$$T = T_0 e^{-Yt} + N_\infty (1 - e^{-Yt})$$

$$T_{\max}\ (\text{equilibrium}) = N_\infty = [(Q/\rho c) + S]/Y$$

b. $Q(t) = Q_\infty (1 - e^{-\alpha t})$

$$T = T_0 e^{-Yt} + N_\infty (1 - e^{-Yt}) - [Q_\infty (e^{-\alpha t} - e^{-Yt})/(Y - \alpha)]$$

$$T_{\max}\ (\text{equilibrium}) = N_\infty = (Q_\infty + S)/Y$$

c. $Q(t) = \beta + \gamma t (\text{no } T_{\max})$

$$T = T_0 e^{-Yt} + \{[1 - e^{-Yt}][Y(S + \beta) - \gamma]/Y^2\} + (\gamma t/Y)$$

5. *No Cooling—Time-Varying Q and Temperature-Varying ρc*

$$\int_{T_0}^{T} \rho c\, dT = \int_0^t Q\, dt$$

The analytical solutions for constant (simple-step) inputs were compared in a numerical example. The following values were selected (in Btu, °R, ft, and arbitrary time units):

$$Q/\rho c = 200$$

$$(h_i A_i T_i + h_e A_e T_e)/V\rho c = 100$$

$$F A_r \sigma \epsilon T_r^4/V\rho c = 1.25$$

$$T_0 = T_i = T_e = T_r = 500$$

Figure 2 shows the resulting heating curves for: combined thermal radiation and convection (1), thermal radiation only (2), convection only (4a), and no cooling (5). Any finite amount of cooling produces an equilibrium temperature, which is not exceeded. This example indicates general trends only; particular environmental factors will affect the relative importance of convective and radiant cooling.

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An Improved Technique for the Determination of Short-Lived Fission-Product Gases*

A number of improvements have been made in the radiochemical technique for determination of short-lived fission gases since publication in the August, 1961, issue of *Nuclear Science and Engineering* (*1*). In the original procedure, release rates of krypton-89, xenon-137, xenon-140, and xenon-141 were determined during irradiation of fuel specimens by collecting the long-lived decay products of these gases in a trap containing pads of stainless steel mesh. The daughter products (strontium-89, cesium-137, barium-lanthanum-140, and cerium-141) were etched from the pads of mesh and analyzed radiochemically. In the improved procedure, the daughter products are collected on a charged rod and analyzed directly by gamma-ray spectrometry.

The design of the new trap is shown in Fig. 1. It is constructed of stainless steel, and all closures are made by welding except for the removable assembly at the top of the trap. The gas stream enters the trap at the bottom, passes

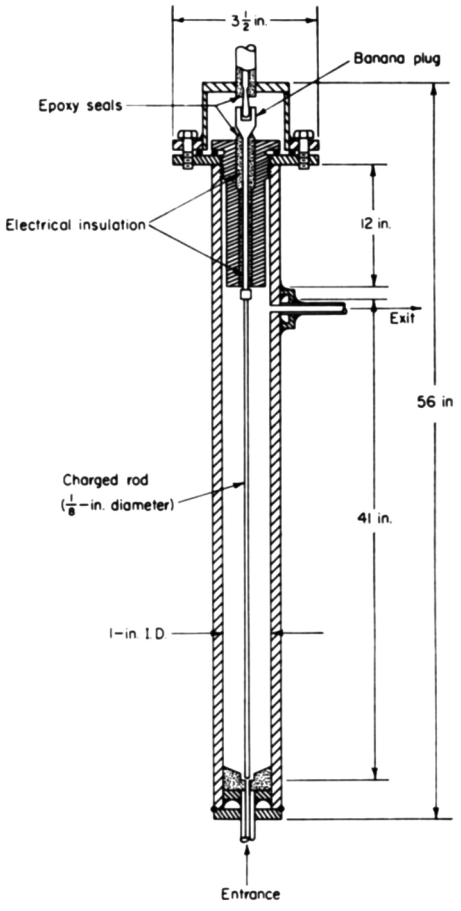

FIG. 1. Charged rod daughter trap

over the charged rod, and exits at the top. The rod is ⅛-in. stainless steel, and a negative potential of 1000 volts is applied to it during operation. Positively charged daughter products are collected on the rod as the short-lived fission gases decay in passing through the trap. To remove the charged rod for analysis, the cap at the top is unbolted, the electrical connection is broken at the banana plug, and the insulated plug through which the electrical lead passes is unscrewed and lifted out.

Radiochemical analyses of the solid daughter products are greatly simplified with the improved trapping system. This is due to the possibilities of more rapid removal of the trap from the system and of performing gamma-ray spectrometry directly on portions of the collecting rod. Only 10 to 15 min are required to remove the collecting rod from the trap and to cut it into 1-in. long sections which can be assayed in a gamma-scintillation well-crystal spectrometer. This permits the analyses to be performed on shorter-lived daughter products (such as 14.9-min rubidium-89), thus increasing the number of short-lived gases that can be determined. The costs of analysis are also considerably reduced, since radiochemical separations are not required when gamma-ray pulse height analysis combined with resolution of decay curves can provide the necessary data.

Currently, release rates are being determined for the

* Work performed under AEC Contract W-7045-eng-92.

following fission gases:

$$Kr^{89} \xrightarrow{3.2\ min} \underline{Rb^{89}} \xrightarrow{14.9\ min}$$

$$Kr^{91} \xrightarrow{10\ sec} Rb^{91} \xrightarrow{14\ min} \underline{Sr^{91}} \xrightarrow{9.7\ hr}$$

$$Kr^{92} \xrightarrow{3\ sec} Rb^{92} \xrightarrow{80\ sec} \underline{Sr^{92}} \xrightarrow{2.6\ hr}$$

$$Xe^{137} \xrightarrow{3.9\ min} \underline{Cs^{137}} \xrightarrow{28.6\ yr}$$

$$Xe^{138} \xrightarrow{17\ min} \underline{Cs^{138}} \xrightarrow{32.2\ min}$$

$$Xe^{139} \xrightarrow{41\ sec} Cs^{139} \xrightarrow{9.5\ min} \underline{Ba^{139}} \xrightarrow{84\ min}$$

$$Xe^{140} \xrightarrow{16\ sec} Cs^{140} \xrightarrow{66\ sec} \underline{Ba^{140}} \xrightarrow{12.8\ days}$$

$$\underline{La^{140}} \xrightarrow{40.3\ hr}$$

$$Xe^{141} \xrightarrow{1.7\ sec} Cs^{141} \xrightarrow{short} Ba^{141} \xrightarrow{18\ min}$$

$$\underline{La^{141}} \xrightarrow{3.8\ hr}$$

The species underlined are the daughter products which are measured. The methods for analysis of each are as follows:

Rubidium-89 (14.9 min). The 1.05 Mev gamma ray (75% abundance) is assayed. Gamma-ray spectra are obtained on six sections of the rod taken from the full length of the trap. The first spectra are obtained at 15 to 20 min after trap shutdown, and the decay is followed for 6 to 8 hr. The major component to be subtracted from the decay curve is 32.2-min cesium-138. A small contribution from 9.7-hr strontium-91 must also be subtracted from the sections in the first half of the trap.

Cesium-138 (32.2 min). The 1.01 Mev gamma ray (25% abundance) is assayed. The cesium-138 data is obtained directly from the decay curve for rubidium-89.

Barium-139 (84 min). Decay of the 0.163 Mev gamma ray (23% abundance) is followed from approximately 1 hr after trap shutdown to 6 to 8 hr after. The same sections of the rod that were used for rubidium-89 and cesium-138 are analyzed. Strontium-91 is the major component to be subtracted from the decay curves.

Strontium-92 (2.6 hr). The 1.37 Mev gamma ray (90% abundance) is assayed. Strontium-92 is normally found on only the first 4 to 6 in. of the trap; so the second- and fourth-inch sections are analyzed. The first- and third-inch sections are reserved for lanthanum-141 analysis. Decay of the strontium-92 is followed from 1.5 to 2 hr after trap shutdown until the following day. The only component to be subtracted from the decay curve is a small quantity of barium-lanthanum-140.

Strontium-91 (9.7 hr). The 0.55 Mev gamma ray (59% abundance) is assayed on sections of the rod from the first half of the trap. The decay is followed from 2 to 3 hr after trap shutdown to 3 days afterwards. A contribution from barium-140 must be subtracted from the decay curves.

Lanthanum-141 (3.8 hr). Lanthanum-141 is a pure beta emitter and thus must be separated chemically and determined by beta counting. After waiting 2 to 3 hr to allow the lanthanum to grow in, the first- and third-inch sections of the rod are etched with hydrochloric acid, and the lanthanum is separated by extraction into 1.5 molar HDEHP (bis-2 ethyl-hexyl phosphoric acid) in toluene. The aqueous phase is first adjusted to pH 3–4 with sodium hydroxide. After a wash step, the lanthanum is back-extracted into 1 molar hydrochloric acid, and an aliquot is beta assayed.

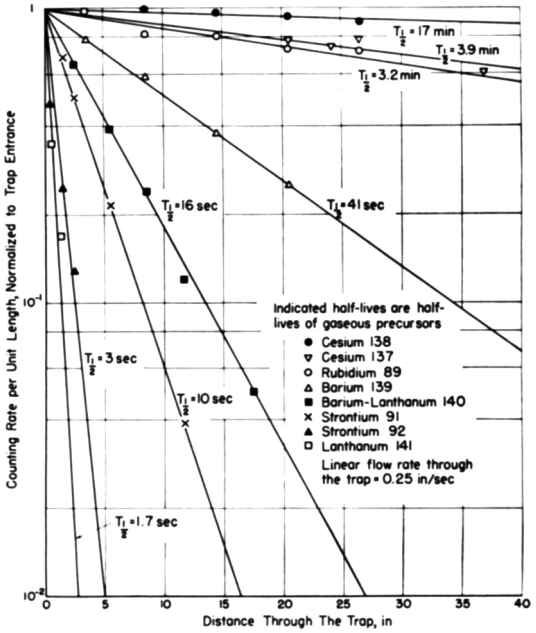

FIG. 2. Distribution of daughter products through the trap

Barium-Lanthanum-140 (12.8 days). The 1.6 Mev gamma ray of lanthanum-140 (88% abundance) is assayed 6 to 8 days after trap shutdown, when the shorter-lived activities have decayed and the lanthanum has grown in. Sections of the rod from the first half of the trap are analyzed.

Cesium-137 (28.6 years). Analysis for cesium-137 is delayed until 6 to 8 days after trap shutdown when the short-lived activities have decayed. The 0.66 Mev gamma ray (82% abundance) is assayed, and to avoid interference by barium-lanthanum-140, only sections from the last half of the trap are analyzed.

A typical set of data obtained with this trap is illustrated in Fig. 2. The concentration of daughter product activities at various points in the trap is plotted as a function of the distance through the trap. The solid lines represent the theoretical distribution of each daughter species. Good agreement was found between the experimental data and the predicted distributions, confirming proper performance of the trapping system.

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