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The electrochemical etching technique involves a number of variables including chamber frequency, voltage, electrode diameter, electrode spacing, electrolyte concentration, etching time, sample thickness and exposed sample area. A significant part of future work will be the study of the effect of changes in these parameters on the etching sensitivity. The data presented here are for samples etched at a frequency of 2 kHz at voltages from 800 V to 1500 V for 5 hours. The polycarbonate samples are 0.25 mm thick. Because the etch time increases significantly with sample thickness,[1] material thicker than 0.4 mm is not useful for routine work.

One variable we had not anticipated was the quality of the plastic surface. The process is very effective for enhancing imperfections in the plastic. These imperfections seem to be the major contribution to the sample background. The etching process amplifies any surface penetration, and produces either a single track or an artifact which is easily distinguished from a true track. Etched tracks in a sample of polycarbonate exposed to ^{252}Cf neutrons are shown in Fig. 3(a). For comparison, artifacts from three surfaces are shown: 3(b) a surface scratch; (3c) a fine particle of polycarbonate pressed into the surface when the sheet was rolled; and 3(d) the etch pattern around a bubble on the film.

The material we have found to have the lowest background is 0.25-mm polycarbonate film from Roland Plastics in Kensington, Connecticut.* It was shipped to us with a thin protective layer of polyethylene film which we leave on to protect the surface until the sample is etched. We should note that the quality of material can be expected to vary from batch to batch and on how it has been handled, so it is worthwhile to obtain samples from a number of suppliers before making a selection.

One set of samples was exposed to each of two neutron spectra from a moderated ^{252}Cf source. The moderation was provided in one case by a sphere of polyethylene with a thickness of 10 cm, and in the other case by a 20-cm-thick sphere of aluminum. A third set of discs was exposed to the source with no moderation. After etching, the samples were counted with an optical microscope at 35X. The results are presented in Table 2. It should be noted that the magnification was low enough that by focusing between the surfaces of the sample, both surfaces could be counted simultaneously. The results presented are the total for both surfaces of a 1-cm^2 area of the sample.

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

The results show that in the range 800 V to 1500 V, the background seems to double every 100 V, but the response increases only by a factor of two. This suggests the need to use low voltages with longer etching times to achieve equivalent track size and lower limit of detection. It will be necessary to see how variation of some of the other parameters affects this situation.

Preliminary results from our use of the electrochemical enhancement of neutron-induced recoil tracks in polycarbonate support the optimism for its value as a fast neutron personnel dosimeter. It has the advantages that the material is cheap, is insensitive to gamma rays, and has good latent track stability. Although it does not appear to be as sensitive as TLD albedo techniques,[3] it would be very useful in conjunction with an albedo system to provide a combination of high sensitivity and improved accuracy at dose levels in excess of a few hundred mrem.

The technique has major drawbacks: (1) long etch times are required; and (2) it is a process that does not lend itself in an obvious way to automation. However, if it is used with an albedo dosimeter, only a small fraction of the dosimeters used, i.e., those having significant exposure indicated by the albedo component would require processing. Work must now be done to (1) characterize the effects of the various parameters in the etching process, (2) select a set of parameters that yield the best sensitivity, and (3) make irradiations with monoenergetic neutrons to define the energy response (particularly from 0.5 to 5 MeV).

Realistic Torso Phantom Development

Introduction. In the previous Hazards Control Progress Report,[4] we reported on the initial stages of construction of a realistic phantom for internal measurement of ^{239}Pu and other heavy elements *in vivo*. In this report we review the current status of the construction, and discuss the work to be done.

Initial work on the phantom[4] included: (1) determination of the external dimensions that most closely represent the stature of a typical radiation worker; (2) construction of a clay model to be used as a guide for contouring the torso; (3) acquisition of the rib cage and major organs from a male cadaver of the same approximate size; (4) molding the torso and interior void of the cadaver with organs removed; and (5) preliminary selection of tissue equivalent (T.E) materials.

The work to be discussed here includes: (1) casting the organs in plaster; (2) casting the torso void to provide a cavity for organ arrangement; (3) more detailed selection of tissue-equivalent materials; and (4) development of a method for filling the rib cage bones with T.E. material to simulate lost bone marrow.

Organ Casting. With the exception of the lungs, it was a simple task to make plaster casts of the major organs. Individual organs were suspended in a box with hypodermic needles (Fig. 4). The box was then filled with polyurethane to make the mold. Non-shrinking plaster was used for the model organs. A sample mold and plaster cast is shown in Fig. 5.

The heart, liver, spleen, and kidneys were left sufficiently rigid by the embalming technique to be cast in this way. The lungs, however, began deflating after removal from the cadaver, and could not have been cast without serious distortion. As a result, we used a simple specimen preparation technique[5] to make the lungs rigid for casting. The lungs were reinflated and dried by passing a tube into the trachea which was still attached to the lungs, and then flowing compressed air through them for a period of about two weeks (Fig. 6). Normally, animal lungs prepared in this way are hard and feel as if they were made of styrofoam. In this case, the glycerin in the embalming fluid left most of the lungs somewhat spongy, but rigid enough to be cast.

The volumes of the organ casts are presented in Table 3, together with average values for an adult male.[6] At the beginning of the project, we were very concerned with trying to produce "Standard Man" organs. However, a tour of the dissection laboratory at the University of California Medical Center Anatomy Department graphically demonstrated to us individual variability in organ shape and size. This variability is reflected in the ranges shown in Table 3.

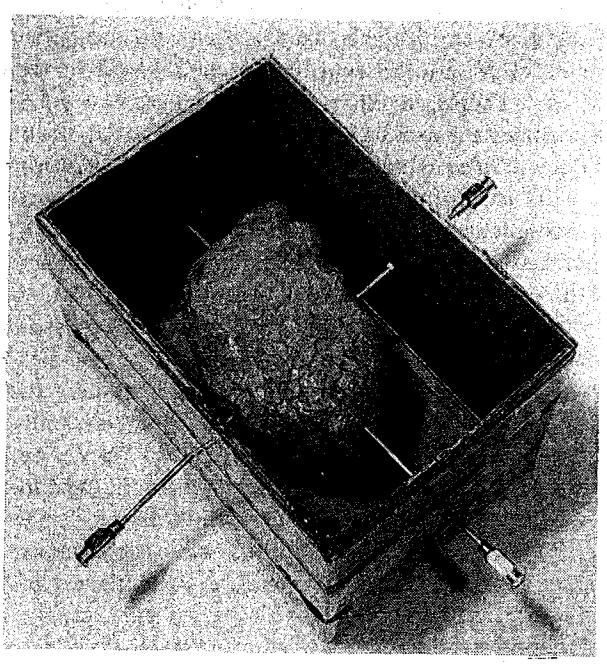

Fig. 4. Spleen in position for molding.

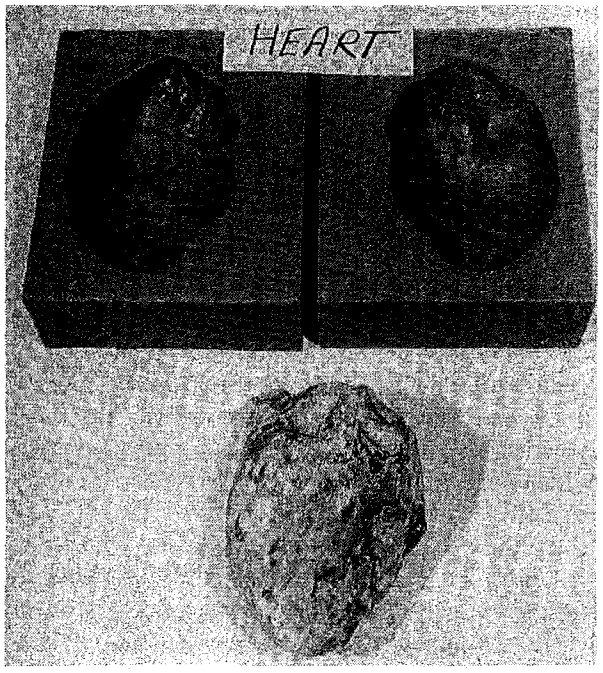

Fig. 5. Sample mold and plaster replica of the heart.

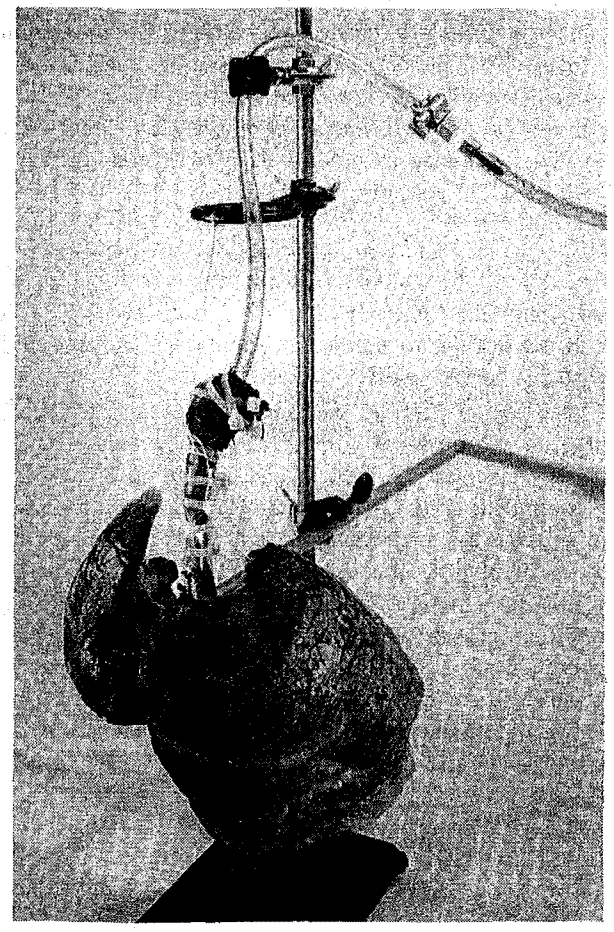

Fig. 6. Air reinflation and drying of lungs.

Table 3. Organ volumes for plaster casts and reference man

	Volume (ml)	
	Plaster casts	Reference man
Heart	865	750(630-870)[a] ml
Liver	2050	1700(1320-2200)[b]
Spleen	155	181(109-300)[b]
Kidneys	150 (right)	149(112-182)[b]
	170 (left)	
Lungs	1410 (right)	5000 (total volume)
	740 (left)	

[a]Values in parentheses represent standard deviation for samples measured.

[b]Values in parentheses represent 80% range for samples measured.

As a result, the main concern now is that the existing organs fit together properly. We do feel, however, that the lungs must be modified because they appear to have shrunk when compared with the cast of the torso cavity.

Torso Cavity Cast. The original torso cavity cast was made by filling the cadaver void with expanding silicon foam. That model was reproduced in plaster in a manner similar to that used for the organs. Because there was some shrinkage in the original foam cast, it was necessary to modify the plaster cast until the rib cage fit properly (Fig. 7).

Fig. 7. Plaster mold of torso cavity with ribs in place. Connection between fourth rib and sternum is a calcified bridge V on the cartilage that developed.

Selection of Tissue-Equivalent Material. Our first preference for a muscle-equivalent material to be used for the heart, liver, spleen, kidneys and torso was based on the relative transmission factors of available T.E. materials.[4] The depolymerized rubber, TEMEX, seemed to have the best simulation of the x-ray transmission properties of lean tissue. However, as we studied samples of depolymerized rubber available to us, there was concern that thin layers such as that containing the ribs and sternum would crack or split easily. We also learned that the attenuation coefficient at 10 keV differed from that for muscle by more than 25%.[7] People in our plastics shop proposed use of polyurethane as a base for our own T.E. composition. Polyurethane is nominally 65% carbon, 9% hydrogen, 5% nitrogen and 21% oxygen, and is generally free of materials having higher atomic numbers. Specific composition depends on the supplier. In addition to the strength of the material, the availability of foamed polyurethane as a possible lung material may be an advantage.

The attenuation coefficient for polyurethane not having significant levels of high Z materials is less than that for lean tissue. The transmission of 17-keV x rays through 4 cm of Scotchcast 221 is four times that of an equivalent thickness of fresh beefsteak. In fact, polyurethane without filler may be a good simulant for adipose tissue. To simulate lean tissue with

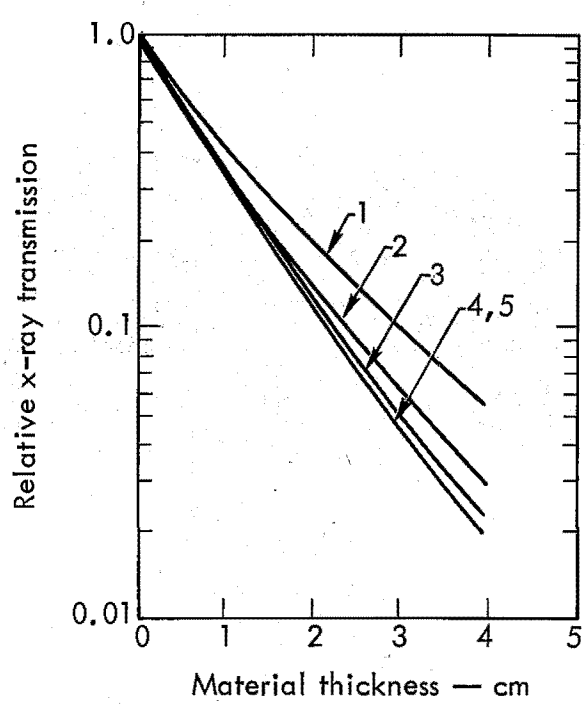

Fig. 8. Transmission of ^{238}Pu L x rays through muscle-equivalent materials. 1. MIX-D (LLL); 2. Rando T.E. material; 3. Temex; 4. LLL T.E. material; 5. Fresh beefsteak.

polyurethane, it is necessary to add a higher Z filler. In selection of a proper filler, it is best to select materials with atomic numbers lower than about 20. If high Z fillers are used, it is more difficult to match the attenuation coefficients of tissue over the range of energies from 10 to 100 keV. However, if very low Z materials are used, the quantities required to achieve the proper attenuation may exceed the capacity of the polyurethane.

A number of commercial polyurethane formulations are available in a variety of compressibilities, so there is a large selection of potentially useful combinations of plastics and fillers for T.E. applications. We selected Scotchcast 221 and added 3.5% sulfur. Calcium carbonate is also under consideration as a filler. It does not have the odor associated with sulfur, but more material is required to achieve a given degree of attenuation. The narrow beam attenuation curve for our T.E. plastic material using ^{238}Pu x rays is shown in Fig. 8, together with curves for TEMEX, MIX-D, RANDO muscle-equivalent material and beefsteak. Attenuation curves for other x-ray energies have not been made, but the use of polyurethane appears to meet our needs as a base to simulate soft body tissues.

Bone Marrow Replacement. When the rib cage was cleaned and degreased, all of the bone marrow was removed. A technique to replace the lost marrow was suggested by Dr. Donald Newton.[8] Because of the ease of handling and its low viscosity after melting, MIX-D[9] was selected as the marrow simulant. The process involves suspension of the bone over a pot of molten MIX-D in a vacuum chamber. The bone is lowered into the fluid MIX-D and the chamber is brought to atmospheric pressure, forcing the T.E. material into the trabeculae of the bone. The mixture is cooled, and the bone is removed just before the MIX-D solidifies. After the bone is removed from the chamber, excess MIX-D is scraped off. The whole process takes about a day to assure proper evacuation and penetration of the MIX-D; however, only about an hour of the operator's time is required to make a run.

We have built and tested such a chamber. Figure 9 shows a neutron radiograph of two ribs acquired from an educational supply firm. The top bone is unfilled, and the bottom bone has been filled as described. There are small voids in the filling, particularly one path near the tip. That particular void connects with a hole in the bone surface. We suspect that the MIX-D drained from that hole after being removed from the molten solution. Redipping the same bone did not improve the situation. A recent run with a new bone has been made, allowing the mixture to cool more before removing the bone. That bone has been radiographed, and the filling is much better. We now consider the technique successful even with vertebrae, and feel small voids are tolerable.

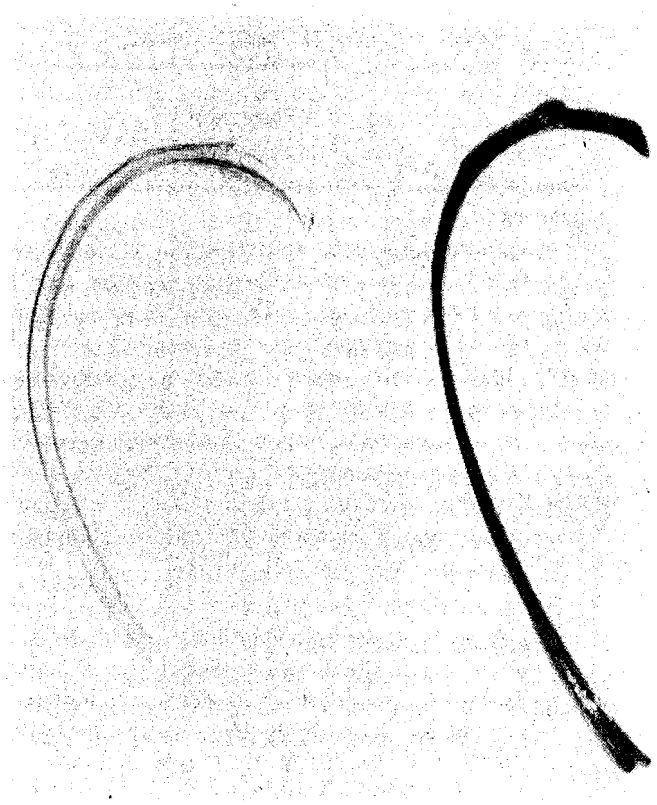

Fig. 9. Neutron radiograph of ribs. Top: Without marrow simulant replacement; bottom: marrow replaced by vacuum filling with MIX-D.

Summary. Recent work on the realistic phantom includes preliminary casts of major organs, plaster casts of the torso and organ cavity, formulation of muscle-equivalent material, and development of a successful technique for replacing lost bone marrow in the rib cage. Considerable effort lies ahead. We must modify the organs to establish a closely packed array in the torso cavity. The torso exterior must be modified, based on ultrasonic chest scans of living subjects, so that the chest wall is 10 to 15 mm thick. The rib cage must be assembled and cast in the torso shell using T.E. plastic. The organs must be cast in T.E. plastic, and we must find a lung material simulant.

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