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THE APPLICATION OF NEUTRON RADIOSCOPY TO LITHIUM-ALUMINUM ALLOY TARGET ELEMENTS

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Abstract

We have shown that neutron radioscopy is very useful in locating the position of a Li-Al alloy core enriched in Lithium-6 in tubular aluminum target elements. The alloy core is displaced during a forming process and its location must be redetermined before processing can be completed. The Army's low-flux mobile neutron radioscopy system was employed in these studies as a model system for possible on-line, in-plant use. A series of core end sections of target tubes containing from 0.1 to 4.6 grams of Lithium-6 per foot of length were examined radioscopically with thermal neutrons. The system was able to determine the extent of lithium alloy core from the highest concentrations down to about 0.2 grams of Lithium-6 per ft within one minute of data collection time. A marked loss of sensitivity below this level could be recovered by providing higher geometrical resolution in the images obtained or by using image enhancement techniques. Film radiography was used to verify the accuracy of radioscopic determinations at the lowest lithium concentrations.

INTRODUCTION

The goal of the studies described here was to provide an accurate alternate method for determination of the post-extrusion location of Li-Al alloy core in aluminum target elements to be used in the production of tritium in nuclear reactors. The work is an effort stemming from a mutual interest of the Department of the Army and the Department of Energy in diverse applications of the Li-Al alloy system. Lithium-aluminum alloys with lithium content in the 0.8 to 2.5 weight-percent range are used as target material in the production of tritium at Department of Energy facilities. Tritium, H^3, is produced through the reaction:[1]

$$ {}_3Li^6 + {}_0n^1 \longrightarrow {}_1H^3 + {}_2He^4 + 4.8 \text{ MeV}. $$

*The information contained in this paper was developed during work under contract No. DE-AC09-76SR00001 with the U. S. Department of Energy.

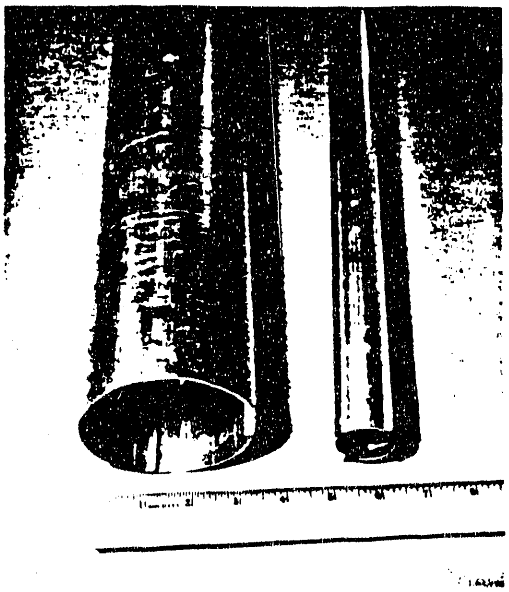


Fig. 1. Photograph of typical target tubes.

The target material,* ^{6}Li, is in the form of an aluminum-clad Li-Al alloy hollow tube. After a controlled period of irradiation with neutrons in a nuclear reactor, the tube is removed and the tritium generated is recovered from the alloy.

TARGET TUBES

Aluminum tubes approximately 12 feet in length and varying in diameter from about 1.3 inches to 3.6 inches are used as carriers of target material in this application. Figure 1 is a photograph of typical tube sections. The target material may be natural lithium or lithium enriched in the ^{6}Li isotope in the form of a lithium-aluminum alloy.* It is common practice to express the lithium content in units of grams of ^{6}Li per foot of tube length. The lithium-aluminum alloy, having essentially the same physical properties as pure aluminum, readily bonds to aluminum in an extrusion cladding operation which results in a uniform metallic tube with the lithium element entirely sealed within aluminum.

Unfortunately, this forming operation displaces the Li-Al alloy in a manner which results in a very nonuniform distribution of the alloy at the two ends of the finished tube. In order to retain all of the target lithium and not defeat the integrity of the cladding seal, it is important to locate the exact extent of the alloy at the core ends. This allows excess aluminum at the core ends to be cut off and disposed of in a later operation.

The present practice is to determine the location of the end of the embedded alloy core with an eddy current probe. An independent nondestructive method for confirming the location of the core end was desired.(2) Ultrasonic pulse-echo time of flight measurements were tried, but consistent results could not be obtained at low Li-Al alloy concentrations. The method explored and described here is to provide a neutron radiologic image of a 10-inch section of the core end which maps out the distribution of the alloy completely. The distribution of uranium fuel in aluminum-clad reactor fuel elements can be determined using x-ray radioscopy in a similar manner. Another requirement was to provide this determination within a short (1 or 2 minute) time frame.

*Lithium occurs in nature as a mixture of two isotopes, 7.5% ^{6}Li and 92.5% ^{7}Li; enrichment alters the ratio of these isotopes in the target alloy. Lithium-6, ^{6}Li, and Li^{6} all refer to the same isotope.

THE NEUTRON RADIOSCOPY SYSTEM

The use of neutron radiation for this work is particularly favorable because enrichment of the Li-Al alloy with its ^{6}Li isotope gives the alloy a very high cross section for neutron removal (typically 940 barns) relative to that of the aluminum (0.9 barns)[4] thereby providing excellent image contrast. Radioscopy refers to the technique of imaging hidden components of an object with radiation transmitted through the object and recorded in a non-permanent manner. In the radioscopy described in this report, the image is stored electronically and presented to the operator on a CRT screen. The Army has an interest in neutron imaging systems for aircraft examination and other nondestructive examination purposes which requires that the neutron source be mobile. This requirement has led the implementation of neutron radiography away from the use of nuclear reactor sources and towards the use of less encumbered, small californium-252 and accelerator sources. The radioscopy in these studies was accomplished primarily with a small accelerator source system which provides about 1/500 of the thermal neutron flux provided by reactor sources for radioscopy.[5,6] The accelerator generates 14.3 MeV neutrons which are moderated in oil to thermal energies for radioscopy. It is shown in operation in Figure 2. The source and collimator system is mounted on a mobile frame, weighs 4900 pounds (2200 kg), and occupies a volume of approximately 15 ft x 5 ft x 4 ft (4.6 m x 1.5 m x 1.2 m). It was appropriate to utilize this unit for this work because it provides a model system for possible installation within a target fabrication plant.

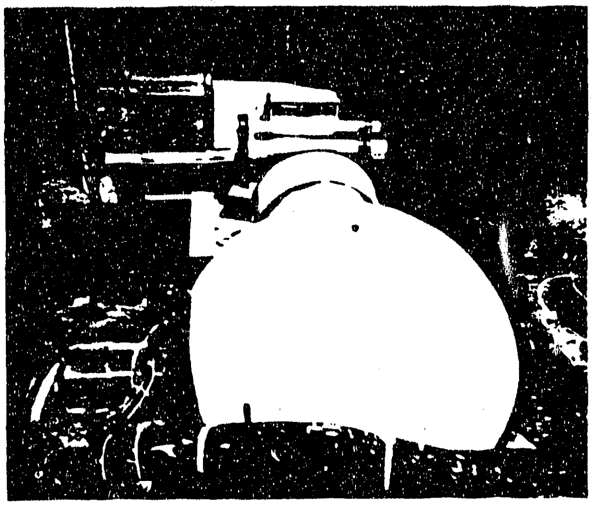


Fig. 2. View of the radioscopic setup. The white sphere in the foreground houses the accelerator source and moderator. The collimated neutron beam from the source head illuminates the two tube sections set up horizontally in front of the 10in x 10in screen of the imaging system.

The electronic imaging system employed is of very high sensitivity, specifically designed to work with the low fluxes of small neutron source systems.[7] In this imaging system, the neutrons are detected by a lithiumloaded phosphor whose light emission is detected with a cooled silicon intensified target tube from which the image is scanned out and placed in memory in digital form under control of a computer. Special hardware and software intervene at the scanning stage to provide a very low noise environment. Normally a series of scanned images is summed and then presented for viewing so that the minimum "exposure" time in these studies was about 3 seconds. Electronic imaging of this type has the advantage of allowing the operator to terminate the exposure when the image has built up sufficient contrast to provide a clear decision regarding the condition of the object under

TABLE 1. TARGET TUBE CHARACTERISTICS

Tube No.	Diameter (in.)	^{6}Li Content (g/ft)	^{6}Li Density (mg/cm^2)	Approx. Imaging Time (sec.)
1	1.3	3.21	10.2	less than 3
2	3.6	4.09	4.67	less than 5
3	1.3	0.65	2.06	10
4	3.6	0.81	0.93	30
5	1.3	0.29	0.92	30
6	3.6	0.55	0.63	60
7	1.3	0.19	0.60	60
8	1.3	0.13	0.41	see text
9	1.3	0.10	0.32	see text

examination. Neutron activation of the object is kept at a minimum by this technique and by the inherently low flux of a small source.

RESULTS ATTAINED

A representative series of tubes examined is listed in Table I. They cover a range of practical interest with lithium-6 isotope contents from 0.1 g/ft to 4 g/ft. For comparison with radioscopic image densities, these concentrations have been expressed as an areal density in mg/cm^2 in column 4 of Table 1. For tubes at the top of the concentration range, clear radioscopic images were presented for viewing in less than 5 seconds. It should be possible to view the lithium distribution in real time for these tubes. Images collected in less than 1/20th second and presented consecutively would allow viewing while the tube is rotated to ensure that the most extreme extent of lithium is located. Our image collection software does not allow for true real-time presentations, so we were unable to demonstrate this during our work.

Clear images from which core end determinations could be made were obtained within one minute of exposure time for all but those having the lowest areal lithium-6 concentration, those noted as 0.10 and 0.13 g/ft. Thus for concentrations above 0.2 g/ft, small source neutron radioscopy would appear to be a satisfactory nondestructive tool. The detection sensitivity seemed to drop markedly for the lowest lithium-6 concentrations, however.

In order to reduce exposure times to a minimum, the radiography system was operated with a low L/D ratio of 14/1, which was expected to provide sufficient resolution in the images for the purpose intended. A radiological determination made from an item having curved surfaces such as cylinders is often difficult because a sharp edge with a well defined contrast change is not available. A typical radioscopic image which shows three tube core ends is reproduced in Figure 3. The tube having the highest concentration of lithium-6 readily shows the location of the Li-Al alloy and graphically demonstrates its nonuniform distribution. Here one can use the whole image to make a determination of the extreme extent of the alloy. The tube on the left in Figure 3 contains a moderate amount of lithium-6 and the contrast over the center region of the tube does not provide a good measure of the core end. Here one relies on the view of the curved edges of the tube where the cylindrical shape places some

Fig. 3. A neutron radioscopic image of three small diameter target tubes in the region of the core ends. The tubes have average areal densities of Lithium-6, left to right, of 2.06, 0.32, and 10.2 mg/cm^2. This CRT image is reversed in radiographic density, black delineates an absorber. L/D is 14.1.

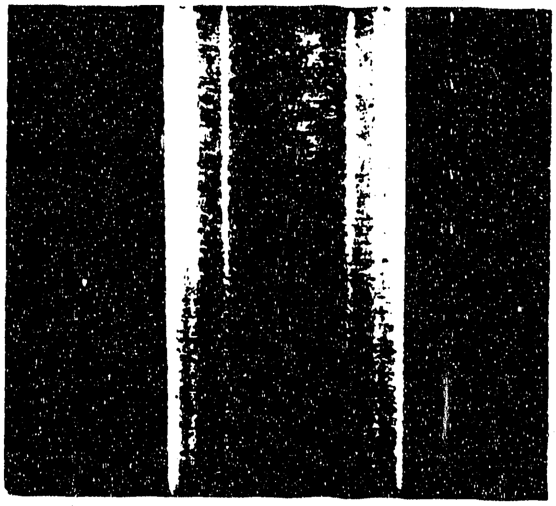


Fig. 4. A neutron radiograph (on x-ray film) of one of the large diameter target tubes with an areal density of Lithium-6 of 0.63 mg/cm^2. It illustrates the need for better resolution when dealing with very low lithium loadings. L/D is 27.4.

depth of lithium-6 in line with the radiation beam. For routine determinations, the tube would be rotated to assure that the extreme of the core end is being viewed. The center tube in Figure 3 contains so little lithium-6 that the low contrast and low resolution has lost even the curved edge image to the casual viewer. The ability to see the edge of any of the core ends is further hindered by the thinning of the alloy core to a shallow wedge shape as the end is approached. It is apparent that greater care with the radiological setup and the sacrifice of a longer image collection time may be needed to attain success at the lowest lithium-6 concentrations.

A neutron film radiograph of a low concentration tube, taken at an L/D ratio of 27.4/1 for improved resolution, Figure 4, makes the factors discussed above clear. Using the radiograph presented in Figure 4, the location of core end can be identified easily. Alsc visible is the wedge-shaped character of the alloy core near its end. This suggests the need for higher resolution or other image improvements to outline the core distribution at the lowest areal densities.

IMAGE PROCESSING

We have found that some form of image processing or enhancement is beneficial to making determinations of core end locations in tubes containing less than about 0.4 g/ft of lithium-6. The extent of the processing is probably best determined by the facilities available at the place where the determinations are made and by the difficulty in making an individual determination. Take the example of the 0.1 g/ft tube shown in the center of Figure 3. A trained viewer can see the general location of the lithium alloy core in this CRT screen view (at the top of the figure), but cannot determine its exact extent.

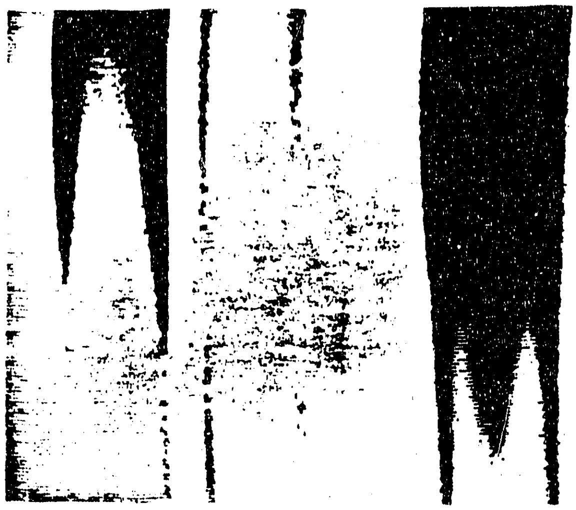
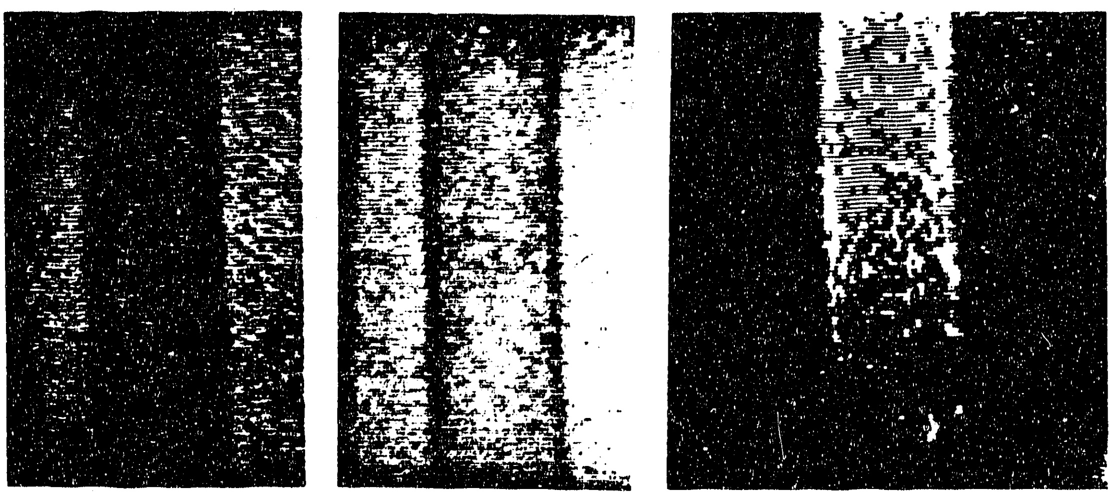


Fig. 5. A CRT screen view showing the result of applying a "masking" process to the radioscopic image in Figure 3 to clarify the location of Li-Al alloy in the center tube.

As a first try, the following simple image enhacement procedure may be executed quickly. A determination is made of the maximum and minimum screen illuminance in the suspected core area. This is usually available as a profile of brightness across the selected portion of the image or as maximum and minimum values of brightness within a selected rectangular area of the image. All values of brightness between the maximum and minimum are then set to "1" (white) in the computer memory and all other brightness values in the image are set to "0" (black). This is a common process sometimes called "masking". The result of applying this process to Figure 3 is shown in Figure 5. The low concentration center tube now shows the presence of alloy core much more clearly. This rather simple enhancement procedure may suffice in many cases. Here, the extent of the core is still questionable.

Adding additional processing steps eliminates any question of core extent. Figure 6(a) is a CRT image of the same tube shown at the center of Figure 3. The tube is now translated along its long axis so that only an all-aluminum



(a) (b) (c)

Fig. 6. (a) A neutron radioscopic image of the low lithium-6 content tube (0.32 mg/cm^2) shown in the center of Figure 3. The Li-Al alloy extent from the top of the tube is uncertain. (b) A neutron radioscopic image of an all-aluminum portion of the same tube. (c) The image resulting from applying a masking process to the pixel-by-pixel quotient of image (a) divided by image (b). The extent of the Li-Al alloy core is now quite certain.

portion of the tube is imaged, Figure 6(b). This image is now subtracted from or divided into that containing the alloy core, pixel by pixel, which results in an image of the core alone. The masking process can now be applied to the resultant image to provide stark contrast for the remaining significant illuminance levels, as shown in Figure 6(c). The full extent of the lithium core is now readily visible. This type of image processing eliminates the clutter in the background which makes it difficult for the human eye to isolate the image imformation of importance.

SUMMARY

The feasibility of using neutron radioscopy utilizing a small neutron source and electronic imaging to determine the location of Li-Al alloy core ends in target tubes fabricated for tritium production has been demonstrated. Accurate determinations appear to be possible by straightforward application of radioscopy within practical time constraints for taget tubes containing concentrations of lithium-6 isotope above 0.2 g/ft of tube length. Below this concentration the usual trade-off between image resolution and exposure time must favor higher resolution in the images and require longer times for a determination to be made. The application of some image enhancement may also be traded off to obtain a shorter exposure time. In a particular application, the available software and its ease of application should determine the most suitable enhancement technique. It was demonstrated further that the required neutron radiology could be accomplished with a neutron source small enough that its installation within the tube fabrication plant should be possible.

REFERENCES

(1) K. H. Beckurts and K. Wirtz, Neutron Physics, Springer-Verlag, New York, 1964, p. 14.

(2) S. R. Salaymeh and T. P. Varallo, Savannah River Laboratory, Technical Division internal reports, June-December, 1988.

(3) Analysis Report, U. S. Army Materials Technology Laboratory, MT&E Branch, 1988.

(4) D. I. Garber and R. R. Kinsey, Neutron Cross Sections, BNL 325, 3rd Ed, Vols. I & II, 1973.

(5) J. J. Antal, W. E. Dance, S. F. Carollo and J. D. Moravec, "Experience with an On-Off Mobile Neutron Radiography System", in Neutron Radiography, J. P. Barton, G. Farney, J. Person and H. Rottger, Eds., D. Reidel Publishing Company, Dordrecht, Holland, 1987.

(6) J. J. Antal and A. S. Marotta, "A Neutron Radiography system for Field Use", in Nondestructive Testing and Evaluation for Manufacture and Construction, H. Reis and W. J. McGonnagle, Eds, Hemisphere Publishers, 1989 (in press).

(7) W. E. Dance and S. F. Carollo, "High Sensitivity Real Time Imaging System for Reactor or Non-Reactor Neutron Radiography", in Proceedings of the 2nd World Conference on Neutron Radiography, J. P. Barton, G. Farney, J. Person and H. Rottger, Eds, D. Reidel Publishing Company, Dordrecht, Holland, 1987.

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