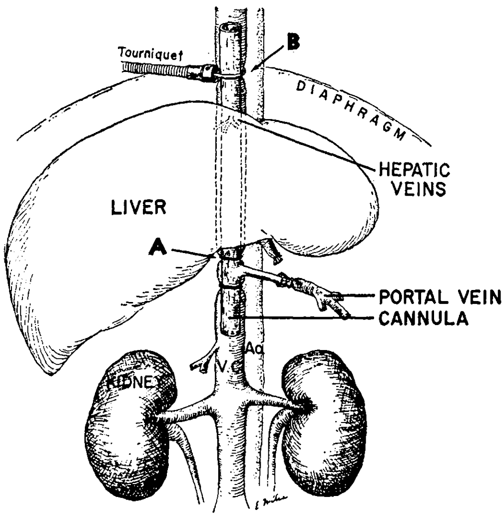

FIG. 1.

non-crushing clamp, rather than divided, so that its integrity can be easily restored. The ligature compressing the vena cava against the tube between the liver and diaphragm should be replaced by a tourniquet; its release immediately reestablishes hepatic outflow. The portal circulation, too, may be restored rapidly by interposing a tube between the divided vein ends(3). This avoids the necessity of a suture anastomosis and can be carried out with great facility. All tubes used for vascular anastomosis must be suitably treated with Desicote to prevent vascular thrombosis. With experience, the mortality of this "reversible hepatectomy" should not exceed 15%.

Summary. An experimental technic has been described by which the liver can be excluded from the dog's circulation and returned promptly, as desired, into its normal anatomical and functional position. This method has a low mortality.

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Uptake of Fission Products and Neutron-Induced Radionuclides by the Clam. (23249)

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Detection of sea water contamination resulting from radioactive fallout or disposal of reactor waste products deserves careful consideration(1,2). Assessment of degree of contamination of water in which levels of activity are low, but nevertheless biologically significant, is difficult owing to the large volume of water required for radioanalysis. A biological indicator which rapidly reflects degree of nuclide contamination by virtue of a concentrating ability is of obvious value. Surveys made of the Marshall Islands one and 2 years after their accidental contamination by fallout, revealed the presence of readily detectable levels of radioactivity in clams (3,4). Radioactivity in these animals was significantly higher per unit body weight than in most marine specimens analyzed. An extraordinary ability to concentrate radionuclides dispersed in sea water was evident from the fact that the level of gamma activity in clams collected at Eniwetok Proving Ground was about 2000 times greater than that of sea water(3). The concentrating ability of the clam probably derives from its mechanism of feeding which involves filtration of large volumes of water. It is estimated that in one year a 3 in. clam filters about 2.3 x 10^4 liters of water(5).

In the current study, the uptake by the clam of radionuclides was examined under controlled conditions. Groups of clams were placed in sea water which contained mixed fission products, Zn^{65}, Co^{60} or Fe^{59} and uptake was measured at various intervals. Zn^{65}, Fe^{59}, and Co^{60}, all of which are neutron-induced activities,* were included in the study since at least 2 of these, Zn^{65} and Co^{60}, were detected in marine animals one and 2 years following exposure to fallout(3,4,6).

Procedure. Japanese littleneck clams averaging 2 in. diameter and weighing about 17 g, obtained from San Francisco Bay were used. A 2-month-old mixture of fission products† and the neutron induced activities Zn^{65}, Fe^{59}, and Co^{60} were each studied separately for each series. Four clams were placed into each aquarium containing one liter of sea water. A total of 80 clams were placed in 4 series of 5 aquaria, all of which were continuously aerated. To each of the 5 aquaria in a series, 5.2 μc Fe^{59}, 1.1 μc Zn^{65}, 5.4 μc Co^{60}, or approximately 5 μc mixed fission products was added. The radionuclides, with the exception of Fe^{59}, were of high specific activity. Clams in each series were killed at intervals of 3 hr, 6 hr, 1, 3 and 6 days. In another experiment, uptake of Co^{60} by clams was studied as a function of concentration. Four clams were placed into each of 3 aquaria which contained 0.9, 5.2, or 280 μc l of Co^{60}. These clams were killed on the sixth day. (1 μc of these solutions contained 0.23 mg of inert cobalt.) At termination of this experiment, the clams were weighed, the shells removed. Weight of shell and of soft tissue from each clam was then determined. Both shell and soft tissue were dried at 100°C and ashed at 550°C overnight. The ash was dissolved in HCl and diluted to volume. The gamma activity for neutron-induced activities in an aliquot was measured in a well-type sodium iodide scintillation detector and scaler. In addition, residual gamma activity in the water was determined at each sacrifice interval. The clams placed in the mixed fission product solution were analyzed radiochemically for Sr^{89}, Zr^{95}, $Ru^{103-106}$, and the rare earth group, as previously described(7). The water in the aquarium was also analyzed radiochemically to determine concentration of these same radionuclides.

* Neutron-induced activities are radionuclides formed by capture of a neutron (released in nuclear fission) by the nucleus of a stable element.

† This fission product mixture was derived from fallout collected from a nuclear detonation.

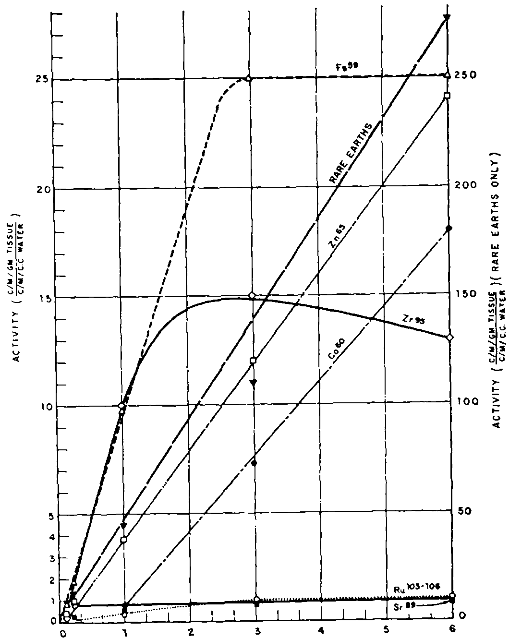

FIG. 1. Concentration ratios of radionuclides in soft tissue of clams.

Results. The results demonstrate that clams are able to take up and retain various radionuclides in both shell and soft tissue. The activity of the various radionuclides in the soft tissue of clams placed in radioactive solutions is shown in Fig. 1. Values are expressed in terms of a concentration ratio (ratio activity per gram soft tissue to activity per ml radioactive solution). This mode of expression was used because concentration of the radionuclide in the medium decreased significantly with time.

In general, much higher levels of activity were observed in the shells than in the soft tissues (Fig. 2). Rates of uptake by the shell of Fe^{59}, Zn^{65}, and Co^{60} are constant in the period from 1 to 6 days (Fig. 2). The concentration ratio for Co^{60} was 10-fold higher than for Zn^{65} and Fe^{59}. Studies performed with shells detached from the animal indicated that the mechanism of retention of the activity by the shell was a nonmetabolic process, since the activity was the same as

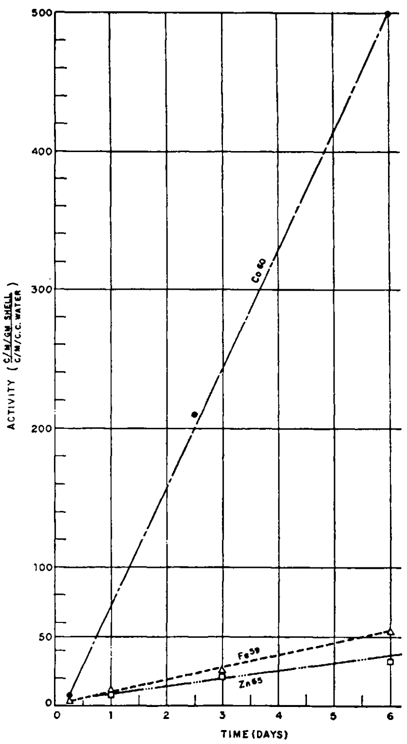

FIG. 2. Concentration ratio of radionuclides in shells of clams.

that of the shell of the living organism. While the uptake of activity by detached shells therefore was probably a surface adsorption phenomenon, the uptake by shells of living animals probably also involves a metabolic process(8). Incorporation of radionuclides into the soft tissues appears to be a metabolic process.‡

The uptake of Co^{60}, the rare earth group, and Zn^{65} by the soft tissues was a linear function in the 1 to 6 day period, and similarly, a linear relation was observed for iron uptake during the first 3 days. From 3 to 6 days, however, concentration of Fe in the soft tissues remains constant, perhaps indicating a saturation condition with respect to this element. The low specific activity of the Fe^{59} probably accounts for this early saturation. Of the radionuclides studied, Fe was taken up at the highest rate, while Zn and Co were taken up at somewhat lower rates. The concentration ratio for the rare earths was 10-fold greater than for any other radionuclide. Rate of uptake of Zr^{95} by the soft tissue was linear for the first day only and leveled off in the period from 2 to 6 days. The values measured during the first day indicate that the clam in most cases was in the process of attaining an equilibrium condition with the new environment. It was noted, for example, that not all the clams began to pump water at the same time after being transferred to the radioactive solutions.

Concentration ratios (activity/g tissue/activity per ml solution) of Co^{60}, Zn^{65}, and Fe^{59} in the soft tissues of the clam at 6 days varied from 18 to 25 (Fig. 1). This close agreement in concentrating ability probably reflects the rather similar chemical properties of these transition elements, which provide a basis for their common metabolic behavior.

Concentration ratios for mixed fission products at 6 days ranged from 1 for $Ru^{103-106}$ and Sr^{89} to 13 for Zr^{95} and 280 for the rare earth elements. Ru and Sr soon attain a concentration ratio of 1 and maintain this over the 6-day period, indicating that they are in equilibrium with, and equal to, the concentration of the solution.

Strontium appears in the tissues of mollusks in the same order of magnitude as it appears in sea water(9,10). Trace quantities of Fe and Zn are found normally in the soft tissues of clams; Fe is found in the hemoglobin of corpuscles of many species; and both Fe and Zn are found in kidney and liver (9,11). Thus, uptake of these radioactive elements is probably on an exchange basis with the same elements, or involves replacement of a chemically similar element already in the organism.

Rate of uptake of Co^{60} by the clam's soft tissue and shell was found to be a function of the level of radioactivity of the medium (Fig. 3). A plot of the log rate of uptake (μg/g tissue or shell/day) as a function of the log of concentration (μg/cc) in the solution indicates that the relationship of the 2 variables may be described by a power function. This finding agrees with the results reported by Rosenthal(12) on rate of uptake of Ca^{45} by guppies as a function of isotopic concentration and of the uptake of Sr,

‡ Incorporation of radionuclides in individual tissues was shown by autoradiographs.

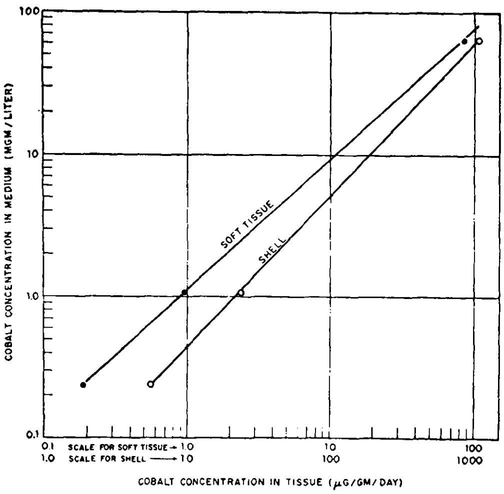

FIG. 3. Rate of uptake of cobalt by the clam *vs* conc. of the cobalt in the medium (each point represents four clams).

Ba, and La in the goldfish(13).

Summary. A study of the uptake of 3 neutron-induced radionuclides (Zn^{65}, Fe^{59}, and Co^{60}) and a 2-month-old mixture of fission products by the clam demonstrated the ability of this marine animal rapidly to concentrate significant quantities of these radionuclides in both the shell and soft tissue. The uptake of radioactive material in the soft tissue is a metabolic incorporation, while the higher uptake by the shell appears to be a surface adsorption phenomenon. Rate of incorporation by the soft tissues was constant and was highest for the rare earth group of fission products. Uptake of Co^{60}, Zn^{65}, and Fe^{59} was also constant but occurred at a much lower rate. Sr^{89} and $Ru^{103, 106}$ were taken up only in equilibrium with the radioactive medium in the experimental interval studied. Further study with the radionuclide Co^{60} indicated that rate of uptake varied as a power function with level of concentration of the radionuclide in the medium.

The ability of the clam to concentrate radioelements to a high degree makes it valuable as a biological indicator of radioactivity. It may be particularly useful in assessing contamination of marine areas with low levels of radioactivity.

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