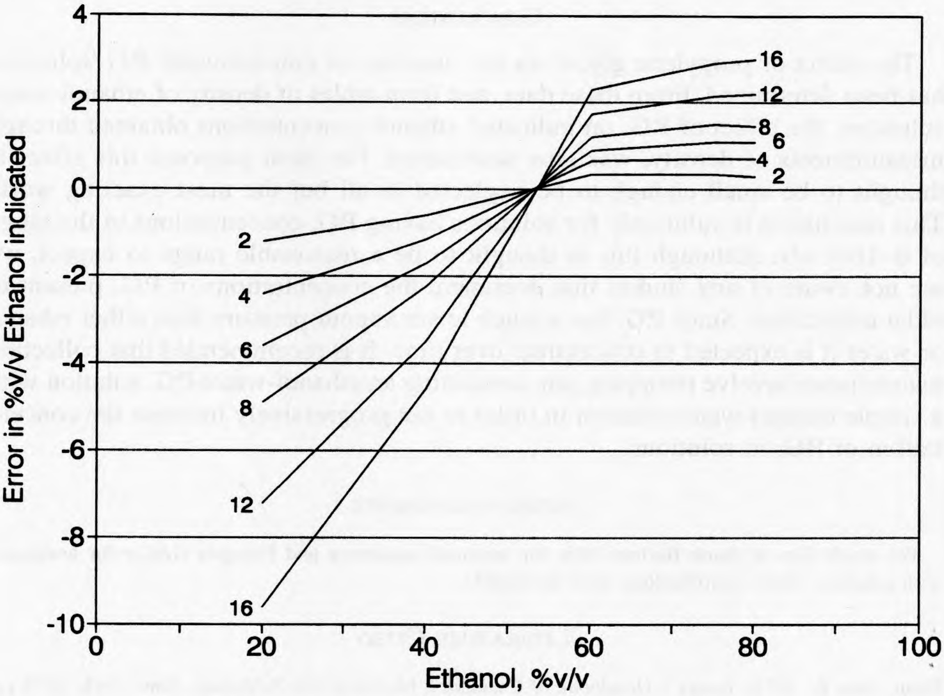

Figure 3. Error in indicated ethanol concentration determined through density measurements as a function of ethanol concentration for solutions containing 0, 2, 4, 6, 8, 12 and 16% v/v propylene glycol.

concentrations indicated by density measurements requires that the dependence of density on ethanol concentration also be taken into account. This was done by evaluating the change in indicated ethanol concentration for a given change in density using the Table for ethanol-water solutions at 25°C in the Canadian Alcoholmetric Tables (Revenue Canada, 1980). The significance of this uncertainty can be expressed in two ways.

First, we could specify the uncertainty in ethanol concentration indicated by a measured density and then determine the maximum P.G. concentration that could be tolerated. Most collections in ethanol-water preservatives have ethanol concentrations ranging several tens of percent. Consequently, a 2% v/v uncertainty in ethanol concentration indicated would be considered acceptable for most routine collection work. For many routine operations a 5% v/v might be considered acceptable. Table 6 shows the concentration of P.G. that would need to be present to cause a specified error in the indicated concentration of ethanol.

Alternatively, the effect of specified concentrations of P.G. on the error in ethanol concentration indicated can be considered (Fig. 3). By error we mean the difference between actual ethanol concentration and the ethanol concentration indicated by tables for a given density. It is evident from Figure 3 that, except at very low concentrations of ethanol, the effect of P.G. on indicated ethanol concentration is not great. In the range of greatest interest (i.e., 60–80% v/v ethanol) almost 12% v/v P.G. can be present before the error in indicated ethanol concentration reaches 2% v/v.

CONCLUSIONS

The effect of propylene glycol on the densities of ethanol-water-P.G. solutions has been determined. From these data, and from tables of density of ethanol-water solutions, the effect of P.G. on indicated ethanol concentrations obtained through measurements of density, was also determined. For most purposes this effect is thought to be small enough to be neglected in all but the most exacting work. This conclusion is valid only for solutions having P.G. concentrations in the range of 0–16% v/v. Although this is thought to be a reasonable range to expect, we are not aware of any studies that document the concentrations of P.G. present in older collections. Since P.G. has a much lower vapour pressure than either ethanol or water it is expected to concentrate over time. It is recommended that collection maintenance involve retopping jars containing an ethanol-water-P.G. solution with a simple ethanol-water solution in order to not progressively increase the concentration of P.G. in solutions.

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STUDIES OF THE RUSSELL EFFECT: PART I. PROCEDURE AND APPLICATIONS

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Abstract.—Procedures for using the Russell Effect for qualitative analyses were developed by extrapolation of published information and by testing different materials to define the working parameters of the technique. A description of an appropriate procedure is given, as well as examples of its application for (1) detecting differential oxidation rates within various parts of some museum materials, (2) comparing oxidation rates of similar materials used in museums, and (3) comparing oxidation rates resulting from different treatments of museum materials.

Most materials are susceptible to free radical damage resulting from oxidation reactions. Although the cumulative effects of low level oxidation are often observed, the slow oxidation of materials at room temperature has not been fully appreciated by the conservation community; however, it may be the most significant chemical cause of deterioration (Daniels, 1984a). The significance of this degradation mechanism to museum objects has been reviewed by Grattan (1980). The ambient rate of oxidation is so low that accelerated aging techniques are often required to measure deterioration. Accelerated aging techniques provide useful information, but they do not always replicate ambient processes, thus the results may be misleading. The Russell Effect, a photographic technique, is able to detect oxidation under ambient conditions. This phenomenon, originally described by W. J. Russell (1897, 1898, 1899, 1904, 1906, 1908), is characterized by the ability of peroxide sensitive photographic films, to acquire images in total darkness, as a result of oxidation of materials in close proximity. The Russell Effect has great potential as a non-destructive method for qualitatively detecting oxidation (Daniels 1984a, b, 1986a, b) because hydrogen peroxide (H_2O_2) is a by-product of oxidation. Daniels (1986a) has outlined three basic applications of the technique: (1) measuring the inherent rate of oxidation occurring within museum objects; (2) evaluating materials used in prolonged contact with objects (i.e., storage materials); and (3) evaluating the effect of certain conservation treatments on the autoxidation rate of treated materials.

The objective of Part I of the current study was to refine the Russell Effect procedure and to demonstrate its usefulness for assessing oxidation rates of collection-related materials. Part II (Leckie and Williams, 1994) of the same study, addresses the interpretation and reproducibility of images formed by the Russell Effect.

METHODS AND MATERIALS

Russell Effect procedure.—The basic steps of treating photographic film for Russell Effect purposes involve (1) sensitizing the film in an ammonia bath (Clifford, 1975), (2) exposing the film to a material that produces hydrogen peroxide (H_2O_2) vapor, and (3) developing the film. This entire procedure must be performed in complete darkness or with limited use of a Kodak #1A safelight. Kodak 2566

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sheet film (Cat. No. 121 4121; 20 × 25 cm) was used, but 27.5 × 35.0 cm sheet film (Cat. No. 128 3829), 35 mm roll film (Cat. No. 127 6153), or similar film that is not protected against peroxide, may be substituted. Acquiring film may require special arrangements with manufacturers or purchases from distributors outside of North America (Seth Gaugh, personal communication).

By viewing a corner of the film in a low light it was possible to determine the emulsion side of the film. The emulsion side was lilac colored as opposed to the burgundy color of the non-emulsion side. It was useful to consistently notch a specific corner of the film to help identify the emulsion side in the dark.

The film sensitizing procedure was standardized to add control to the film's responsiveness to H_2O_2. In this study the film was: (1) immersed for five minutes in an ammonium hydroxide solution (3% NH_4OH (vol/vol) plus 0.01% (vol/vol) undiluted Kodak Photoflo); (2) washed for two minutes in tap water; and (3) immersed for five minutes in 50% ethanol. All solutions were used at room temperature (typically 20°C). The NH_4OH solutions and tap water were used once for each batch and then discarded. To improve chemical consistency between batches, the NH_4OH solution was prepared in 30 liter quantities, easily allowing over ten batches to be processed with each preparation. The alcohol solution was replaced periodically as it became discolored.

To reduce procedural variation and to enable batch processing of film, a rack was built to process multiple sheets of film simultaneously (Fig. 1). The rack for the film was constructed of cardboard and designed to slip over the perimeter of the tanks containing sensitizing solutions. Notches were cut along the upper edge of the rack to position and separate stiff wires supporting individual sheets of film. This device was used to place the film in the three liquids previously described.

Glass tanks (17.5 cm H × 23.5 cm W × 16 cm D) were used to hold the sensitizing solutions. Sheet film was cut (16.25 cm × 21.25 cm) to fit the glass tanks. Each sheet was attached to a stiff wire with plastic clips, thus the film hung vertically on the rack and could be dipped into the appropriate tanks. Plastic clips were secured with rubber bands to maintain proper position on the wire.

After immersion in solutions, the sensitized sheets of film were laid on drying racks with the emulsion side up, and then allowed to air-dry for ten minutes. Afterward, drying was accelerated with a 15-minute exposure to circulated air (room-temperature) inside a filter flow air dryer.

Dried, sensitized film was stored in a plastic film bag within a film box to avoid exposure to light. Although film was often used immediately after sensitizing, on occasion it remained in storage for up to 18 hours before use. Clifford (1975) reported treated film can be stored in the dark for up to seven days without loss of sensitivity.

To ensure images would result from H_2O_2 alone, total darkness was required when exposing sensitized film to test material surfaces. The film was placed as close as possible to the material being tested. If actual contact was necessary, care was taken to avoid scratching the emulsion; damaged emulsion can sometimes confuse the interpretation of images. The length of exposure varied according to the rate of oxidation of the material being tested. Through trial-and-error, it was determined that most organic and inorganic materials produced images with 16- to 48-hour exposures.

Exposed film was developed for one minute in Kodak-D 19 (full strength), rinsed in Kodak indicator stop bath, and fixed for four minutes in Kodak Ektaflo. The film was then washed for at least 20 minutes in running tap water, rinsed in Kodak Photoflo, and air-dried.

Although it is relatively easy to demonstrate the Russell Effect, it can be challenging to use the procedure in ways that provide meaningful results. Variables, such as length of exposure, raise questions about the significance of some observations. For this reason, several applications of the Russell Effect were tested, specifically (1) detecting differential oxidation rates within materials, (2) comparing oxidation rates of related materials, and (3) comparing oxidation rates of common materials subjected to different treatments.

Detecting differential oxidation rates within materials.—The first application of the Russell Effect tested the inherent oxidation of an object or material. Various materials were tested, including flat rodent skins and laminated pasteboard used for storage containers.

The skin received no treatment other than being air-dried after mechanical removal of extraneous flesh and fat. The flesh side of the skin sample was placed in direct contact with the film. The skin and film were placed between two plates of glass. Exposure time was 24 hours.

Testing of the laminated pasteboard storage tray required that both sides of the pasteboard be tested. The samples were placed in direct contact with the sensitized film for 17 hours.

Comparing oxidation rates of related materials.—The second application involved assessing the relative rates of oxidation of similar materials. A variety of cellulosic material were tested, including

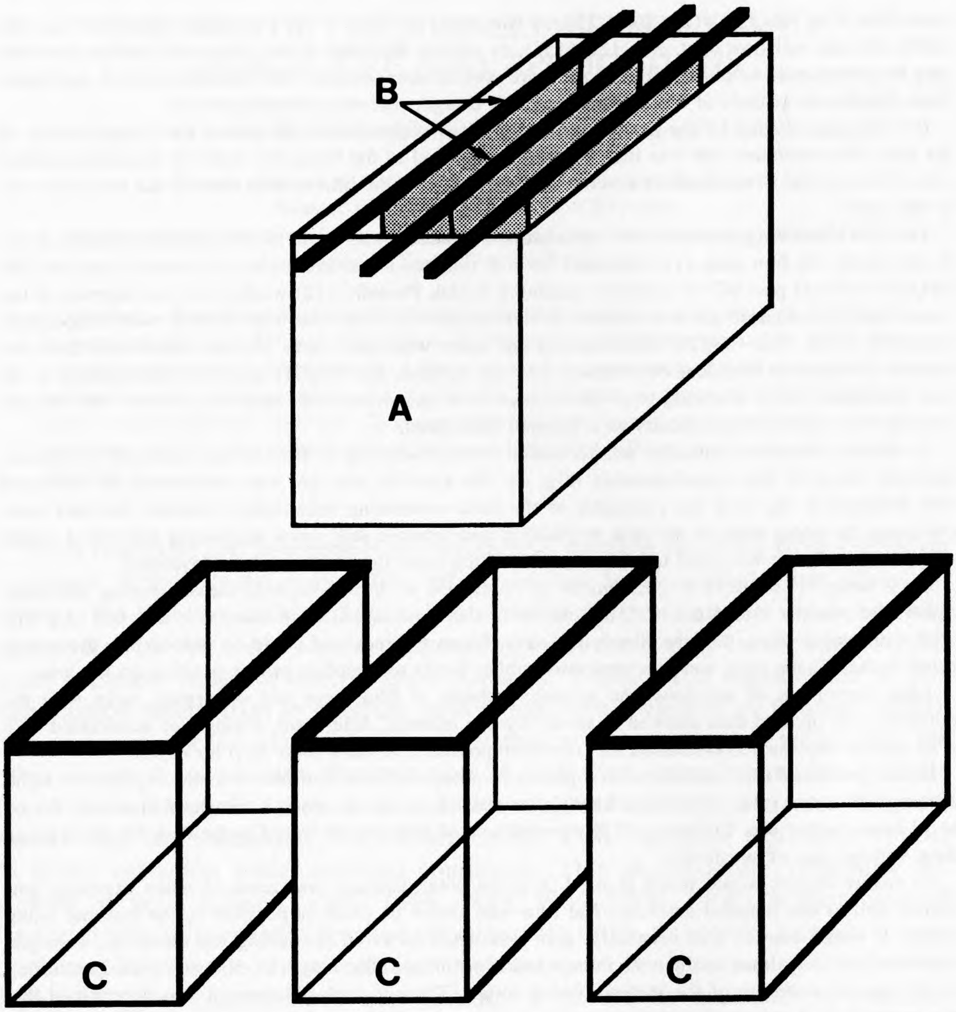

Figure 1. Illustration of materials and procedure for sensitizing film for making Russell Effect images as described in the text. The cardboard rack (A) is notched to hold and separate multiple sheets of film, each clipped to a wire hanger (B). By fitting the rack over the solution containers (C) the sheets of film can be sensitized simultaneously. From left to right, the containers hold solutions of 3% ammonium hydroxide, tap water, and 50% ethanol.

chromatography paper, specimen labels, and newspaper. Samples, in direct contact with the film, were placed in an X-ray cassette case for a 17-hour exposure.

Comparing oxidation rates resulting from different treatments.—The third application tested the ability of the Russell Effect to detect changes in oxidation levels as a result of a particular treatment. Two experiments were set up to compare controls with treated samples.

The first experiment, which complemented pesticides studies reported by Williams *et al.* (1989), compared the oxidation rates of fumigated and unfumigated skin samples. A rodent skin was air-dried after mechanical removal of extraneous tissues. The skin was split in half longitudinally. One half was treated in a microenvironment of saturated dichlorvos fumes for 12 months and then allowed to off-gas for over six months. The other half served as a control and was treated in the same manner, except without pesticide exposure. At the end of the test-period, the flesh side of both halves was placed in direct contact with sensitized film for 16 hours.

The second experiment compared the oxidation rates of paper treated by various solvents to remove impregnated animal lipids that were permitted to migrate through a sheet of Permalife® paper. Lipid-saturated paper samples were removed with a 9 mm hole-punch. These disks were weighed with a Mettler analytical balance and compared to unsaturated disks to determine the approximate quantities of lipids. Individual disks were placed in five milliliters of solvent for three minutes, air-dried, and reweighed to determine the amount of lipids removed. The solvents tested included naphtha, Stoddard solvent, carbontetrachloride, chloroform, trichloroethylene, trichloroethane, 95% ethanol, acetone, ether, methyl cyclohexane, cyclohexane, hexane, toluene, heptane, and xylene. Following the treatment, the Russell Effect was used to compare oxidation rates of the disks. The controls consisted of a Permalife® disk that had not been exposed to lipids or chemicals, and other disks that had been exposed only to lipids. A series of wells (diameter, 9.5 mm; depth, 5.4 mm) were made by drilling holes in a plate of Plexiglas®. Disks were placed in the bottom of the wells. The film was laid emulsion side down, on top of the wells for 17.5 hours. A glass plate on top of the film was used to provide a better seal of the film over the wells.

RESULTS AND DISCUSSION

Daniels (1986a) recognized the ability of the Russell Effect to indirectly detect oxidation as potentially useful to conservation. The purpose of our project was to comment on the practicality of the three applications proposed by Daniels (1986a), as well as to observe any limitations associated with the Russell Effect.

The first application of the Russell Effect tested the oxidation rates within materials. Testing of the flesh of a rodent skin suggested different rates of oxidation in different regions of the skin. Comparisons between the Russell Effect image and the actual specimen revealed that dark spots corresponded to patches of skin that had yellowed, probably as a result of oxidation of fatty tissue that was not removed during preparation (Fig. 2A). This test clearly shows problems encountered with improperly processed skins.

The laminated pasteboard used for storage trays and boxes produced dark images, suggesting high oxidation levels. The surface of the board that coincides with the exterior of the trays was a glossy, smooth paper that probably had been calendared and coated. The image produced by this side included an unusual pattern of dark dots occurring in parallel lines. Dissecting the laminate revealed that these lines corresponded to an adhesive that had probably been applied with a roller (Fig. 2B). The object side of the laminates did not produce a strong response. In this test the Russell Effect not only showed differential oxidation rates of the visible composite laminates, but it also detected higher oxidation rates of materials that were not visible.

The second application of the Russell Effect compared oxidation rates in chromatography paper producing a faint image, newspaper generating a slightly darker image, and a specimen label generating the strongest image. This comparison of relative oxidation rates of paper-based materials provided a perspective for evaluating the quality of materials to be used with specimens. Although it would be hoped that specimen labels would be more stable than common newspaper, the higher oxidation rate of the labels suggests other factors may be compromising product integrity. The labels tested were made from Resistall® paper which incorporates melamine and an alum solution to make the paper resistant to fluids (Williams, 1990). Acids formed by the alum will break the covalent bonds connecting the glucose molecules of the cellulose chains, thus resulting in the formation of free radicals that perpetuate the oxidation process.

The third application of the Russell Effect compared the effect of different

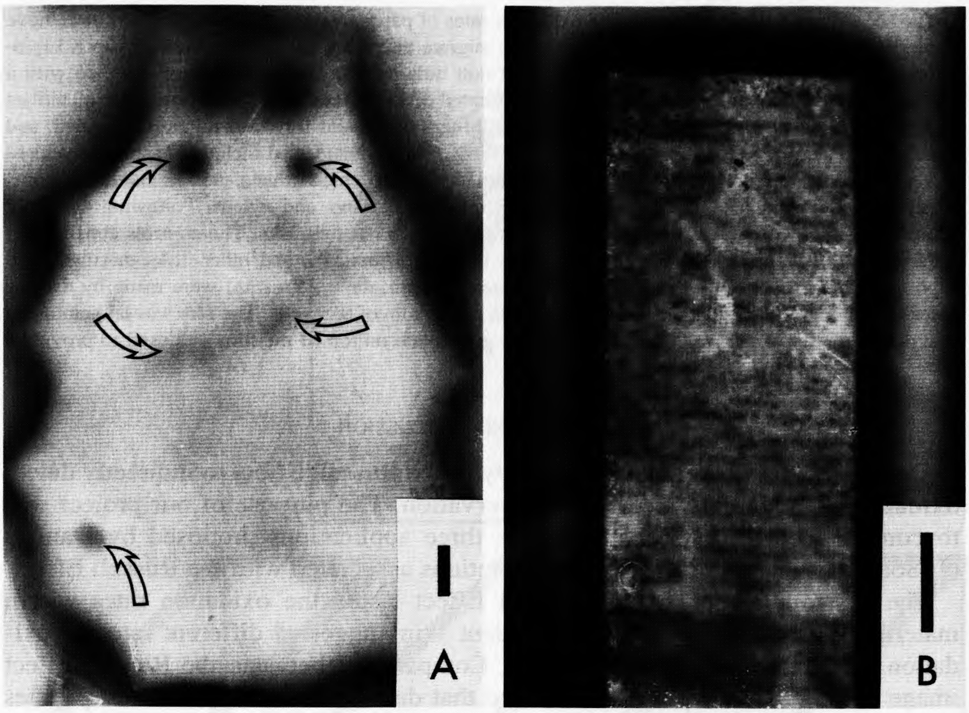

Figure 2. Photographs of Russell Effect images on photographic film, showing differential oxidation rates of (A) a flat rodent skin (exposure time = 24 hours), and (B) laminated pasteboard used for storage trays (exposure time = 17 hours). The dark spots on the skin, indicated with arrows, correspond to areas probably affected by fatty tissues. The banding on the pasteboard corresponds to adhesive patterns, probably laid down by a roller, between paper layers. Scales in each photograph are equal to one centimeter.

treatments on a material. Dichlorvos fumigation was one of the treatments used to compare rates of oxidation between control and test samples. No differences could be detected by visual or manual inspection; however, the Russell Effect image indicated the treated sample evolved much more H_2O_2 vapor than the control sample (Fig. 3).

Solvent treatments also were used to test Russell Effect applications. Weight changes of the paper disks subjected to solvent treatments suggest that all but one of the chemicals tested removed at least 75% of the lipids. The one exception was ethanol which removed only 8.1% of the lipids. The most effective solvents were chloroform (94.6%), trichloroethylene (95.7%), acetone (92.4%), ether (97.3%), hexane (95.2%), toluene (94.2%), and heptane (92.1%). With regard to the results of the tests involving the Russell Effect, the sample treated with ethanol revealed the greatest level of oxidation, which was similar to a lipid-saturated sample that had not been treated with any chemical. Chloroform, acetone, ether, and hexane had responses that were closest to the control sample having no lipid or solvent treatment. Although some chemicals (i.e., toluene and heptane) were effective in removing lipids, the treatment seemed to contribute to accelerated oxidation (Fig. 4).

The actual results of the experiments involving pesticides and solvents should

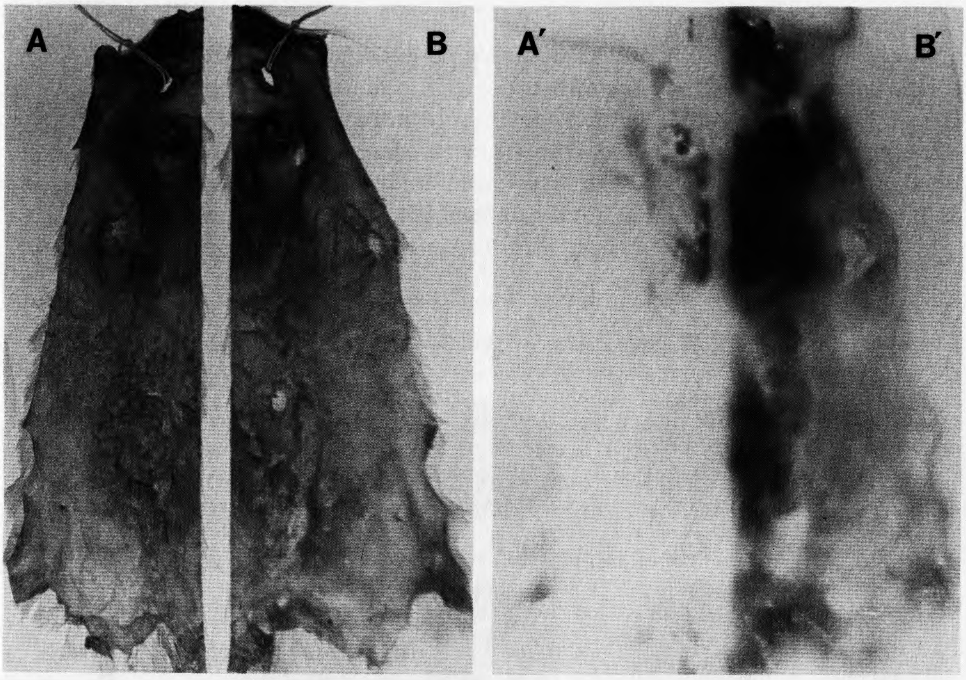

Figure 3. Photograph of Russell Effect images (A′ and B′) on photographic film, created with a 16-hour exposure of a pelt that had one half untreated (A) and the other half (B) fumigated 12 months with dichlorvos. The dark areas of the fumigated half (B′) show greater levels of oxidation.

be considered only preliminary and in need of further investigation; however, the Russell Effect appears to be very useful for comparing treatments. In the tests conducted, the significance and implications of the treatments were not realized by standard, non-destructive examination methods. Based on visual and manual examination of both halves of the rodent pelt, one could have assumed that dichlorvos was an acceptable method of pest control. Similarly, simple examination of Permalife® paper would suggest that a variety of solvents could be used for removing lipids. The differences in oxidation rates, as demonstrated by the Russell Effect, can be quite useful in determining the preferred treatments.

The primary strength of the Russell Effect lies in its ability to detect problems that are not necessarily visible or detectable by other non-destructive procedures. Although the procedure seems to have great potential in focusing on problems involving oxidation of materials, certain basic limitations must be considered.

The usefulness of the Russell Effect is seriously restricted by variability of film sensitivity and the risk of film contamination. To minimize these problems, a highly regimented procedure is necessary.

Another problem is the selection of test samples that are suitable for comparison. Russell Effect image densities reflect the total H_2O_2 that interacts with the emulsion. This primarily depends on the amount of oxidation that has occurred during the exposure. The amount of oxidation that has occurred depends on the rate of oxidation, as well as modifying factors, including thickness, volume, den-

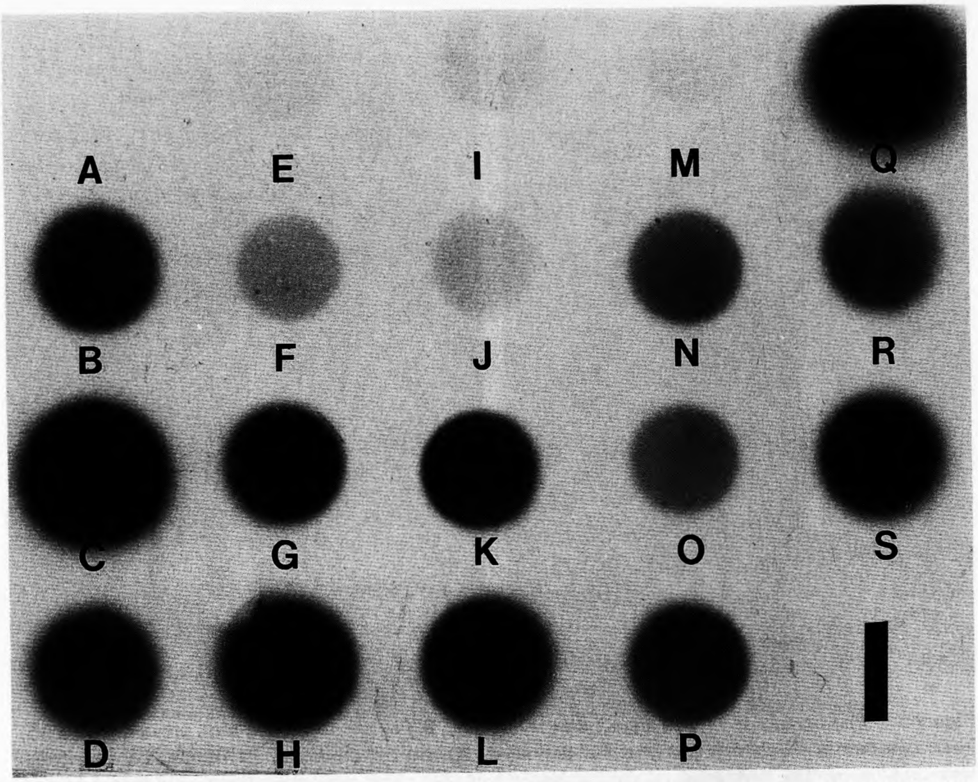

Figure 4. Photograph of Russell Effect images on photographic film, showing different oxidation rates resulting from various solvent treatments of lipid-saturated Permalife paper (A = untreated paper serving as control; B = naphtha; C = Stoddard solvent; D = carbontetrachloride; E = chloroform; F = trichloroethylene; G = trichloroethane; H = ethanol; I = acetone; J = ether; K = methyl cyclohexane; L = cyclohexane; M = hexane; N = toluene; O = heptane; P = xylene). Images Q, R, and S show samples not treated with solvents, with the latter two samples showing visible discoloration. The scale equals one centimeter; exposure time was 16 hours.

sity, surface to volume ratio (i.e., solid wood and sawdust), and surface (i.e., freshly abraded surfaces and oxidized patina). The set-up of the exposure is also important. If an object is in contact with the film, H_2O_2 vapor exposes the film directly; however, open spaces between the object and film, can allow H_2O_2 vapor to diffuse or escape before it reaches the emulsion, thus resulting in reduced image density or resolution. A less obvious factor is the test material's environment prior to the film's exposure. For instance, exposure of test materials to bright light may cause a temporary elevation in oxidation even after the lights have been removed (Daniels, 1986a).

All these variables must be carefully considered before relative densities of images can be used to evaluate relative rate, or amount of oxidation that has occurred. Despite some limitations the procedure can prove useful and interesting. The potential applications of the Russell Effect are limited only by a clear understanding of the inherent parameters of the procedure and the imagination of the user.

CONCLUSION

The Russell Effect has tremendous potential as a non-destructive method for evaluating low levels of oxidation that cause cumulative damage to materials. It is best suited for rapid generation of qualitative information which can be used for rough comparison of materials, or to identify potential projects for more sophisticated studies that will require more time and specialized analytical techniques. The primary drawback of the Russell Effect, producing film of comparable sensitivity, can be minimized by using a highly regimented sensitizing procedure.

ACKNOWLEDGMENTS

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STUDIES OF THE RUSSELL EFFECT: PART II. INTERPRETATION AND REPRODUCIBILITY

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Abstract.—The Russell Effect is a photographic response of sensitized film to peroxide exposure. Although it can be a valuable, non-destructive indicator of oxidation levels of various materials, its use has been restricted by problems of interpreting the significance of image densities as well as problems of documenting and replicating results. Series of hydrogen peroxide solutions of various concentrations were used to create different image densities. These were used to evaluate variables that can influence Russell Effect images. It was determined that standardization of the sensitizing procedures can allow close reproducibility of Russell Effect images for a given set of circumstances. Also, it was speculated that hydrogen peroxide concentration gradients could be used to effectively compare levels of oxidation between different observations.

The ability for some photographic films to form oxidation images in the absence of light has been referred to as the Russell Effect in honor of W. J. Russell who investigated the phenomenon at the turn of the century (Russell, 1897, 1898, 1899, 1904, 1906, 1908). This phenomenon has been recognized as being potentially valuable for conservation studies because it is a non-destructive method for detecting oxidation in different materials (Daniels 1984a, b, 1986a, b). Although the Russell Effect has been known since the mid-1800s, and has been discussed in the literature (Bullock, 1927:136–152; Clifford, 1975; Daniels, 1984a, b, 1986a, b; Keenan, 1926), it has had little use in conservation studies. Two probable factors contributing to this lack of use are (1) uncertainty about the actual causes of the Russell Effect images, and (2) the inability to provide reproducible and meaningful results.

With regard to the causes of the Russell Effect, images might be caused by light emitted from the material in the form of chemiluminescence or phosphorescence because autoxidation can result in weak light emission (Grattan, 1980). If light was the active agent it should be able to pass through thin plate glass placed between the active material and the film. When this possibility was tested by Russell (1897) using ordinary soda glass and by Daniels (1984a) using silica glass, no images resulted. The argument that the Russell Effect was caused by a small amount of light emitted by the material was not supported.

In preliminary experiments Russell (1897) determined it was not necessary to have direct contact between the active material and the film for an image to appear on the film. This discovery led him to believe that the active agent was a vapor. Subsequent experiments supported this hypothesis (Russell, 1898). In an attempt to identify the vapor, Russell (1898, 1899) considered all the known active organic materials he had encountered. He deduced the property common to all of them was, "their reducing or oxygen-absorbing power, hence the conclusion that it is this property which enable them to act on the photographic plate." Russell (1899) also identified various active metals. He believed these metals could, "decompose

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water, and in the presence of oxygen cause the formation of hydrogen peroxide." Using various qualitative tests he confirmed that hydrogen peroxide was being evolved from active materials. This brief review of Russell's experiments strongly suggests that hydrogen peroxide (H_2O_2) is the major active agent. Seth Gaugh at the Kodak Research Laboratories in Rochester, New York, also conducted experiments which support this view (Gaugh, personal communication).

The mechanism by which H_2O_2 creates an image is unclear; however, Daniels (1986a) postulated that H_2O_2 causes the reduction of silver halide to silver. Although it seems clear that H_2O_2 can cause the Russell Effect and H_2O_2 is released by certain materials, the actual relationship between optical density and the amount of H_2O_2 released has not been determined (Daniels, 1986a). It would seem likely that other peroxides, peroxy radicals, or single oxygen atoms also could be involved (Clifford, 1975; Daniels, 1984a); however, there is little doubt that H_2O_2 is the primary chemical reacting with silver compounds on film.

Problems of sensitizing film for H_2O_2 exposure make the Russell Effect difficult to reproduce quantitatively. Although the use of ammonia has been used routinely to increase the sensitivity of various photographic plates and films (Carroll and Hubbard, 1933; Jenkins and Farnell, 1976; Leckie and Williams, 1994), little has been done to develop ways of assessing the sensitivity of individual sheets for Russell Effect images (Daniels, 1984a). The lack of a suitable standard with every exposure does not provide a means for comparing exposures (Daniels, 1986a) or for making meaningful comparisons except between images on the same sheet of film.

The authors have described, in Part I of the current study, the sensitizing procedures that make it possible to produce Russell Effect images (Leckie and Williams, 1994); however, questions remain regarding interpretation and reproducibility. Part II of the study has produced various image density gradients and used them to assess variables that potentially affect Russell Effect images. It is suggested that such density gradients could be useful for image interpretation and comparison if incorporated as part of the exposure.

MATERIALS AND METHODS

For this project it was necessary to develop conditions where Russell Effect images would exhibit (1) a wide range of densities, (2) clear increments of image densities, and (3) reproducibility for a specific exposure under given environmental conditions. To achieve these objectives, suitable image gradients were created and these image gradients were used to examine variables that might affect reproducibility.

Image gradients were produced with a series of dilute H_2O_2 solutions capable of generating a range of concentrations of H_2O_2 vapor. A stock solution of H_2O_2 (Fisher H325-500; label indicates 30–32% concentration) was diluted with distilled H_2O to a 2% stock solution. Further dilutions were made by adding a solution of glycerol and distilled H_2O (50/50 vol/vol); the glycerol was used to help control evaporation of the H_2O_2 solutions.

Series of tests were conducted to determine the effect of different H_2O_2 volumes and H_2O_2 concentrations on Russell Effect images. To examine the effect of H_2O_2 volume, two concentrations (0.01% and 0.05%) were tested with three different volume gradients—(1) a "linear" gradient was produced by reducing the solution volume by 2 ml from each preceding solution volume (10, 8, 6, 4, and 2 ml); (2) a "Base-2" exponential gradient was produced by reducing the solution volume to one-half of each preceding solution volume (10.00, 5.00, 2.50, 1.25, and 0.63 ml); and (3) a "Base-10" exponential gradient was produced by reducing the solution volume to one-tenth of each preceding solution volume (10.0, 1.0, and 0.1 ml). The H_2O_2 solutions were tested simultaneously using 25 flint-glass vials (diameter, 18.5 mm; depth, 48.5 mm), secured in five rows and five columns with a Plexiglas®

template. This template also served as a platform for the film (emulsion side down) to be exposed to the rising vapors. To control peripheral diffusion of the vapors, a glass plate was used to weigh down the film and hold it securely over the vial openings.

Based on the previous test it was determined that the linear and the Base-2 gradients had the greatest potential for producing detectable differences of image densities over an acceptable range of concentrations. To obtain a desirable range of images for density gradients, the numbers of H_2O_2 solutions were expanded from five to 14.

A polystyrene tissue culture plate (Corning 25855) provided smaller wells but in numbers sufficient to test a greater number of concentrations. The culture plate also served as a platform for the film and glass plate. Tests for concentration were based on one- and two-hour exposure times.

To test the effects of concentration, 0.25 ml of each H_2O_2 solution was used. Concentrations followed "linear" and "Base-2" exponential increments. The linear concentration gradient, produced by diluting the concentration of the previous solution by 0.2%, ranged from 2.0% to 0.0025%; the weakest concentration (0.0025%) would be considered 0.0%, but H_2O_2 was added so that H_2O_2 vapor would be produced). The Base-2 exponential gradient, produced by diluting the concentration of the preceding solution by one-half, ranged from 1.0% to 0.000125%.

To examine the reproducibility of image densities, as described by Leckie and Williams (1994), a single sheet of sensitized film was cut in half and the two parts were exposed simultaneously to equivalent H_2O_2 solutions to determine if solutions could be duplicated to produce similar images. Russell Effect images also were created on four quarters of nine sheets of film giving a total of 36 images. The nine sheets of film were sensitized in three batches of three sheets each. Eighteen images, created with linear and Base-2 exponential solution gradients, were based on one-hour exposures; the other eighteen images, created with identical solutions, were based on two-hour exposures. Individual images were examined on a light table to determine which solution concentrations produced opaque, clear, and transition images. Image patterns were then compared with one another to evaluate reproducibility of results.

RESULTS

It was determined that different volumes of H_2O_2 solution were not useful in producing Russell Effect images with a wide range of densities or clear increments of image densities. Although the 10-ml volume consistently produced a darker image (possibly because of closer proximity to the film) it seemed anomalous in comparison with the other volumes.

The 0.01% concentration provided clearer results than 0.05% concentration. This indicated image density is more dependent on H_2O_2 concentration than volume, thus series of H_2O_2 gradients based on concentration were better for producing Russell Effect images that fit the criteria described above. The linear series (H_2O_2 concentration from 2.0% to 0.0025%) produced the greatest range of image densities, but was not considered useful because of problems of reaching exposure extremes and unsuitable increments of image density. The Base-10 exponential H_2O_2 gradient tended to give either a positive or negative indication of the presence of H_2O_2, thus an image gradient was not satisfactorily achieved. The Base-2 exponential gradient (H_2O_2 concentration from 1.0% to 0.000125%) produced a wide range of image densities, and more of the overall scale was correctly exposed. Because the range also exhibited clear increments in image density, the Base-2 exponential H_2O_2 gradient was the most suitable sequence for producing useful images (Fig. 1).

With regard to the evaluation of reproducibility, the image densities produced with the Base-2 exponential gradient were very similar within and between different batches; only one batch (B1) out of six, produced darker Russell Effect images than expected. For both exposure times opaque images were formed with solutions having H_2O_2 concentrations of 0.063% or more. The lowest concentra-

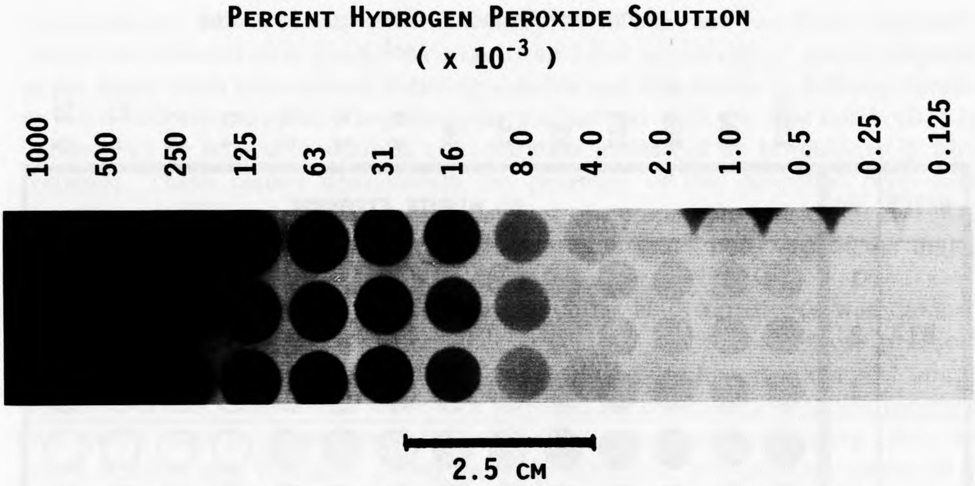

Figure 1. Photograph of Russell Effect images on photographic film, showing an image density gradient produced with a series of hydrogen peroxide solutions where each column, from left to right, was diluted to half the concentration of the preceding column.

tion that usually produced opaque images with one-hour exposures was 0.063% (55% of the cases); however, 0.015% was the lowest concentration for two-hour exposures (78% of the cases). The transition from opaque to clear images averaged 4.2 increments for both exposure times with the one-hour exposure having the greatest range of three to five, as opposed to four to five for two-hour exposure (Fig. 2). Although there was good consistency among the images produced (except for B1), there were inconsistencies in the processing quality. These inconsistencies may have been partially caused by the amount of film handling in the dark during sensitizing, positioning for exposure, and developing.

DISCUSSION

An important factor affecting the use of the Russell Effect as an analytical tool in museums has been a lack of information about methods for obtaining reproducible images. Sources of variability include environmental conditions (i.e., light, temperature, and relative humidity), sensitizing solutions, and processes of immersing and drying film. To control some of these variables the concentration of the ammonia bath was made more consistent by preparing large volumes of solution and dispensing a fresh aliquot for each batch of film processed. Variations due to immersing and drying film were controlled by a regimented series of steps which allowed sheets to be sensitized concurrently, as described by Leckie and Williams (1994). However, the utility of the procedure is still affected by the ability to produce an image density gradient for comparative purposes. The image density gradient must exhibit (1) a wide range of densities, (2) clear increments of image densities, and (3) reproducibility for a given exposure under the same environmental conditions. Of the methods tested, the most suitable was a gradient of H_2O_2 solutions that varied in concentration exponentially (Base-2).

The standard, or "reproducible image," was used on the assumption that sheets with the same H_2O_2 sensitivity, simultaneously exposed to equivalent concentra-

PERCENT HYDROGEN PEROXIDE SOLUTION
(x 10^{-3})

		1000	500	250	125	63	31	16	8.0	4.0	2.0	1.0	0.5	0.25	0.125
BATCH	NO	60 MINUTE EXPOSURE													
B3	1	●	●	●	●	●	◍	◍	◍	◍	○	○	○	○	○
	2	●	●	●	●	●	◍	◍	◍	◍	○	○	○	○	○
	3	●	●	●	●	●	◍	◍	◍	◍	◍	○	○	○	○
B2	1	●	●	●	●	●	◍	◍	◍	◍	◍	○	○	○	○
	2	●	●	●	●	●	◍	◍	◍	◍	◍	○	○	○	○
	3	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○	○
B1	1	●	●	●	●	●	●	●	◍	◍	◍	○	○	○	○
	2	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	3	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
BATCH	NO	120 MINUTE EXPOSURE													
B4	1	●	●	●	●	●	●	◍	◍	◍	◍	◍	○	○	○
	2	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	3	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
B6	1	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	2	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	3	●	●	●	●	●	●	●	◍	◍	◍	◍	◍	○	○
B5	1	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	2	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○	○
	3	●	●	●	●	●	●	●	●	◍	◍	◍	◍	○	○

Figure 2. Illustration summarizing the results of the reproducibility tests. Each row represents an image density gradient similar to Figure 1, and each is positioned according to the progression of the images produced. The closed circles represent opaque images, whereas the open circles represent the absence of an image. The stippled circles represent the transition between the two extremes. Note (except for B1) the similarity of images between batches and numbers of the same exposure time.

tion gradients, would produce identical images. For one- and two-hour exposures, respective concentration gradients demonstrated that sensitivity of sheets prepared in the same batch were almost indistinguishable and that sheets in different batches were still very similar. The discrepancy observed with the first batch (B1) is believed to be related to solution concentration instead of an irregularity in film response. These results demonstrate the potential of the described procedure (Leckie and Williams, 1994) to produce film of comparable sensitivity to H_2O_2, an important ability because uncontrolled variability has been one of the major issues of the Russell Effect in the past.

Although the ability to produce film of similar H_2O_2 sensitivity was demonstrated, the H_2O_2 concentration gradient potentially has a much more practical application. A H_2O_2 concentration gradient could be used to generate an "image density gradient" that would serve as a standard for comparing densities between film sheets used in conventional Russell Effect exposures that require 16 to 48 hours (Leckie and Williams, 1994). In such situations, the gradient serves as a viable method of interpreting Russell Effect images because identical image density gradients on different sheets of film allow meaningful comparisons of images produced by the test materials. As a result, an image density gradient can be used like a gray-scale used in black and white photography, for detecting variations in film sensitivity, exposure duration, and/or developing conditions.

Unfortunately, the image density gradients used in this study are not as reproducible as photographic gray-scales. This is due to variation in concentrations of H_2O_2 vapor, due to the effects of photodegradation and evaporation. Control over these factors is enhanced by using properly stored batch-mixed H_2O_2 solutions to make the concentration gradients when the film is to be exposed. It is also important that H_2O_2 vapors are not allowed to diffuse before exposing the sensitized film. By controlling these conditions, image density gradients can be used as a standard for density comparisons between various Russell Effect exposures. In the current study, short exposures were used to elucidate the basic characteristics of image density gradients. In actual practice, it would be necessary to experimentally determine the H_2O_2 dilutions that would correspond to the materials to be examined with Russell Effect procedures.

CONCLUSIONS

This study investigated the reproducibility of Russell Effect images. Based on this work it is possible to reproduce the Russell Effect for qualitative analysis. Further control of variables, such as length of exposure and density gradient stability, will have to be gained before the procedure might have quantitative applications. This study showed that a Base-2 exponential gradient of H_2O_2 concentrations could be used for documenting and comparing levels of oxidation between different observations.

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IONISING RADIATION ASSOCIATED WITH THE MINERAL COLLECTION OF THE NATIONAL MUSEUM OF WALES

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Abstract.—Measurements of radiation and radon gas levels in the Mineral Store at the National Museum of Wales indicated that amounts were sufficiently high for the Ionising Radiations Regulations to apply (The Ionising Radiations Regulations, 1985). Radiation surveys of the Mineral Collection of the National Museum of Wales were carried out for both direct gamma radiation levels and for radon contamination. Whole body gamma ray dose rates of up to 90 μSv hr^{-1} and radon levels of 750 Bq m^{-3} were measured. At these levels the 1985 Ionising Radiation Regulations of the United Kingdom required steps to be taken for radiation dose restriction. Following these measurements, rules, drawn up in June 1986, to limit access to the Mineral Store and its radioactive specimens were considered unsatisfactory. Additional measures were taken in 1989 and 1992 to further minimise radiation exposure to staff using the Mineral Collection. In 1989, radioactive specimens were segregated to a section of the Mineral Store allocated for them. Two criteria were used to identify specimens for segregation. The first criterion was whether a specimen included a known radioactive species; tables of approved uranium and thorium mineral names, synonyms and obsolete terms were drawn up for this purpose. The second criterion was whether a specimen contained sufficient adventitious radioactivity to be readily detectable above background. A radiation contamination monitor was used for this and adventitious radioactivity was detected in rare-earth (lanthanide) minerals and other specimens. In 1992, an isolation store, equipped with radon purging ventilation, was established at the National Museum of Wales, and the segregated radioactive specimens from the Mineral Collection were transferred there. Radioactivity no longer presents a hazard in the main Mineral Collection and access to it, formerly subject to dose limitation rules, has ceased to require radiation safety restrictions.

The Mineral Store at the National Museum of Wales is an internal room about 8 metres square by 3 metres high housing approximately 25,000 specimens. The store (ca. 200 m^3) is air-conditioned by a recirculatory system with no outside make-up air and no external ventilation. The system recycles the air through a disposable paper filter at a rate of several air changes per hour. The system conditions the air to 50% RH and a temperature of 20°C. The specimens are kept in 13 banks of plywood drawers mounted on a custom built mobile compacta storage system (Howe, 1986).

The Mineral Collection is a resource for research and for display material, and although it is available to the public by appointment it is not open for casual perusal. Dixon (1983) investigated radiation hazards to collectors of small numbers of geological specimens containing natural radioactivity. Whereas the results of his work showed that dose rate, radon exhalation, and loose activity arising from radioactive geological specimens can be high enough to warrant consideration of the hazards, he concluded that for small collections of about 500 specimens containing only five radioactive specimens the risk from radiation is small. The Radioactive Substances (Geological Specimens) Exemption Order (1962) permits geological collections containing up to 100 kg of uranium and thorium to

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be exempted from the constraints of the Radioactive Substances Act (1960). All uranium and thorium minerals are radioactive and 2% (about 500 specimens) of the Mineral Collection in the National Museum of Wales is composed of uranium or thorium mineral specimens; another 1% (about 250 specimens) has been found to contain adventitious radioactivity sufficient to be detected easily. In view of the number of known radioactive specimens, it was considered advisable to examine the collection for its potential as a radiation hazard (The Ionising Radiations Regulations 1985. Approved Code of Practice. The protection of persons against ionising radiation arising from any work activity). Acting on this concern, the Museum purchased a Berthold LB133 dose rate meter and a Berthold LB1210B contamination monitor. The Museum later purchased a Pylon radiation monitor with Lucas scintillation cells for measuring radon gas.

IONISING RADIATION HAZARDS

Hicks (1983), Brunton *et al.* (1985), King (1986) and Howie (1987) have presented advice on handling radioactive geological specimens but included no quantitative radiation data. The radiation hazard presented by a geological collection containing radioactive specimens depends on the quantity of radiation emanating from the specimens and the amount of radioactive contamination being released to the surroundings. These are in turn dependent upon the collective radioactive strength of the specimens and quantity of radon exhaled by them.

The radioactive strength, or activity, of a substance is measured in becquerels per gram (Bq g^{-1}). The activity of radioactive mineral specimens is markedly variable (Dixon, 1983) and depends on the species concerned, its purity and the amount of mineral present. The activity of a collection is the sum of the activities of its specimens.

The quantity of radon exhaled by minerals is measured in becquerels per hour per kilogram (Bq $hr^{-1}kg^{-1}$) and is also highly variable (Dixon, 1983). Because radon is radioactive and decays it will attain a dynamic equilibrium with its source if not dispersed. Therefore there will be an equilibrium quantity of radon, in Bq, associated with any collection of radioactive mineral specimens. The actual concentration of radon gas in a mineral store, in becquerels per cubic metre (Bq m^{-3}), will depend on the ventilation rate of the store as well as the quantity of radon associated with the collection. If the store has no appreciable ventilation then the radon concentration in Bq m^{-3} will be approximately the radon equilibrium value in Bq divided by the volume of the store in m^3. This is a simplified approach to assessing the radon hazard. Many other factors, not described here, need to be considered for precise risk assessments. Nevertheless, in order to give an indication of the scale of the radon hazard this simplified model of radon behaviour was adopted at the National Museum of Wales.

GAMMA RAY DOSE RATE SURVEY

A Berthold LB133 portable dose rate meter was employed to survey the gamma ray radiation levels in the Mineral Store. The radiation level inside the compacta storage varied widely along each bay but was in places two orders of magnitude above normal background level. The radiation dose rate was measured at a number of points along each bay at a height of 1 m. The results are plotted on a plan of

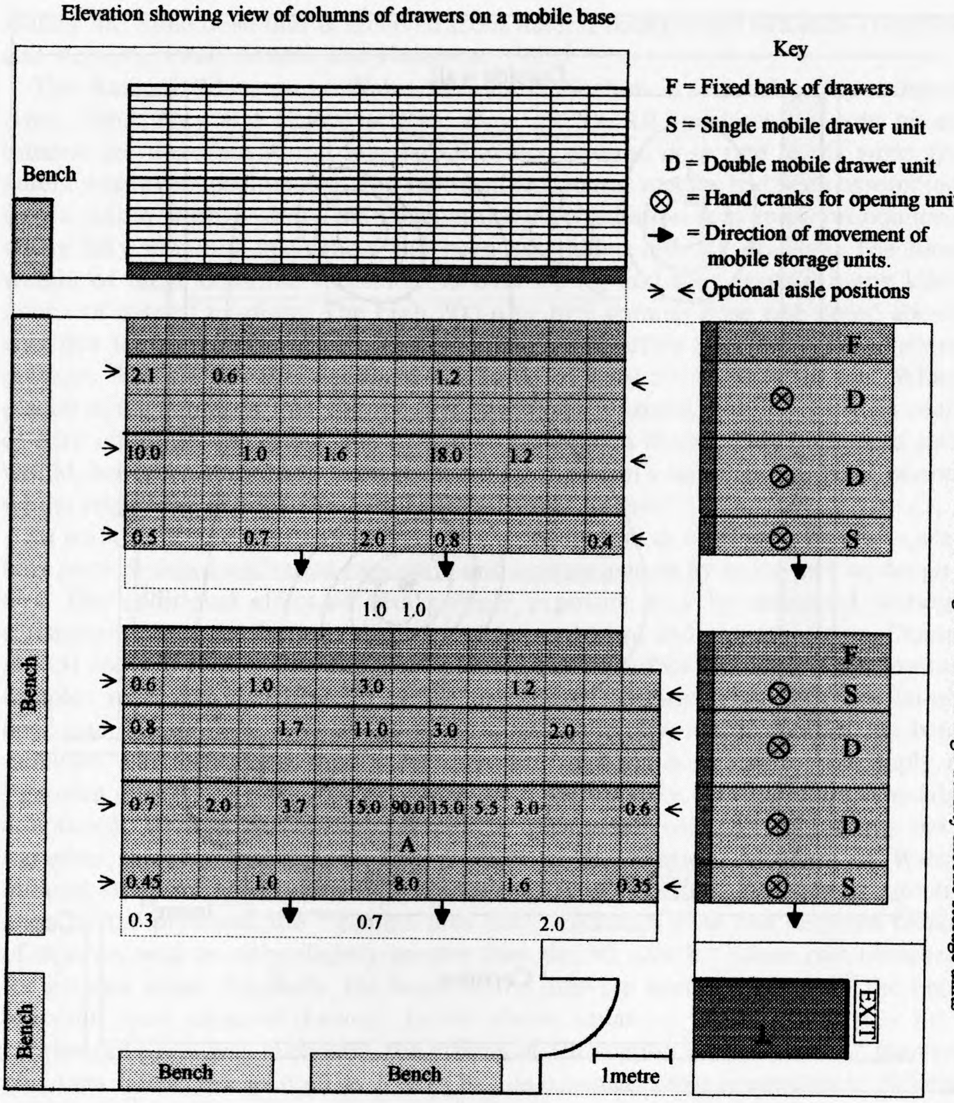

Figure 1. Plan of Mineral Store at the National Museum of Wales showing 0.5 m grid over area covered by high density mobile storage (compacta) system. Numbers refer to gamma ray dose-rate measurements (μSv hr^{-1}) made along aisles in July 1989. A measurement of 200 μSv hr^{-1} was made in a drawer at position marked "A."

the room in Figure 1. The contoured results (Fig. 2) represent the gamma radiation dose rate in a horizontal section through the store at 1 m height.

Gamma survey remarks.—Although no systematic investigation was made of the vertical variation in dose rate, the scale of the radiation contours (Fig. 2) suggests that the contours may also be considered to represent the approximate whole body dose rate received at corresponding locations throughout the store. It can be seen from Figure 2 that a person standing in the "hot spot" would receive a gamma dose rate of approximately 90 microsieverts per hour (μSv hr^{-1}).

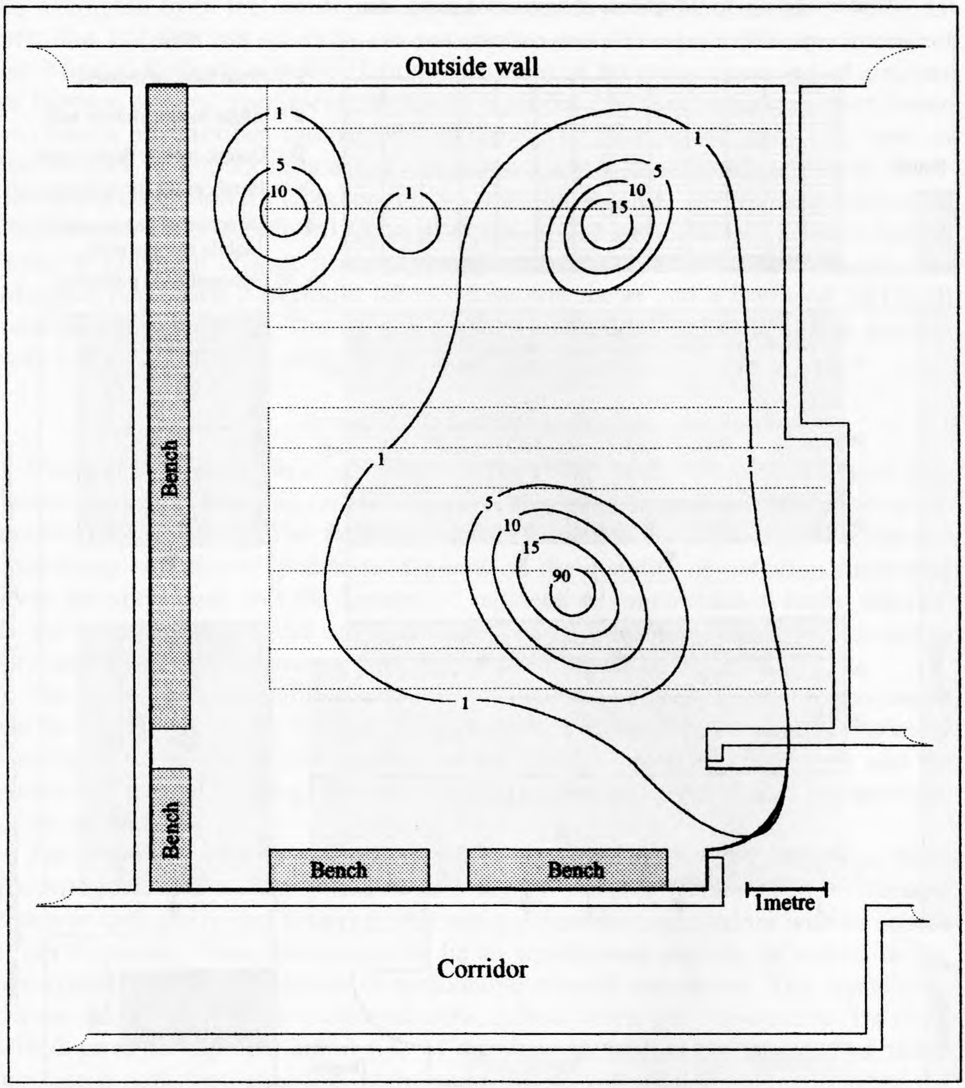

Figure 2. Plan of Mineral Store at the National Museum of Wales showing gamma ray dose-rate contours (μSv hr^{-1}) for July 1989.

The natural background gamma dose rate measured outside the National Museum of Wales building was 0.14 μSv hr^{-1}. The door to the Museum Mineral Store opens off a main internal corridor. The dose rate immediately inside this door was 1.3 μSv hr^{-1}, 10 times the dose rate outside the building. The maximum gamma radiation dose rate between banks of drawers was 90 μSv hr^{-1}; the maximum dose rate measured in the store was 200 μSv hr^{-1} (Location A, Fig. 1). This last measurement was obtained by inserting the probe of the dose rate meter into the half-opened drawer at the site of highest concentration of radioactive material. For comparison, the average annual occupational radiation exposure in the U.K. is 2 millisieverts (mSv) (New Scientist, 1/5/93:6), which is approximately the same dose that is received from natural background radiation (Hughes and Roberts, 1984; Martin and Harbison, 1986).

The National Museum of Wales Mineral Collection is stored by Hey number (Hey, 1963; Hey and Embrey, 1974; Hey, 1975). All specimens of any given mineral are therefore stored together. Elevated gamma dose rate levels were apparent wherever specimens of any radioactive mineral species had been assembled into a single storage site. This concentration of radiation was most pronounced where fifty uraninite specimens had been assembled into six drawers. The total weight of these uraninite specimens is over 10 kg and they contain many kilograms of natural uranium. The high 200 μSv hr^{-1} gamma dose rate noted above was due to the combined effect of so many radioactive specimens in adjacent drawers. The six drawers occupied a volume of only 50 × 50 × 50 cm. When placed at the center of this volume, the probe was no more than 25 cm from each of fifty uraninite specimens and in many cases much closer. This high dose rate would, however, only have been received by a person's hand for the brief period whilst retrieving or replacing a specimen in this drawer.

In addition to the gamma ray dose rate, contributors to total radiation dose are: beta particle exposure; radon exposure; and contamination by radon and its daughters. The additional effect of beta particle exposure may be estimated without considering the contributions made by radon exposure and contamination. Dixon (1983) showed that measurement of gamma ray dose rate from some geological samples represented only 20% of the combined "gamma plus beta" radiation dose rate. If this 20% representation pertained generally, and if none of the beta radiation was attenuated, then a 200 μSv hr^{-1} gamma dose rate would imply a "gamma plus beta" dose rate of 1 mSv hr^{-1}. Fortunately beta radiation is easily attenuated, 10 mm of acrylic (perspex or plexiglas), used for laboratory beta radiation shields, is sufficient. The drawers in the National Museum of Wales mineral store are constructed of 8 mm birch-faced plywood. Because of attenuation by the plywood, the "gamma plus beta" radiation dose rate between banks of drawers will be only slightly greater than the 90 μSv hr^{-1} dose rate obtained for gamma alone. Similarly, the bases of the drawers attenuate much of the beta radiation from adjacent drawers. In the above situation, where a 200 μSv hr^{-1} gamma dose rate was measured, the effects of attenuation indicate that a "gamma plus beta" dose rate as high as 1 mSv hr^{-1} is a considerable overestimate. Where gamma measurements have been made at a distance from the specimen, or when significant other beta attenuation has occurred, a 20% representation of "gamma plus beta" by gamma alone must be considered pessimistic (i.e., 20% is an underestimate).

MEASURES ADOPTED 1989

In view of the elevated radiation levels caused by the radioactive mineral specimens it was decided to segregate them from the main collection. The outermost bay of the compacta storage system, adjacent to an outside wall of the Museum and abutting a light well, was allocated solely for storing radioactive specimens. In this "radioactive bay" the specimens were dispersed one or two per drawer to minimize the local concentration of radiation. This simple measure of rearranging the radioactive specimens reduced gamma radiation levels in the rest of the store. Despite dispersing them, elevated radiation levels did persist, albeit to much reduced degrees, in the "radioactive bay." In this bay gamma radiation levels of up to 10 μSv hr^{-1} were recorded which necessitated it being designated a "Radiation Controlled Area" as defined in the "Ionising Radiations Regulations 1985." These regulations require steps to be taken for dose restriction in any area where the radiation dose rate exceeds 7.5 μSv hr^{-1}. The store was kept locked and access to the controlled area was permitted for authorized staff only. In accordance with written local rules, authorized persons were restricted to an average of 5 hours exposure in the controlled area per week.

IDENTIFICATION OF RADIOACTIVE SPECIMENS

As radioactivity is ubiquitous in the environment the question of which mineral specimens are "radioactive" depends to a certain extent on the degree of radioactivity with which one is concerned. The removal of specimens from the National Museum of Wales Mineral Collection for storage in the "radioactive bay" was based on either of two criteria: the catalogue description of a specimen included a known uranium or thorium mineral; or a specimen contained sufficient adventitious radioactivity to be readily detectable above background. During the first part of the operation it was found useful to draw up a list of uranium and thorium mineral names. This enabled the most obviously radioactive material, those minerals that contain either uranium or thorium as constituents in their published composition, to be located with comparative ease.

Identification of radioactive mineral species.—There are nearly 3,500 valid mineral species names (Fleischer and Mandarino, 1991) approved by the International Mineralogical Association (I.M.A.) There are also many varietal, obsolete and discarded names and synonyms which may appear as identifications in catalogues of museum specimens. All uranium and thorium mineral species are radioactive. For the purpose of locating specimens of radioactive species, therefore, Tables 1, 2, and 3 were drawn up. Published mineral glossaries were used as the basis for these tables (Hey, 1963; Hey and Embrey, 1974; Hey, 1975; Fleischer and Mandarino, 1991). Table 1 is composed of I.M.A. approved names of uranium and/or thorium mineral species, including minerals exhibiting limited or complete solid solution of uranium or thorium. Table 2 is composed of names of uranium and/or thorium mineral species that do not occur in Fleischer and Mandarino (1991). This second table includes a few names, such as "monazite" and "yttrialite," which have been used for minerals known to permit considerable substitution of radioactive elements. Thorium, for instance, is commercially recovered from "monazite," a phosphate of light rare-earth elements. Table 3 represents synonyms of the names used in Tables 1 and 2. The lists are comprehensive but not exhaustive catalogues of uranium and thorium mineral names. No doubt there are omissions but it is hoped the lists will prove useful to other workers. By using Tables 1, 2, and 3, unfamiliar minerals may be checked against listed names without constant referral to the complete mineral glossaries listed above. Minerals named on these lists will be radioactive; however, some specimens of minerals not named on these lists may also be radioactive.

Identification of adventitious radioactivity.—Specimens exhibiting adventitious radioactivity fall into two groups. The first group is composed of minerals known to be commonly radioactive because of ionic substitution, and the second group is composed of specimens not expected to be radioactive but which by chance

Table 1. Approved names of uranium and/or thorium bearing mineral species. (Data from Fleischer and Mandarino (1991).)

1 Abernathyite
2 Aeschynite-(Ce)
3 Aeschynite-(Y)
4 Agrinierite
5 Andersonite
6 Arsenuranospathite
7 Arsenuranylite
8 Autunite
9 Bassetite
10 Bayleyite
11 Becquerelite
12 Bergenite
13 Betafite
14 Bijvoetite-(Y)
15 Billietite
16 Boltwoodite
17 Brabantite
18 Brannerite
19 Brockite
20 Calciouranoite
21 Calcurmolite
22 Carnotite
23 Cerianite-(Ce)
24 Cheralite
25 Chernikovite
26 Chevkinite
27 Clarkeite
28 Cliffordite
29 Cobalt-zippeite
30 Coconinoite
31 Coffinite
32 Compreignacite
33 Cousinite
34 Cuprosklodowskite
35 Curienite
36 Curite
37 Davidite-(Ce)
38 Davidite-(La)
39 Demesmaekerite
40 Derriksite
41 Dewindtite
42 Dumontite
43 Ekanite
44 Euxenite-(Y)
45 Eylettersite
46 Fourmarierite
47 Francevillite
48 Francoisite-(Nd)
49 Fritzcheite
50 Furongite
51 Grayite
52 Grimselite
53 Guilleminite
54 Haiweeite
55 Hallimondite
56 Heinrichite
57 Hügelite
58 Huttonite
59 Ianthinite
60 Iraqite-(La)
61 Iriginite
62 Ishikawaite
63 Johannite
64 Joliotite
65 Kahlerite
66 Kamitugaite
67 Kamotoite-(Y)
68 Karnasurtite-(Ce)
69 Kasolite
70 Kivuite
71 Kobeite-(Y)
72 Lehnerite
73 Lepersonnite-(Gd)
74 Lermontovite
75 Liandratite
76 Liebigite
77 Magnesium-zippeite
78 Margaritasite
79 Marthozite
80 Masuyite
81 Mckelveyite-(Y)
82 Meta-ankoleite
83 Meta-autunite
84 Metacalciouranoite
85 Metahaiweeite
86 Metaheinrichite
87 Metakahlerite
88 Metakirchheimerite
89 Metalodevite
90 Metanovácekite
91 Metaschoepite
92 Metastudtite
93 Metatorbernite
94 Metatyuyamunite
95 Meta-uranocircite
96 Meta-uranopilite
97 Meta-uranospinite
98 Metavandendriesscheite
99 Metavanmeersscheite
100 Metavanuralite
101 Metazellerite
102 Metazeunerite
103 Moctezumite
104 Moluranite
105 Monazite-(Ce)
106 Moreauite
107 Mourite
108 Mundite
109 Nickel-zippeite
110 Ningyoite
111 Niobo-aeschynite-(Ce)
112 Novácekite
113 Orthobrannerite
114 Oursinite
115 Paraschoepite
116 Parsonsite
117 Perrierite
118 Petscheckite
119 Phosphuranylite
120 Phuralumite
121 Phurcalite
122 Plumbobetafite
123 Plumbomicrolite
124 Plumbopyrochlore
125 Polycrase-(Y)
126 Polymignite
127 Protasite
128 Przhevalskite
129 Pseudo-autunite
130 Rabbittite
131 Rameauite
132 Ranunculite
133 Rauvite
134 Richetite
135 Roubaultite
136 Rutherfordine
137 Sabugalite
138 Saléeite
139 Samarskite-(Y)
140 Saryarkite-(Y)
141 Sayrite
142 Schmitterite
143 Schoepite
144 Schrockingerite
145 Sedovite
146 Sengierite
147 Shabaite-(Nd)
148 Sharpite
149 Sklodowskite
150 Soddyite
151 Sodium autunite
152 Sodium boltwoodite
153 Sodium uranospinite
154 Sodium zippeite
155 Steenstrupine-(Ce)
156 Strelkinite
157 Studtite
158 Swamboite
159 Swartzite
160 Tengchongite
161 Thorbasnäsite
162 Thorianite
163 Thorite
164 Thornasite
165 Thorogummite
166 Thorosteenstrupine
167 Thorutite
168 Threadgoldite
169 Torbernite
170 Triangulite
171 Tristramite
172 Tritomite-(Ce)
173 Trögerite
174 Tyuyamunite
175 Ulrichite
176 Umbozerite
177 Umohoite
178 Upalite
179 Uramphite
180 Urancalcarite

Table 1. Continued.

181 Uraninite
182 Uranmicrolite
183 Uranocircite
184 Uranophane
185 Uranophane-beta
186 Uranopilite
187 Uranosilite
188 Uranospathite
189 Uranosphaerite
190 Uranospinite
191 Uranotungstite
192 Uranpyrochlore
193 Uvanite
194 Vandenbrandeite
195 Vandendriesscheite
196 Vanmeersscheite
197 Vanuralite
198 Vanuranylite
199 Vochtenite
200 Voglite
201 Vyacheslavite
202 Walpurgite
203 Weeksite
204 Widenmannite
205 Wölsendorfite
206 Wyartite
207 Xiangjiangite
208 Yttrialite-(Y)
209 Yttrobetafite-(Y)
210 Yttrocolumbite-(Y)
211 Yttrocrasite-(Y)
212 Yttropyrochlore-(Y)
213 Yttrotantalite-(Y)
214 Zellerite
215 Zeunerite
216 Zinc-zippeite
217 Zippeïte
218 Zirkelite

Table 2. Unapproved, varietal and obsolete names of uranium and/or thorium bearing minerals. (Data from Hey (1963), Hey and Embrey (1974), Hey (1975) and Fleischer and Mandarino (1991).)

219 Absite
220 (Aeschynite)
221 Aldanite
222 Ånnerödite
223 Auerlite
224 Barium uranophane
225 Blomstrandite
226 Bröggerite
227 Calciosamarskite
228 Calciothorite
229 Calciouraconite
230 Calcium-ursilite
231 Caryocerite
232 Cerhomilite
233 Cleveite
234 Cuprozippeïte
235 (Davidite)
236 Djalmaite
237 Ellsworthite
238 (Euxenite)
239 Fenghuanglite
240 Ferrithorite
241 Freyalite
242 Gastunite 1
243 Gilpinite
244 Gummite
245 Hagatalite
246 Hjelmite
247 Hyblite
248 Hydroauerlite
249 Hydrocerite
250 Hydrosamarskite
251 Hydrothorite
252 Irinite
253 Jiningite
254 (Karnasurtite)
255 (Kobeïte)
256 Lead-becquerelite
257 Lodochnikite
258 Lyndochite
259 Magnesium-ursilite
260 Medjidite
261 Mendeleyevite
262 Metabayleyite
263 Metaliebigite
264 Metasaléeite
265 Metauramphite
266 Metauranocircite II
267 Miomirite
268 (Monazite)
269 Naëgite
270 Nenadkevite
271 Niobo-tantalo-titanate
272 Nohlite
273 Obruchevite
274 Orangeite
275 Paraphane
276 Phosphate-walpurgite
277 Phosphothorogummite
278 Pilbarite
279 Písekite
280 Pitchblende
281 Plumboniobite
282 (Polycrase)
283 Priazovite
284 Ranquilite
285 Renardite
286 (Samarskite)
287 Samiresite
288 (Sary-arkite)
289 Shentulite
290 Silicosmirnovskite
291 Smirnovskite
292 (Steenstrupine)
293 Tantalohatchettolite
294 Tantalopolycrase
295 (Tanteuxenite)
296 Thoro-aeschynite
297 Thorobritholite
298 Thucholite
299 Toddite
300 (Tritomite)
301 Uraconite
302 Uranite
303 Uranoanatase
304 Uranochalcite
305 Uranocircite II
306 Uranohydrothorite
307 Uranoniobite
308 Uranothorianite
309 Uranothorite
310 Uranothorogummite
311 Urhite
312 Ursilite
313 Usihite
314 Vietinghofite
315 Voglianite
316 Yanshynshite
317 (Yttrialite)
318 (Yttrobetafite)
319 (Yttrocolumbite)
320 Yttro-columbo-tantalite
321 (Yttrocrasite)
322 Yttrogummite
323 (Yttropyrochlore)
324 (Yttrotantalite)

Parentheses ( ) indicate names now appended with suffix element, e.g., Aeschynite-(Ce).

Table 3. Synonyms for uranium and/or thorium bearing mineral names of Tables 1 and 2. (Data from Hey (1963), Hey and Embrey (1974), Hey (1975) and Fleischer and Mandarino (1991).)

Synonym	Table/No	Synonym	Table/No	Synonym	Table/No
Aanerödite	2/222	Hyblite-α	2/247	Schoepite-I	1/143
Aannerödite	2/222	Hyblite-β	2/247	Schoepite-II	1/91
Ampangabéite	2/286	Hydroeuxenite	2/286	Schoepite-III	1/115
Arsenothorite	2/289	Iianthinit	1/59	Schroeckingerite	1/144
Arsenouranocircite	1/86	Jáchymovite	1/34	Shen-t'u-shih	2/289
Arsenuran	1/181	Janthiniet	1/59	Shinkolobwite	1/149
Äschynit	2/220	Janthinit	1/59	Smirnovite	1/167
Barium autunite	1/183	Kalio-carnotite	1/22	Soddite	1/150
Barium-phosphoruranit	1/183	Kalkurancarbonat	1/76	Stasite	1/41
Barium-phosphuranylite	1/12	Kalkuranglimmer	1/8	Steenstrupite	2/292
Barium uranite	1/183	Kalkuranit	1/8	Thorium brannerite	2/219
Bariumuranit	1/183	Khlopinite	2/286	Thoruranin	2/226
Baryturanit	1/183	Kozhanovite	2/254	Thoruraninite	2/226
Beta-uranophane	1/185	Kupferarsenuranit	1/215	Torberite	1/169
Blomstrandine	1/3	Kupferautunit	1/169	Torite	1/163
Blomstrandinite	1/3	Kupfer-Uranglimmer	1/169	Troegerite	1/173
Calciocarnotite	1/174	Kupfer-Uranglimmer	1/215	Ulrichite	1/181
Calcium-autunite	1/8	Kupferuranit	1/169	Uranatemnite	1/181
Calcium carnotite	1/174	Kupferuranit	1/215	Uranglimmer	2/302
Calcium-uranospinite	1/190	Lambertite	1/184	Urankalk-Cabonat	1/76
Calciumphosporuranit	1/8	Lime-uranite	1/8	Uran-Kalk-Kupfercabonat	1/200
Calcouranite	1/8	Mackintoshite	1/165	Uran-mica	2/302
Chalcolite	1/169	Magnesio-autunite	1/138	Uranniobite	2/286
Chalkolith	1/169	Magnesium autunite	1/138	Uranniobite	2/307
Chinkolobwite	1/149	Magnesium-phosphoruranit	1/138	Uranocircite I	1/183
Chlopinite	2/286	Maitlandite	1/165	Uranoniobite	2/286
Chlorothorite	1/165	Mendeleeffite	2/261	Uranopilite-α	1/186
Copper autunite	1/169	Mendelejevite	2/261	Uranopilite-β	1/96
Copper uranite	1/169	Mendelejewite	2/261	Uranopissite	1/181
Cuprosklodovskite	1/34	Mendelyeevite	2/261	Uranopissinit	1/181
Cuprosklovskite	1/34	Meta-arsenuranocircite	1/86	Uranotantal	2/286
Cuprosklowskite	1/34	Metacalciouranite	1/83	Uranotantalite	2/286
Cuprouranite	1/169	Metachalcolite	1/93	Uranothallite	1/76
Dakeite	1/144	Meta-Kahlerit	1/87	Uranotile	1/184
Dauberite	1/217	Metakalkuranit	1/83	Uranotile-α	1/184
Delorenzite	2/295	Meta-Kirchheimerit	1/88	Uranotile-β	1/185
Diderichite	1/136	Metakupferuranit	1/93	Uranpecherz	2/280
Epiianthinite	1/143	Meta-uranocircite I	1/95	Uranphyllite	1/169
Eschinite	2/220	Nasturan	1/181	Uranpyrochlore	1/192
Eschwegeïte	2/295	Natroautunite	1/151	Uranspat	1/188
Eschynite	2/220	Neogastunite	1/144	Uranvitriol	1/63
Eytlandite	2/286	Nicolayite	1/165	Vandendriesscheite-I	1/195
Ferrothorite	2/240	Nivenite	2/233	Vandendriesscheite-II	1/98
Flutherite	1/76	Orthotorbernite	1/169	Wisaksonite	2/309
Gastunite	1/203	Peligotite	1/63	Yttertantal	2/324
Gastunite-1a	1/54	Polycrasite	2/282	Ytrocolumbite	2/324
Gastunite-1b	1/185	Polykras	2/282	Yttroilmenite	2/286
Green mica	1/169	Polymignyte	1/126	Yttroilmenite	2/324
Hatchettolite	1/192	Potassio-carnotite	1/22	Yttrokrasit	2/321
Hielmite	2/246	Potassium autunite	1/82	Yttroniobit	2/319
Hlopinite	2/286	Saléite	1/138	Yttrotantal	2/324

are. The instrument used for detection of radioactive specimens was a Berthold LB1210B contamination monitor. This instrument is a battery operated portable rate meter for locating and measuring radioactive contaminations. It has an effective window are of 100 cm^2 and measures radioactivity in counts per second

Table 4. Rare-earth (lanthanide) minerals encountered in the Mineral Collection of the National Museum of Wales with detectable levels of radioactivity.

(Allanite)
Allanite-(Ce)
Allanite-(Y)
(Bastnäsite)
(Cerite)
(Fergusonite)
Fluocerite-(Ce)
(Gadolinite)
Hibonite
Johnsrrupite
Koppite
(Loparite)
Loparite-(Ce)
Lovchorrite
(Melanocerite)
Meta-gadolinite
Mosandrite
Risorite
(Stillwellite)
(Synchisite)
(Tengerite)
(Thalenite)
Wiikite
(Xenotime)
Yttrotitanite

Parentheses ( ) indicate names now appended with suffix element, e.g., Allanite-(Ce).
Bold type indicates an IMA approved name.

(cps). This instrument gives a response of 6 to 8 cps for background radioactivity. Mineral specimens inducing readings of 50 cps or more at 10 mm distance from the specimen surface were classed as sufficiently radioactive to be removed from the main collection. This degree of radioactivity represented a level easily detected with the instrument and not any perceived degree of hazard. The level is in fact extremely low. To avoid an arbitrary "safety level" the lowest easily detectable value was adopted. Removing such specimens from the main collection reduced radiation doses there to "As Low As Reasonably Achievable," a radiation safety principle known by the acronym ALARA.

Adventitious radioactivity due to ionic substitution.—Minerals such as "xenotime" and "columbite" are commonly radioactive because of ionic substitution of uranium or thorium in the lattice of the ideal mineral. A tendency to permit ionic substitution is particularly common in minerals of the rare-earth elements (REE). Over 160 mineral species contain REE as a major component (Cesbron, 1986). Radioactive specimens of the rare-earth minerals listed in Table 4 have been detected in the Mineral Collection of the National Museum of Wales. Adventitious radioactivity has also been encountered in some specimens of minerals of the metallic elements scandium, titanium, vanadium, yttrium, zirconium, niobium and tantalum. Minerals of these elements, part of the transition group of the periodic table, also have a tendency to permit ionic substitution; yttrium shows a similar geochemistry to that of the rare-earths and is sometimes included with them in descriptive accounts (Henderson, 1984). Radioactive specimens of minerals of these elements have been found in the National Museum of Wales collection. These are listed in Table 5.

Adventitious radioactivity due to chance.—The second group of specimens containing adventitious radioactivity is composed of those specimens which are radioactive by chance. The radioactivity in these specimens is frequently due to the presence of uranium or thorium in the matrix of the specimen on which the catalogued mineral happens to occur. For example, the National Museum of Wales has a radioactive specimen catalogued as "gold in conglomerate." Simple examination of the catalogue name would not suggest a radioactive specimen; however the locality information shows the specimen to be from South Africa, a known source of radioactive conglomerate. The radioactivity emanates from the conglomerate and not the gold. Uraninite has been recovered as a by-product from conglomeratic gold ores of the Witwatersrand, South Africa (Barnes, 1988).

Knowledge of the better known sources of radioactive ores may be used to

Table 5. Sc, Ti, V, Y, Zr, Nb and Ta minerals encountered in the Mineral Collection of the National Museum of Wales with detectable levels of radioactivity.

Alaïte
Baddeleyite
Bariandite
Britholite-(Y)
Columbite
Corvusite
Cyrtolite
Eucolite
Fervanite
Häggite
Hellandite
Hewettite
Hiortdahlite
Ilmenorutile
Metahewettite
Metarossite
Microlite
Montroseite
Murmanite
Narsarsukite
Niocalite
Pascoite
Pucherite
Roscoelite
Rosenbuschite
Sphene
Steigerite
Tantalite
Thortveitite
(Tombarthite)
Wöhlerite
(Xenotime)
Zircon

Parentheses ( ) indicate names now appended with suffix element, e.g., Tombarthite-(Y).
Bold type indicates an IMA approved name.

advantage in locating radioactive specimens. Uranium ore is found worldwide. It occurs in: Africa, in Zaire and in South Africa (the Witwatersrand region); Europe, in the Czech Republic (Joachimstal, now Jachymov), France (in the Massif Central) and the former Soviet Union (Ukraine and Estonia); Australia, in northwest Queensland (the Mary Kathleen deposit), in South Australia (the Radium Hill Mine) and in the Northern Territory (the South Alligator River area); South America, at Jacobina in Brazil; Canada, in the Great Bear Lake area and the province of Ontario; and in the western United States, such as the Colorado Plateau, New Mexico, and localities in Wyoming, Utah and Nevada (Barnes, 1988; Roberts, Campbell and Rapp, 1990).

CONTAMINATION SURVEY

Following the rearrangement of the radioactive specimens the Berthold contamination monitor was used to survey the store for radioactive contamination. Contamination could have occurred if any of the radioactive specimens had been abraded and the eroded particles had inadvertently fallen onto bench tops or to the carpet. A few of the radioactive specimens had become abraded but, it appeared, all the particles remained in the specimen trays. Some crystals had broken off delicate specimens of torbernite, for example, but remained in the specimen tray. No detectable contamination was found on the carpet or on any of the bench tops. Contamination was, however, unexpectedly found on the disposable paper air-conditioning filter.

The contaminated air-conditioning filter has an external case measuring 30 cm × 75 cm × 5 cm (height, width, thickness) within which a concertina filter-paper is held. The contamination monitor, with a window area of 100 cm^2, recorded approximately 400 cps above background when held next to the filter (background response is about 7cps). Using the calibration for an unknown isotope, this response corresponds to a filter contamination of 114 Bq cm^{-2}. Multiplying this value by the area of filter-paper gives a total activity on the air-conditioning filter of 9.7 kilobecquerels (kBq). Due to the variety of radioactive daughter isotopes in natural uranium and thorium mineral specimens it is not possible to determine precisely the limit of detection of radioactive contamination. Using the instrument calibration for an unknown isotope however, it is estimated that the limit of detection is 7 Bq cm^{-2}.

The filter was removed from the air-conditioning system, sealed in a plastic bag to prevent the spread of radioactive contamination, and taken out of the store. This operation was carried out by the author wearing a laboratory coat, rubber gloves and a nuisance dust mask. Removal of the filter from the Mineral Store resulted in rapid decay of its radioactivity; within a few days levels had dropped below the limits of detection. Reinstating the filter to the air-conditioning system in the store resulted in its re-contamination and return to a radioactive condition within a day or so.

Contamination survey remarks.—The observations of rapid decay and subsequent rapid build up of radiation on the air-filter confirmed two hypotheses. The first hypothesis was that the elevated radiation on the filter was due to a build up of radon daughters, not uranium or thorium mineral dust contamination; the immediate daughters of radon have short half-lives measured in minutes whereas uranium and thorium have half-lives of millions of years; the rapid decay of radioactivity observed on the air-filter showed the contaminations had short half-lives and thus confirmed the radon daughter hypothesis. The second hypothesis was that the quantities of radon generated by the Mineral Collection were tending to establish an equilibrium radon concentration in the store. This was confirmed by the rapid re-contamination of the air-filter. As before, because of the short half-lives of radon daughters, radioactive contamination of the air-filter would rapidly decay in situ it was not constantly replenished.

PRELIMINARY RADON SURVEY

Following the above finding of radioactive contamination of the air-conditioning filter a preliminary survey of the radon build-up in the store was conducted. Two assessments were made using the National Radiological Protection Board (NRPB) charcoal canister method. This involved exposing two activated charcoal canisters to the atmosphere in the store for 48 hours. One canister was placed on a workbench and the other in the "radioactive bay." The canisters were then returned to the NRPB for analysis. The results indicated levels of 370 Bq m^{-3} and 400 Bq m^{-3}. These values represent a mean radon concentration over a period of two days. The technique is valuable as a survey method but is not claimed to be precise. The results indicated levels sufficiently elevated for the Museum to consider a more detailed investigation of the radon regime in the store (The Ionising Radiations Regulations. Approved Code of Practice—Part 3).

PYLON RADON SURVEY

A decision was made by the Museum to purchase radon monitoring equipment, at the same time it was concluded that the radioactive mineral specimens should be removed to storage completely separate from the main mineral collection. Before transferring the radioactive minerals to the new store, a survey of the existing radon gas concentration in the main mineral store was carried out.

The survey was carried out using a Pylon AB5 portable radiation monitor with a Lucas 100A scintillation cell with a volume of 151 ± 3 ml. The Pylon AB5 instrument is multipurpose but for this survey was programmed to sample the atmosphere continuously and to record the radon concentration hourly. The results are presented in Figure 3. A sequence of 90 hourly measurements was made from 4:30 pm on Friday 3 July 1992 to 10:30 am on Tuesday 7 July 1992. The detectors

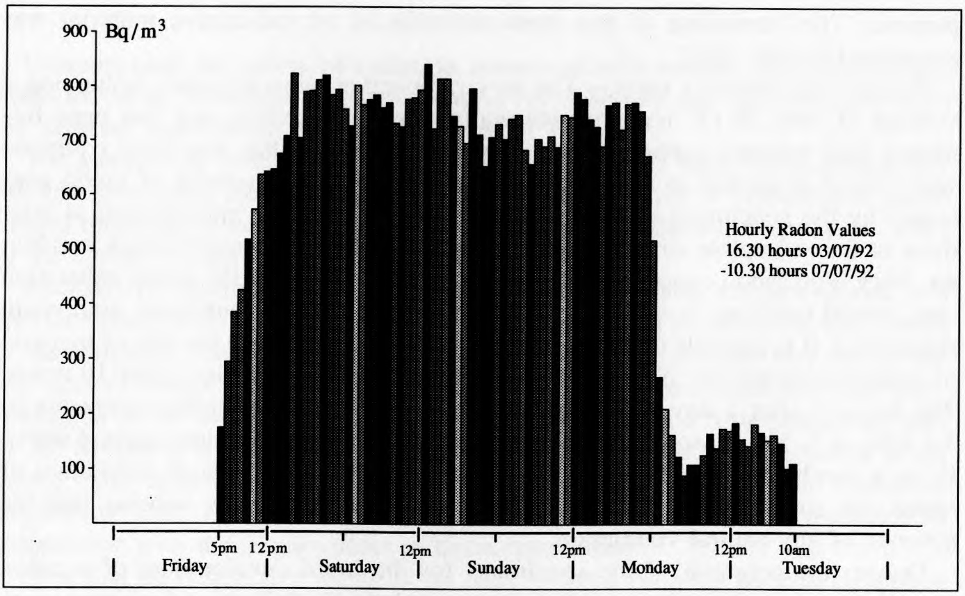

Figure 3. Radon Survey of the Mineral Store at the National Museum of Wales, July 1992.

and instrumentation required 3.5 hours to come to equilibrium. The first 3 to 4 readings reflect this transition.

The door to the store was opened at 9:00 am on Friday 3 July 1992 to allow much radon to disperse from the store. The equipment was assembled and the survey started at 4:30 pm at which time the door to the store was closed. The store remained undisturbed until 9:00 am the following Monday. The store was reopened on the Monday and the door remained open whilst the radioactive specimens were removed to their new location. The radon monitoring equipment was left running until 10:30 am the following day (7 July 1992).

Radon survey remarks.—The variation of radon concentration with time is recorded in Figure 3. Ten hours after closing the door to the store the radon concentration had risen to over 700 Bq m^{-3}. The radon concentration remained at an average of about 750 Bq m^{-3} until the door was reopened at 9:00 am on Monday 6 July 1992. The concentration then dropped rapidly as radon dispersed from the room through the open door.

It has been estimated that the quantity of radon in equilibrium with the mineral collection is of the order of 150 kBq. This estimate is based on the measured radon concentration of approximately 750 Bq m^{-3} in a room of 200 m^3. It is assumed that the measured 750 Bq m^{-3} concentration represents approximately an equilibrium value.

MEASURES ADOPTED 1992

Early in 1992, in order to minimize radiation and radon exposure of Museum staff, it was decided to isolate the radioactive geological specimens in a completely separate store. A small vacant room, approximately 3 m square by 3 m high, in a little frequented part of the Museum, was considered suitable for this purpose. The furnishing of this store and transfer of radioactive material was completed in July 1992.

Radioactive minerals store.—The new radioactive minerals store, occupying a volume of only 28 m^3, has concrete walls, floor, and ceiling, and has been furnished with wooden cupboards and plywood drawers. It has also been equipped with forced extraction to the outside of the building. The quantity of radon generated by the specimens and the small volume of the store indicate that at least three or four complete air changes per hour are required to prevent radon building up. Very high radon concentrations, based on calculations of the radon exhalation rate, would build up in a very short period of time if the ventilation equipment should fail. It is possible using half-life calculations to estimate the rate of increase of radon concentration. Approximate values would be 360 Bq m^{-3} after 10 hours, 700 Bq m^{-3} after 1 day, 2.7 kBq m^{-3} after 4 days, and thereafter increasing to 5.4 kBq m^{-3}. The reasons for the comparatively high radon values quoted above lie in a combination of adverse factors; these are the rapid rate of exhalation of radon, the small size of the room, which precludes dilution by volume, and the absence of any natural ventilation.

Due to the potential of the specimens for the rapid development of a radon hazard, the extract system was designed to include the following features:

1. An extract rate of at least three or four air changes per hour prevails at all times. (A standard fan was selected that extracts at a rate 46 m^3 per minute which gives in practice 100 air changes per hour.)
2. The extract fan is located outside the store and connected to it by ductwork.
3. A shutter is fitted in the extract ductwork so that the fan can be isolated from the radon gas in the store during servicing and maintenance.
4. The grilled air inlet to the store is also fitted with a shutter that, in the event of a fan failure, can be closed to minimize radon seepage into the main building atmosphere.
5. A fan-failure alarm is fitted and connected to the continuously manned museum control room.

The extract system outlet is 4 m above ground level on a Museum wall next to an open space. The radon concentration in the extract is low due to dilution (46 m^3 air per minute) and this, coupled with the open aspect and height of the outlet, is considered to disperse the radon safely.

DOCUMENTATION

With regard to documentation, proxy trays with cards were inserted into the main collection wherever specimens were removed. The proxy labels were typed on yellow card and appended "Radioactive Specimen." It is clear therefore where specimens have been removed to the radioactive section of the collection. The curatorial details, registration number, mineral name, locality and storage location are also entered into the Department of Geology "Storage by Exception" file. This file identifies all the mineral specimens not stored in the main run for whatever reason. In addition to the radioactive specimens this file is used to identify the location of large specimens, specimens on loan, display, etc.

CONCLUSIONS

Concern over the safety of radiation associated with natural geological specimens led to an investigation of the gamma ray dose rate and the radon levels in the Mineral Store of the National Museum of Wales.

The gamma ray dose rate survey and the radon survey have demonstrated that the 750 specimens identified as radioactive were sufficient to constitute a health hazard requiring remedial action under the Ionising Radiation Regulations 1985 of the United Kingdom.

Radioactive specimens at the National Museum of Wales are now stored in a specially designated radioactive mineral store with ducted extraction to the outside of the Museum. Measurements of radon in the new store indicate that the extraction system purges radon emitted by the specimens and maintains the radon concentration in the store at background levels. The store, in a little frequented part of the Museum, is visited only when access to the radioactive specimens is required. The store is designated a controlled area under the Ionising Radiation Regulation 1985 legislation of the United Kingdom and access is restricted in compliance with the requirements of these regulations.

Now that all radioactive material has been isolated from the mineral collection all incoming specimens are routinely checked with the Berthold contamination monitor to ensure that no unexpected radioactivity is inadvertently reintroduced. Any future accessions found to be radioactive will be stored in the special radioactive store. The former restrictions necessary for compliance with the Ionising Radiations Regulations no longer pertain in the main store and consequently the main mineral collection may now be used without restriction.

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BOOK REVIEWS

MATERIALS FOR CONSERVATION, 1994, C. V. Horie. (Butterworth-Heinemann, Boston, Massachusetts, 281 pp.) Historically, the approaches to the conservation of natural history materials are varied, crossing over a wide range of materials, traditions and professional disciplines. The physical and chemical properties of different treatment materials and the long term consequences to the objects upon which they were used were not regularly considered or well understood. Within the past decade, however, as the conservation field has evolved, traditional approaches to examinations and treatments have begun to yield to a more focused scientific understanding of the composite nature and complexities of the object materials themselves, the causes for their deterioration (rather than the symptoms), and the evaluation of specific treatment materials that fulfill a defined conservation need. As an awareness of collection care needs has grown and professionals have become more sensitive to the problems associated with treatments, both past and present, and the reasoning behind them, a need to more clearly understand materials and their relationships to each other has become apparent.

This paperback book in its third reprint fills an important instructional gap that aims to provide background information on one aspect of conservation treatments; the properties of organic consolidants, adhesives and coatings as they affect the treatment of objects. Considered a basic manual for the conservation profession, this text is a helpful resource for anyone seeking to gain an understanding of how polymers are used and to identify the properties of polymers as they relate to museum objects.

The book is divided into two sections. Part I of the book is qualitative rather than technical in nature and in a readable fashion, details the overriding principles of conservation, treatment philosophies, and the properties of polymers that are important in their interaction with objects. Chapters 1 and 5 provide an especially digestible introduction and summary of the scientific basis for defining and assessing those properties. They form the building blocks for understanding the technical and detailed evaluations of individual polymers as found in Part II of the book.

In Part I, Chapter 1 focuses on the use of resins in conservation, the setting processes, reversibility and the history of resins. These important principles set the foundation for evaluating polymers and conservation treatments. Chapter 2 discusses polymer science and the differing optical, chemical and physical properties of polymers. It clearly relates how these properties affect treatments. Chapter 3 evaluates solvents, their uses and their relationship to polymers, including the different properties that are important to note, and the associated hazards. Chapter 4 details the principles of adhesion which are important to understand when evaluating how and why an adhered joint broke or can be reversed. Chapter 5 is a clear summary outlining the uses and requirements of polymers.

Part II of the text details technical information on a majority of individual polymer types that have been or are used in the field of conservation. At the end of the book are a series of appendices that summarize with graphs and charts the individual polymer properties, solvent properties and warnings, solubility parameters, and manufacturers' index. For those who are comfortable reading this kind

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of format, they provide a handy reference tool. A comprehensive bibliography on polymers and their uses compiled through 1984 for the original edition concludes the book.

I consider this an important resource for any professional who is involved with the care of natural history specimens. For those who are not professionally trained conservators or whose eyes glaze over at the thought of chemistry, a quick visual review of the book may put one off. Do not be deterred and try not to "judge the book by its cover." A knowledge of chemistry is not required, in spite of its formidable title and use of graphs, charts and chemical formulas in the later half of the book. While a complete reading of the book may not be necessary for non-conservators, I strongly encourage the reading of the introductory chapters 1, 2 and 5 in Part I Background Information. These chapters assume no knowledge of chemistry and provide a valuable basis for considering the philosophy and evaluating the preservation problems associated with adhesives, consolidants and coatings. As a conservator working in a developing field, I am most grateful to be able to participate in a dialogue to evaluate treatment approaches and techniques with professionals charged with collection care. While polymers are only one class of materials currently used in treatment of natural history materials, their application is widespread and often with failure to understand the ramifications for the future use of the object, potential reversibility, or even physical and chemical incompatibility. This text allows conservators and collection care managers a common language and departure point from which to develop strategies in the best interest for the preservation of the object.—*Alexandra O'Donnell, Conservator, 200 Briarwood Lane, Portsmouth, Rhode Island 02871.*

CURACIÓN MODERNA DE COLECCIONES ORNITOLÓGICAS, 1993, Patricia Escalante-Pliego, ed. (American Ornithologists' Union, 169 pp.) This is a collection of papers presented at a symposium entitled "Modernization of Collections" during the IV Congreso de Ornitología Neotropical, 1991. The present title more correctly reflects the scope of the symposium.

The purpose of the symposium, and the publication and distribution of this spiral-bound book, is to encourage the careful preservation and full documentation of ornithological specimens in the face of the accelerating destruction of undisturbed habitats. The book is aimed at the inexperienced curator and should serve its targeted audience well.

The editor has provided an introduction to the volume and concluded with a particularly useful directory to Latin American ornithological collections, many of which were unknown to this reviewer who considers himself well-informed on Latin American ornithology.

In between, there are eight contributions, six of which are concerned with the topic at hand. One paper, on geographical variation in vocalization, while informative, is outside the scope of the symposium; another paper deals first with the curation of anatomical material but soon launches into a discussion of avian phylogeny and evolution, with no bearing on the topic of the meeting.

The six papers that are aptly focused are concerned with the kind and amount of data that should be recorded and accompany a specimen, on how to prepare skeletons, on the methods for preserving eggs and nests, on the preservation of tissue samples in the field, on techniques for the long-term preservation of specimens, and, finally, suggested methods for entering data from museum specimens into a computer database.

The first five papers codify techniques which are generally well known and accepted by curators in large institutions. These will be instructive and helpful to those with part-time responsibilities for older collections or for those establishing new collections. The sixth paper, "Computerizing a collection of birds," touches a new field and one for which there are no agreed standards. For example, five of the six largest bird collections in this country each employs a different computer program, while the sixth institution hasn't yet entered the computer age. Nevertheless, although the author fails to note the lack of uniformity in computerization, even among our largest institutions, he does stress that to facilitate the later recovery, manipulation and utilization of data, it is necessary to thoughtfully and carefully plan ahead. And that advice is applicable to any computer and any program.—*Raymond A. Paynter, Jr., Museum of Comparative Zoology, Harvard University, 26 Oxford St., Cambridge, Massachusetts 02138.*

PRESERVING NATURAL SCIENCE COLLECTIONS: CHRONICLE OF OUR ENVIRONMENTAL HERITAGE, 1993, W. D. Duckworth, H. H. Genoways, and C. L. Rose, eds. (National Institute for the Conservation of Cultural Property, Inc., Washington, D.C., iii + 140 pp.). This publication represents the culmination of two years of intensive work by NIC's Conservation and Preservation of Natural Science Collections Project in cooperation with the Association of Systematics Collections and the Society for the Preservation of Natural History Collections. The work was partially funded by the National Science Foundation. The stated goal of the project is to improve the care of natural science collections.

This report arrived with a cover memo that alluded to the herculean effort involved in the overall project. There are 20 other reports that summarize meetings with 250 people from disciplinary societies in natural science and panel discussions on materials science. This particular report represents ideas, strategies, and recommendations resulting from those meetings held between February 1991 and April 1992. A modest description of the overall effort is stated in the Preface.

An Executive Summary describes succinctly what follows in Chapters One, Two, and Three. Chapter One, The Significance and Value of Natural History Collections, devotes three pages to describing the importance of natural science collections. This is followed by a full-page figure listing the many users of natural history collections. The list is used to demonstrate that, although many collections staff appear to work in an introverted environment, the utility of the specimens is broad based. Chapter Two, The Scope and Nature of the Conservation Challenge, allots seven pages to further describing the complexity, diversity, and value of natural science collections. Several examples are used to emphasize the conservation problems unique to natural science collections. Difficulties involving specimens, their documentation, and collection environments are explored. The chapter closes with three figures on consecutive pages. These are lists of specimens, materials used in preparation and care, and forms of documentation that briefly but dramatically underscore the "conservation challenge." Chapter Three, Meeting the Challenge: Recommendations and Strategies, reiterates the areas for action that are introduced in the Executive Summary. Fourteen pages are devoted to the coverage of six topics: Stewardship of Collections; Public Awareness; Staffing, Education, and Training; Technology Transfer; Conservation Research; and Guidelines and Standards of Practice. Each target area is discussed in some detail, followed by recommendations stated in bold print. Each recommendation is followed by several suggested strategies for implementation.

The body of the report is contained within these first 40 pages. They are nicely illustrated with striking black and white photographs. The text is confined to a single, 105 mm column on a 215 mm page. This allows a wide outside margin to display photos or pertinent quotations. These passages are printed in red, as are captions for the photographs.

The report also includes a 38-page selected bibliography which is extremely useful; a 14-page glossary with source references—also very good; and five appendices. Appendix A offers a suggested program for the training of natural science conservators including prerequisites and a curriculum. This is quite a thorough treatment of the subject. It is unfortunate that more space was not devoted to more specific information about training of other collection staff. Appendix B lists recommended topics for Research and Technology Transfer. This is a terrific compendium of ideas which adds a lot of value to the publication. Appendix C gives a Project Chronology starting in May 1989. Appendix D is an inventory of participants and contributors. These two appendices highlight the fact that the project was much bigger than this single report. Appendix E presents the "Resolutions from the International Symposium and First World Congress on the Preservation and Conservation of Natural History Collections." The final four pages list the credits for all photographs and quotations used in the report.

The use of figures and appendices allows for compact presentation of a great deal of information. These entities stand alone without need for reading the text. However, the placement of so much information outside what is normally considered "the body" of the report may cause it to be overlooked. These are meaty segments that would be a shame to disregard. The report contains a considerable amount of information that would be useful to the museum professional. It is written in a style that would be informative to an educator, a legislator, or a trustee as well.

The publication is available for the price of handling and air mail shipping (Domestic $8; Canada & Mexico $9; Elsewhere $16.50) by contacting National Institute for the Conservation of Cultural Property, 3299 K St. NW, Suite 403, Washington, D.C. 20007.—*Suzanne B. McLaren, Carnegie Museum of Natural History, Edward O'Neil Research Center, 5800 Baum Blvd, Pittsburgh, Pennsylvania 15206-3706.*

PREPARATION OF MANUSCRIPTS

General.—It is strongly recommended that, before submitting a paper, the author ask qualified persons to appraise it. The author should submit three copies of the manuscript either typewritten or printed on letter quality printers. **All parts of the manuscript must be double spaced** with pica or elite type on 8½ × 11 inch (21.6 by 27.9 cm) or A4 paper and at least one inch (2.5 cm) margins on all sides. Manuscripts should not be right justified, and manuscripts produced on low-quality dot matrix printers are not acceptable.

Each page of the manuscript should be numbered. Do not hyphenate words at the right-hand margin. Each table and figure should be on a separate page. The ratio of tables plus figures to text pages should generally not exceed 1:2.

The first page includes the title of the article, names of authors, affiliations and addresses of authors, and the abstract if present. In the top left-hand corner of the first page, indicate the name and mailing address for the author to whom correspondence and proofs should be addressed. All subsequent pages should have the last names of the authors in the upper left-hand corner.

The preferred language for manuscripts is English, but a summary in another language can precede the literature cited, if appropriate. Manuscripts written in other languages will be considered if the language uses the Roman alphabet, an English summary is provided, and reviewers are available for the language in question.

Abstract.—An abstract summarizing in concrete terms the methods, findings and implications discussed in the paper must accompany a feature article. The abstract should be completely self-explanatory and should not exceed 200 words in length.

Style and abbreviations.—Symbols, units, and nomenclature should conform to international usage. Cite all references in the text by the author and date, in parentheses. Footnotes should be avoided. For general matters of style authors should consult the "Chicago Manual of Style," 13th ed., University of Chicago Press, 1982.

Literature cited.—This section includes only references cited in the manuscript and should be typed double spaced. References are listed alphabetically by authors' names and take these forms:

Jones, E. M., and R. D. Owen. 1987. Fluid preservation of specimens. Pp. 51–64 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, 219 pp.

Sarasan, L. 1987. What to look for in an automated collections management system. Museum Studies Journal, 3:82–93.

Thomson, G. 1986. *The Museum Environment,* 2nd ed. Butterworths, London, 293 pp.

Tables and illustrations.—Tables and illustrations should not repeat data contained in the text. Each table should be numbered with arabic numerals, include a short legend, and be referred to in the text. Column headings and descriptive matter in tables should be brief. Vertical rules should not be used. Tables should be placed one to a page, after the references.

All figures must be of professional quality as they will not be redrawn by the editorial staff. They may include line drawings, graphs or black and white photographs. All figures should be of sufficient size and clarity to permit reduction to an appropriate size; ordinarily they should be no more than twice the size of intended reductions and whenever possible should be no greater than a manuscript page size for ease of handling.

Photographs must be printed on glossy paper, with sharp focus and high contrast essential for good reproduction. Photos should be trimmed to show only essential features.

Each figure should be numbered with arabic numerals and be referred to in the text. Legends for figures should be typed on a separate sheet of paper at the end of the manuscript. Magnification scale, if used, should be indicated in the figure by a scale bar, not in the caption. Notations identifying the author and figure number must be made in pencil on the back of each illustration. All illustrations must be submitted as an original and two copies. Note placement of tables and illustrations in the margins of the manuscript.

Evaluation of a manuscript.—Authors should be aware that the following points are among those considered by the editorial staff when evaluating manuscripts: 1) Is the content appropriate to the purpose of the journal and society? 2) Are the contents clearly and logically presented and the paper well organized? 3) Is the methodology technically and logically sound? 4) Does the paper contribute to the body of knowledge and literature? 5) Is the study integrated with existing knowledge and literature? Is the literature cited appropriate for the study? 6) Are the conclusions supported by sufficient data? 7) Does the title reflect the thrust and limitations of the study? 8) Are the tables and figures clearly presented? Are they necessary to support the text?

SUBMISSION PROCEDURE

Manuscripts intended either as feature articles or general notes should be submitted in triplicate (original and two copies) to the Managing Editor. Letters to the Editor and correspondence relating to manuscripts should be directed to the Managing Editor. Books for review should be sent to the Associate Editor for Book Reviews.

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