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PERFORMANCE OF MECHANICAL EQUIPMENT FOR DEJACKETING SPENT SRE CORE 1 FUEL

by

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ABSTRACT

About 1.8 tonnes of NaK bonded 2.7% enriched unalloyed uranium SRE Core 1 fuel which had been exposed to an average irradiation of 675 Mwd/tonne was successfully dejacketed at rates up to 9.2 kg of uranium per hour. Hardening and/or embrittlement of the jacket and adherence of the jacket to fuel slugs interfered with the three dejacketing methods tried. The dejacketing program was accomplished successfully, but it was concluded that methods used in the future should be more independent of changes in physical properties of the fuel caused by reactor operation, storage, or shipping environments.

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INTRODUCTION

At the 8th Conference on Hot Laboratories and Equipment at San Francisco in 1960, a processing facility and equipment to mechanically disassemble, dejacket, steam clean, and recan spent SRE Core 1 fuel was described and the operational experience with unirradiated prototype fuel presented.[1] This concluding paper presents the operational experience and performance evaluation of the mechanical dejacketing complex during the processing of the spent fuel itself. The entire hot operational sequence including a summary of processing data was documented in a 16-mm sound color film.

The Chemical Technology Division of Oak Ridge National Laboratory mechanically dejacketed 26 SRE Core 1 clusters as part of a continuing effort to develop economically feasible processing methods[2,3] for new power reactor fuels. The principal economic advantage offered by mechanical methods is in providing versatility to existing plants and the disposal of the metallic fuel jackets and accessories as solid waste rather than as aqueous solutions of metal salts. In addition, mechanical removal of metallic jackets from liquid metal bonded fuels such as from the SRE, Fermi, and Hallam reactors, prior to dissolution, avoids liquid metal--acid explosion hazards.[4]

The operations involved in dejacketing a spent SRE fuel assembly are: (1) transfer of the assembly from the shipping cask to the cell, (2) removal of the assembly end hardware and the tube spacer wires by abrasive disk sawing, (3) removal of the fuel slugs and NaK from the fuel tube, (4) steam cleaning of NaK and oil from the fuel slugs and subsequent recanning of the fuel in an aluminum can for storage, (5) the waste handling operations of flattening and rolling of the empty fuel tube into a coil, and (6) destruction of the NaK by reacting it with steam followed by disposal of the alkaline reaction products to intermediate liquid level waste.

DESCRIPTION OF FUEL AND PROCESSING FACILITY

The SRE Core 1 fuel element is a cluster of seven rods, each containing 12 NaK (22-78%) bonded 2.7% enriched uranium metal slugs jacketed in a thin-walled type 304 stainless steel tube (Fig. 1). At the top end of each rod is a helium-filled space, ~ 18 in. long, for expansion of the NaK bond (~ 100 cc) and collection of fission gases released during irradiation.

The fuel processed had been irradiated to an average exposure of 675 Mwd/tonne during two years' residence time in the Sodium Reactor Experiment in Santa Susanna, California, followed by cooling and decay for about two years. Thirteen of 43 assemblies had ruptured as a result of undesireably high temperature operation,[5,6] which occurred when coolant channel flow was restricted by organic decomposition products formed when pump seal coolant leaked into the core. The exterior surfaces of 26 of the unruptured fuel clusters were steam-cleaned free of sodium coolant by Atomics International, Canoga Park, California, and shipped by rail to

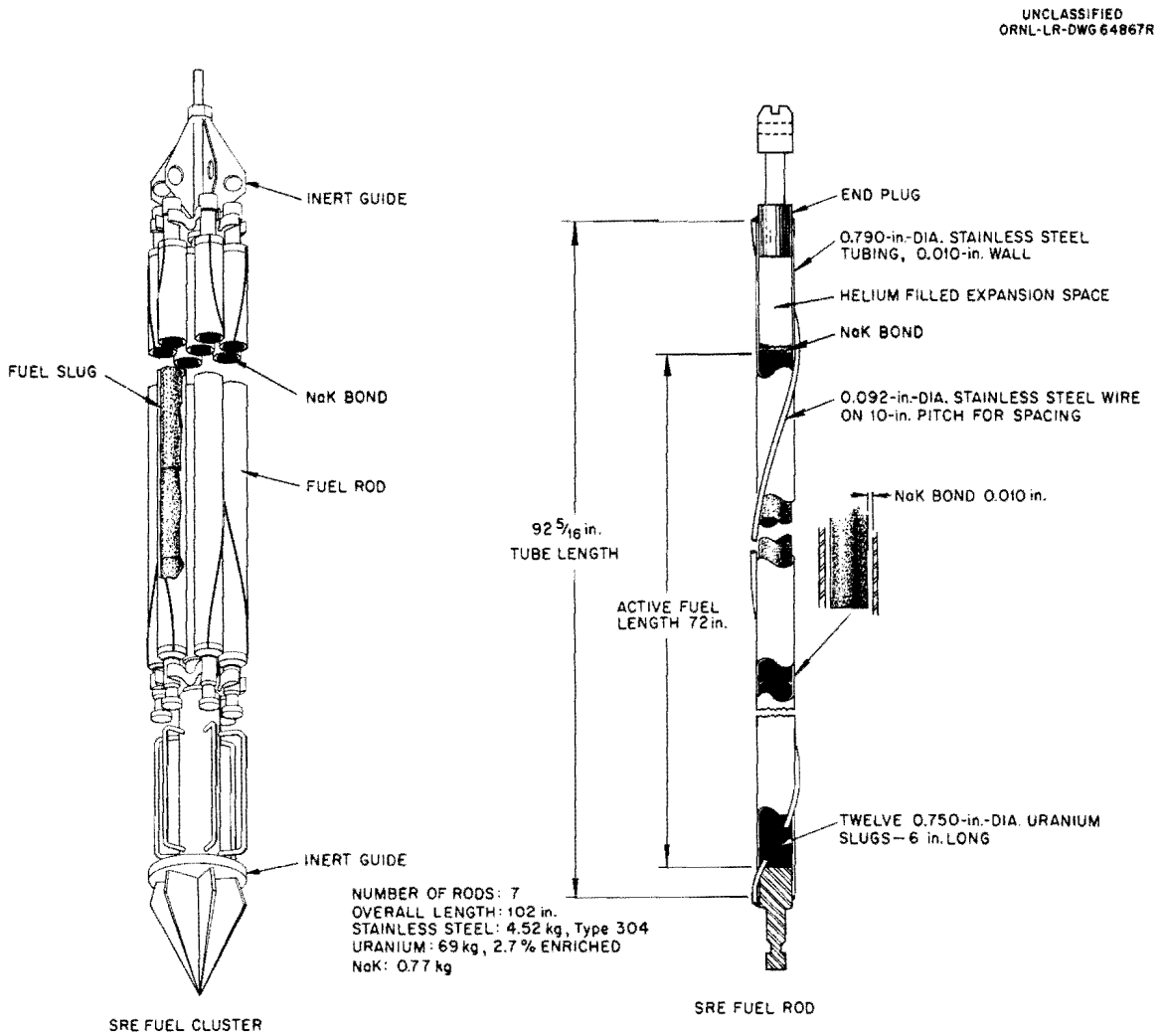

Fig. 1. SRE Core 1 fuel.

Oak Ridge, Tennessee. Although these clusters appeared to be externally intact, they very possibly experienced some abnormally high temperature operation which would have produced undesirable metallurgical effects. Up to ten of these clusters per shipment were sent in a 30-ton boral poisoned cask with 8 in. of lead shielding.[7]

The possibility of a critical event occurring during mechanical processing was minimized by limiting the amount of fuel handled at any time in the remotely operated high-activity-level segmenting facility (Figs. 2, 3) to a single fuel cluster of 7 rods. This quantity of fuel was calculated[7] to be critically safe when immersed in oil or water. The facility, formerly of solid wall construction, was converted to a direct viewing facility by core drilling cubes of concrete of about 5 tons each from the walls to permit installation of windows. The cell area, 25 by 10 by 15 ft high, is formed by 5-ft-thick concrete walls lined with stainless steel, with three zinc bromide-filled viewing windows, 5 ft thick, at appropriate intervals. To thwart leakage of radioactive gases and particulate matter from the processing cells into the building proper, (a) the cell was provided with a fail safe ventilation system,[8] (b) all manipulators were encased in leaktight plastic booting both inside and outside the operating face of the cell, and (c) the charging face of the cell and the top of the cell were enclosed by separate entry rooms. The entry rooms were maintained at a pressure lower than the building proper and the cells were maintained at a lower negative pressure than the entry rooms. Fuel was charged to the cell from a shipping cask through a large cavity in a 30-ton concrete mobile shielded door. Dejacketed and recanned fuel was discharged from the segmenting cell to a storage cell (Fig. 9) through a shielded underground tunnel and stored in critically safe tiers.[7]

MECHANICAL DEJACKETING PROCESS

The mechanical dejacketing complex was designed to convert SRE Core 1 fuel, as discharged from the reactor, to a product that could be dissolved safely in nitric acid preparatory to solvent extraction recovery of uranium and plutonium. To accomplish this requirement, sequential mechanical processing steps were performed as shown in (Fig. 4):

(a) Receiving - receiving of fuel and charging to the facility,

(b) Sawing - abrasive disk saw removal of inert end adapters with simultaneous freeing of spacer wires,

(c) Wire Removal and Shearing - removal and shearing of spacer wires into short disposable lengths,

(d) Roll Cutting - immersion of fuel rods singly into the oil-filled hydraulic dejacketing unit and roll cutting of the top end cap,

(e) Hydraulic Expansion - insertion of the decapitated rod into the hydraulic collet and expansion of jacket by applied internal hydraulic pressure of up to 2700 psig,

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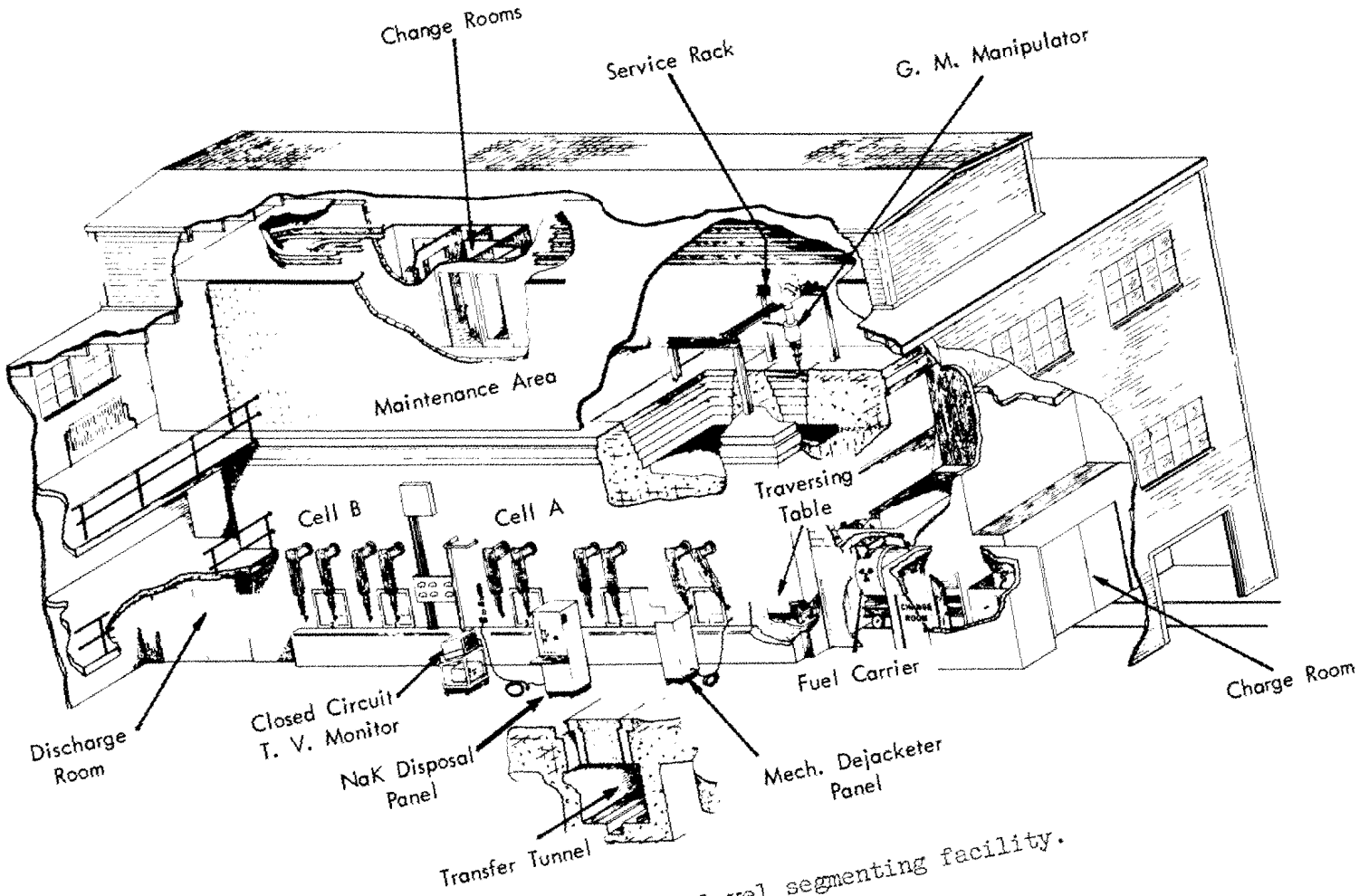

Fig. 2. High-activity-level segmenting facility.

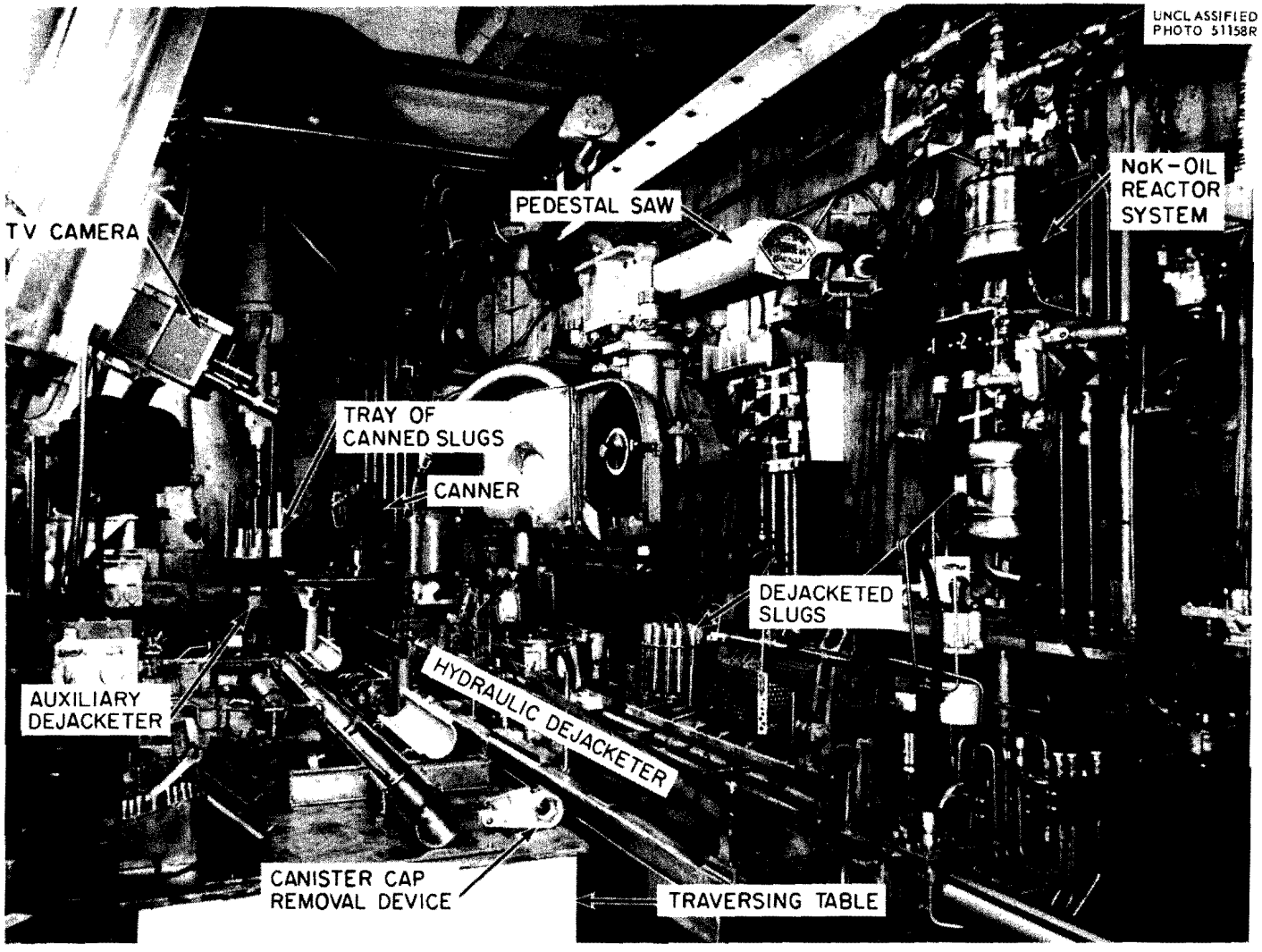

Fig. 3. Mechanical processing equipment for dejacketing of SRE Core 1 fuel (interior view, Cell A) in ORNL segmenting facility.

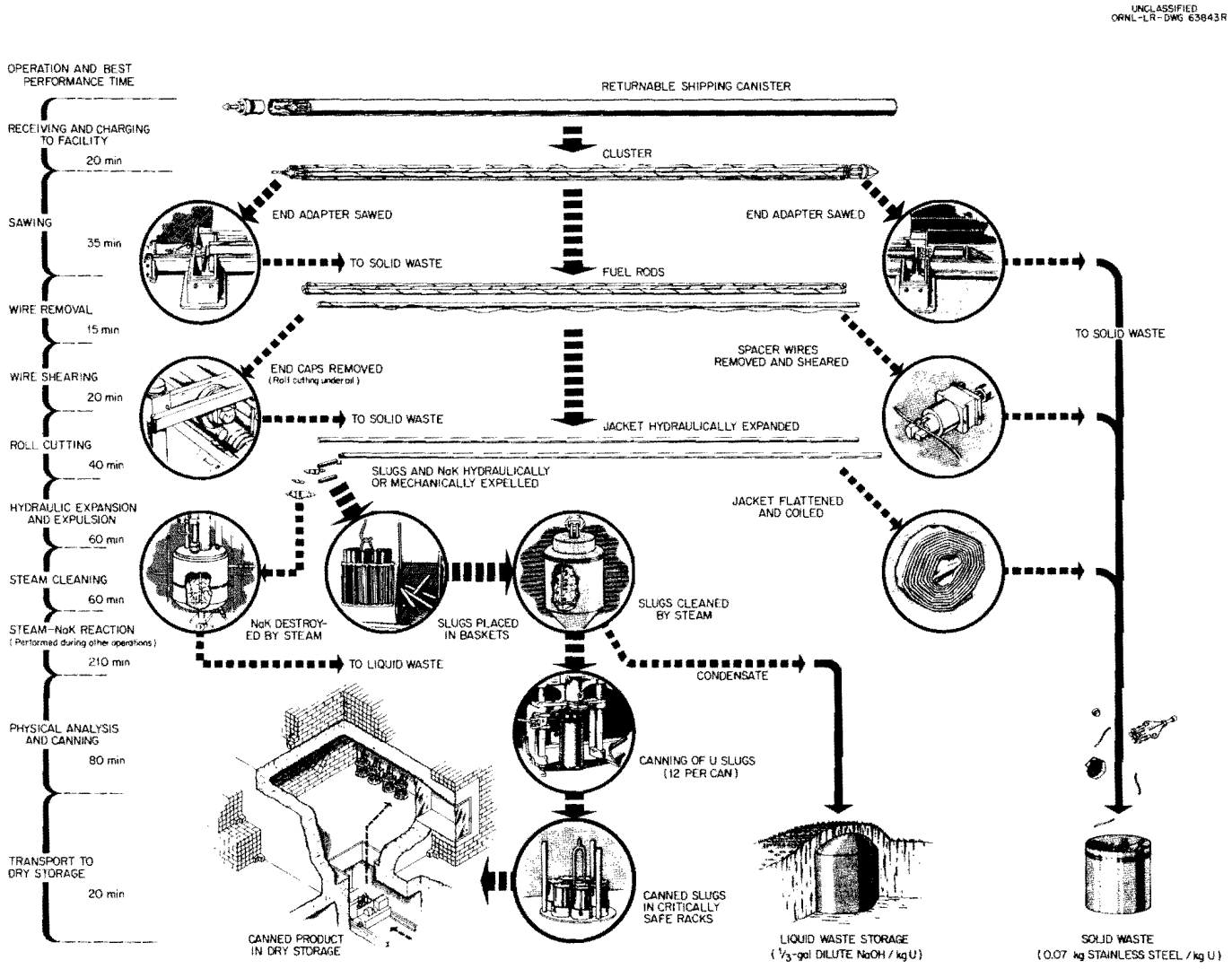

Fig. 4. Mechanical dejacketing flowsheet for SRE Core 1 fuel.

(f) Roll Cutting - release and removal of rod from the internal collet and roll cutting removal of the bottom end cap,

(g) Hydraulic Expulsion - re-insertion into the internal hydraulic collet and hydraulic expulsion of the slugs and NaK or by alternate de-jacketing methods listed below,

(h) Waste Solid Disposal - removal of the empty jacket from the internal collet and flattening and coiling by a rotating split shaft,

(i) Decomposition of NaK and Liquid Waste Disposal - vacuum displacement of NaK in 100-cc increments and decomposition with steam followed by discharge of decomposition products to intermediate level liquid waste storage.

(j) Cleaning - rotation of basket at 1000 rpm by steam jets impinging against basket and fuel slugs. Decomposition of NaK droplets and removal of oil film in a 2-min cleaning operation.

(k) Physical Measurements and Canning - Profilemeter measurements of fuel slugs to determine warping and swelling and canning of 12 cleaned and measured slugs in aluminum cans.

(l) Transport of 7 cans of fuel slugs in a critically safe storage tray via a tunnel and deposition in a storage cell.

The mechanical dejacketing complex permitted fuel to be processed by a primary dejacketing method and two alternate methods. The primary technique used was hydraulic expansion of the jacket followed by hydraulic explusion of fuel slugs and NaK. Alternate method 1 dislodged slugs and NaK by a long mechanical screw which passed through the entire length of fuel tube or jacket. Alternate method 2 employed roll cutting of each fuel rod into pieces of about one slug length and the pushing of each piece through roller cutters followed by prying or cutting of the jacket from each slug with special hand tools. The alternate 2 method was used only when the primary and the first alternate method had been tried in succession and failed.

PROCESSING RESULTS

About 1.8 tonnes of uranium contained in 175 spent fuel rods was de-jacketed, washed with steam, recanned in aluminum, and placed in storage in air with uranium and plutonium losses of 0.02-0.2% and 0.0002-0.002%, respectively. Based on total operational time including maintenance, the production rate was 2.0 kg of uranium per hour. Near the end of the campaign, when ideal operating conditions prevailed, a maximum rate of 9.2 kg/hr was reached. Of the 830 hr of operation required to process the fuel only 30% was required for mechanical treatment and the remaining 70% for repairs and maintenance. About half the downtime was necessary for repairs to the NaK disposal system, which was damaged twice by explosions from water inadvertently contacting NaK through leaky valves.

The primary dejacketing method was used successfully 16% of the time; the first alternate method employing displacement of slugs by a long mechanical screw 77%; and the second alternate or roller cutting method was required for 7% of the rods. The primary method of dejacketing failed because the jackets were harder and less ductile than expected, and pressures which in preliminary tests had produced up to 380 mils expansion and burst the tubes gave only 0-5 mils expansions in a few cases with the irradiated tubes. The yield stress of prototype fuel determined experimentally in the hydraulic dejacketer was approximately 35,000 psi. Irradiated fuel was not expanded by internal pressures of up to 2,700 psi, indicating a yield stress of at least 104,000 psi.

Some important steps of the mechanical dejacketing flowsheet photographed during processing were: charging of fuel to the mechanical complex preparatory to sawing of inert end adapters (Fig. 5), hydraulic expansion of the jackets and discharge of slugs under oil hydraulically or physically with a mechanical screw (Fig. 6), transfer of slugs to the steam cleaner (Fig. 7), coiling of jackets (Fig. 8), and dry storage of fuel (Fig. 9). The complete processing operation, including summary data, was documented in a 12-min, 16-mm sound color film (9).

Changes in Physical Properties. Since the primary purpose of dejacketing SRE Core 1 fuel was to demonstrate and evaluate mechanical processing methods, equipment to determine changes in physical or metallurgical properties of the fuel was not included in the complex. When it was obvious that spent fuel could not be processed as easily as prototype fuel, some measurements were made by the ORNL Metals and Ceramics Division to determine the factors responsible. Metallographic examination (10) of randomly selected samples of portions of jackets taken from the central rod and an outer rod of several fuel clusters showed occasional intergranular attack of the sensitized external surfaces of jackets (Fig. 10) from about the midpoint of a fuel rod up to the top portion. Atomics International, from experience with prototype test specimens, suggests the intergranular attack could have occurred in air storage at the Santa Susana Mountain site. Specimens from areas exhibiting intergranular attack were easily broken (Fig. 11) when bent, probably accounting for the observed brittle behavior of the tubing. An unidentified metallic layer was found on external jacket surfaces of lower portions of fuel rods, but specimens from these areas did not break on bending. A eutectic-like scale composed of uranium and stainless steel (Figs. 12, 13) was discovered confined to extremely small areas but distributed fairly uniformly on internal jacket surfaces. The composition of the scale was 83.5 wt % U, 12.0 wt % Fe, 2.8 wt % Cr, and 1.8 wt % Ni. The Fe-Cr-Ni ratio is approximately that of 18-8 stainless steel. The microhardness of the 10-mil-thick wall of one jacket varied from 263 to 400 DPH.* The original hardness was specified to be about 180 DPH.[11] Fuel samples examined by Atomics International prior to dejacketing attempts had shown the eutectic formation in fuel which had swelled excessively, split or melted down during the abnormally high operating temperature of the SRE. The intact

*Diamond pyramid hardness, 0.5-kg load.

fuel assemblies handled in the dejacketing operations showed no outward signs of high temperature damage, so the presence of the eutectic-like scale showed that it may have been subjected to high temperatures for short periods insufficient to produce drastic physical damage. The uranium slugs were pitted and were bent as much as 7-20 mils, elongated 1-6% and swollen 1-5%. Hardness measurements[10] on a single specimen ranged from 200-300 DPH (1-kg load).

Uranium and Plutonium Losses. Ten jackets that had cracked when flattened and coiled (Fig. 8) were dissolved in boiling aqua regia (3 M HCl-4 M HNO_3) and the uranium and plutonium losses determined. Uranium and plutonium losses varied from 0.1 to 0.2% and 0.003 to 0.002%, respectively. These losses apparently result from the formation of stainless steel—uranium eutectic, particles dislodged from slug surfaces or both. The loss due to particles dislodged from the slug surfaces must be small since all tubular jackets emptied of slugs were scoured with a torpedo shaped plastic scrubber to remove as much residual NaK as possible. This device with stiff multicircumferential fins should have displaced essentially all loose uranium particulates.

Waste. About 18 liters of NaK containing about 1 curie of Cesium-137 and traces of uranium and plutonium were collected and decomposed in 100-ml increments by reaction with steam in a separate disposal system. Metallic and liquid waste resulting from disassembly and dejacketing, steam cleaning of slugs, and destruction of NaK amounted to about 0.07 kg and 0.3 gal per kilogram of uranium processed, respectively. For each cluster of fuel processed, the solid waste consisting of stainless steel jackets, wires, end adapters, etc., loosely packed, filled a 3-gal pail. Similarly, washing of the slugs and decomposition of NaK from one cluster produced a total volume of aqueous waste of 22 gal.

The volume of waste produced by mechanically dejacketing fuel is always much less than the volume of waste generated by chemical dejacketing methods. For example, if the stainless steel jackets and accessories of the SRE clusters processed were dissolved in 4 M H_2SO_4 to a concentration of 40 g of stainless steel per liter followed by neutralization with an equal volume of caustic, 1,550 gal of waste is produced. The same amount of inert stainless steel removed by mechanical means can be stored in 26, 3-gal pails or in a tank of 78-gal total capacity, a saving in storage volume of a factor of 20.

The cost of perpetual storage of intermediate level liquid waste has been estimated[12] to be $2.00/gal and solid metallic waste at $5.00/gal.[13] At these rates, the cost of storing solid waste produced from a mechanical dejacketing operation would be only 1/8 of the cost of storing the liquid waste produced from chemically dejacketing the same amount of fuel. In addition to the cost advantage, solid wastes stored dry are not as corrosive as liquid waste and the nuclides contained in the solid waste are in a nonionic form.

EQUIPMENT PERFORMANCE

In general, the mechanical components of the dejacketing complex performed satisfactorily, especially equipment which could be adjusted and aided by a human operator. From a design viewpoint, the operation of nearly all equipment components would have benefited by increased ruggedness obtained by a much larger overdesign factor and by an increase in size of power units.

The hydraulic dejacketing unit was the heart of the experimental SRE fuel dejacketing facility. The unit consists of several basic subassemblies: (1) roll and cutter assemblies, (2) collet, (3) the hydraulic system, (4) mechanical pressure screw, (5) jacket winding and disposal equipment, and (6) hydraulic pusher assembly and accessories. It was supported by a frame and mounted in a trough so that all operations were conducted under a blanket of oil to prevent oxidation of the NaK and to reduce the possibility of fire or explosion. After the individual rods were removed from a fuel cluster by the multipurpose saw and the spiral spacer wires were removed by the hydraulic wire cutter, the dejacketing machine breached the jacket with roll cutters, removed the NaK bonding and uranium slugs from the tubular jacket by either hydraulic pressure or an automated mechanical screw and flattened and rolled the empty jacket for disposal.

The inability of the dejacketer to consistently expand the jackets of irradiated fuel was disappointing since ductile fuel prototypes supplied by Atomics International were easily expanded and processed. Although all fuel rods were processed through the hydraulic unit, 83% of the fuel could not be expanded and the slugs discharged. The unit processed 17% of the fuel without aid from auxiliary methods and prepared the remaining 83% of the fuel for proper handling in the auxiliary dejacketing operations. It was obvious, however, that the hydraulic dejacketing unit alone could not process irradiated fuel which had become hardened or embrittled.

Operational experience indicates that the design of the hydraulic dejacketer could be simplified and the number of handling steps involving the collet portion decreased about 50%. Maintaining proper lubrication of moving parts in the refined kerosene oil blanket was exceedingly troublesome and was not adequately solved. The auxiliary mechanical screw required only minor mechanical adjustments while successfully processing 92% of the fuel supplied to it.

The auxiliary dejacketing unit was used to remove jackets from slugs which could not be processed using the standard hydraulic unit. It was designed to accept pieces of jacketed fuel one slug in length as prepared by roll cutting of a fuel rod in the main dejacketing machine. The unit functioned exceedingly well on prototype fuel consistently cutting the jacket without actually cutting the slug surface. Generally, light score marks were found on the slug, but no chipping or metal removal occurred. Roll cutting of irradiated jackets was more difficult than expected. Roll cutters, V edge with 60° included angle, made from Carpenter, Vega-KW and hardened and ground under oil, had cut through prototype stainless steel

jackets into unirradiated uranium repeatedly without being dulled and performed excellently when cutting stainless steel jackets backed by stainless steel end caps. However, when used in cutting irradiated stainless steel backed by irradiated uranium, the cutters were rapidly dulled and chipped. In its present form, the performance of the auxiliary dejacketer does not justify its use as a production unit.

Abrasive saw decapitation of inert end adapters while simultaneously cutting the spacer wire worked well. The longest lived blade severed eight clusters and the three canisters which required sawing. A total of eight blades were used to disassemble all the fuel processed. All blades were broken before they were sufficiently worn to justify replacement. Breakage was caused by severed end adapters falling into the blade during the terminal portion of a cut.

About 300 operational hours was required to repair the NaK reactor system damaged by two separate explosions. This is equal to the time spent in repairs and maintenance to the remainder of the mechanical complex. The explosions that occurred during decomposition of NaK showed that a foolproof simpler method was needed. The deliberate formation of a NaK-oil emulsion and its destruction by spraying it through a nozzle into a body of water may be a preferable method. Handling of liquid NaK bonded fuel in a shielded cave with an air atmosphere but with the aid of oil and an oil blanket appears to be quite practical. The primary safeguard employed was in limiting the amount of NaK handled at any time to about 1 liter or less.

If dejacketing of this type of fuel was a continued requirement, redesign of certain features of some of the equipment components to improve performance and operability would be desirable (Table I).

CONCLUSIONS

Spent SRE NaK-bonded Core 1 fuel was successfully dejacketed mechanically but at production rates lower by a factor of 2 to 3 than predicted from the processing of prototype fuel. In some fuel rods the presence of a eutectic-like scale of stainless steel—uranium on the interior surfaces of the jacket, presenting potentially a high uranium loss, probably defeats hydraulic expansion and expulsion techniques, jackscrew dislodgment or roll cutting of the jacket. This scale, however, would probably not be expected under normal reactor operating conditions. The uranium bearing scale could possibly be tolerated by installing a scavenging leaching step prior to disposal of the jackets. The mechanical methods tried could not adequately cope with hardened and/or embrittled jackets, bent and swollen slugs adhering to the jacket or badly damaged fuel* (Fig. 14). Dejacketing by hand operations to overcome these conditions is much too time consuming.

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*One cluster of the 26 clusters received was in this condition.

Table 1. Performance of SRE Core 1 Dejacketing Equipment

Equipment Component	Performance: Excellent	Performance: Good	Performance: Fair	Remarks
Receiving and Charging				
Fuel Carrier		X		- - - - - - - - - -
Fuel Carrier Dolly	X			- - - - - - - - - -
Fuel Winch			X	Underpowered, speed control and positioning poor, take-up of cable on air winch spool poor.
Fuel Rod Lifter	X			- - - - - - - - - -
Cap Removal Device		X to	X	No provisions for galled threads. Fabricate of steel instead of aluminum.
Grappling Hook	X			Awkward to attach with Model 8 manipulator.
Sawing				
Saw Box Enclosures		X		Needs improved alignment method and more positive particulate seals.
Pedestal Saw		X		Hydraulic control of peripheral speed poor, vertical feed control erratic, blade placement and removal difficult with Model 8's.
Wire Shearing				
Hydraulic Shear	X			Replace hand control with foot control.
Cleaning, Canning, and NaK Disposal				
Slug Washer	X			Improved seal closures desired.
Canning Machine	X			Drying of molykote lubricant caused a single malfunction from parts seizure.
NaK Reactor		X		Complex valving system — simplified system desired.
Dejacketing				
1. Hydraulic Dejacketing Unit		X		More rugged design indicated, need hydraulic system of greater capacity and volume, many undesirable blind spots.
a. Roll Cutters	X			Increased toughness desired.
b. Rolls	X			Bearings failed in refined kerosene but worked well in mineral oil.
c. Collet		X		Did not release or seal consistently, difficult to adjust remotely.
d. Pressure Screw		X		Underpowered, clutch slipped.
e. Pusher Cylinder Expander			X	Underpowered, underdesigned.
f. Jacket Winder		X		Underpowered, difficult to insert empty tubular jacket.
g. Slug Basket	X			Removal of slugs with Model 8's difficult.
h. Hydraulic Controls and System		X		Larger capacity needed, better seals.
i. Micrometallic Filters	X			- - - - - - - - - -
2. Auxiliary Dejacketer			X	Underpowered, needs tougher cutters and better method of removing slugs from discharge port.

The methods evaluated were too dependent upon spent fuel remaining unchanged by exposure to reactor environment, storage, or shipping events and thus are not sufficiently versatile to guarantee the processing of other similar fuels in the future such as the Fermi blanket or Hallam fuel rods. If, however, (a) the fuel is not damaged in the reactor, (b) the eutectic-like scale of stainless steel—uranium does not form, (c) the jackets are not hardened or embrittled, and (d) the slugs do not adhere to the jackets, hydraulic expansion of jackets and expulsion of fuel slugs could be used advantageously. In this respect it is important to note that the SRE fuel which was exposed to abnormal reactor conditions, may not represent a typical core loading.

The SRE Core 1 fuel furnishes some insight into the handling of fuels of this general type. Intergranular attack of sensitized fuel rods emphasizes the need for controlled storage conditions to preserve fuel rod integrity subsequent to irradiation. Hardened and/or embrittled jackets endanger any mechanical process that is dependent upon ductility, for example, spiral stripping of EBR II jackets.[14]

In the future, two other mechanical methods will be given scouting evaluations: (a) shearing into a steam atmosphere to destroy the highly reactive bonding agent followed by leaching of the core in acid and (b) breaking of such fuels at slug junctures, as has been practiced at Brookhaven,[15] followed by roll expansion to remove the jacket. The mechanical method most likely to succeed regardless of the physical conditions of the fuel as discharged from the reactor appears to be shearing and leaching. This method is already being developed for stainless steel jacketed or Zircaloy-2-jacketed fuels of UO_2 or UO_2-ThO_2.

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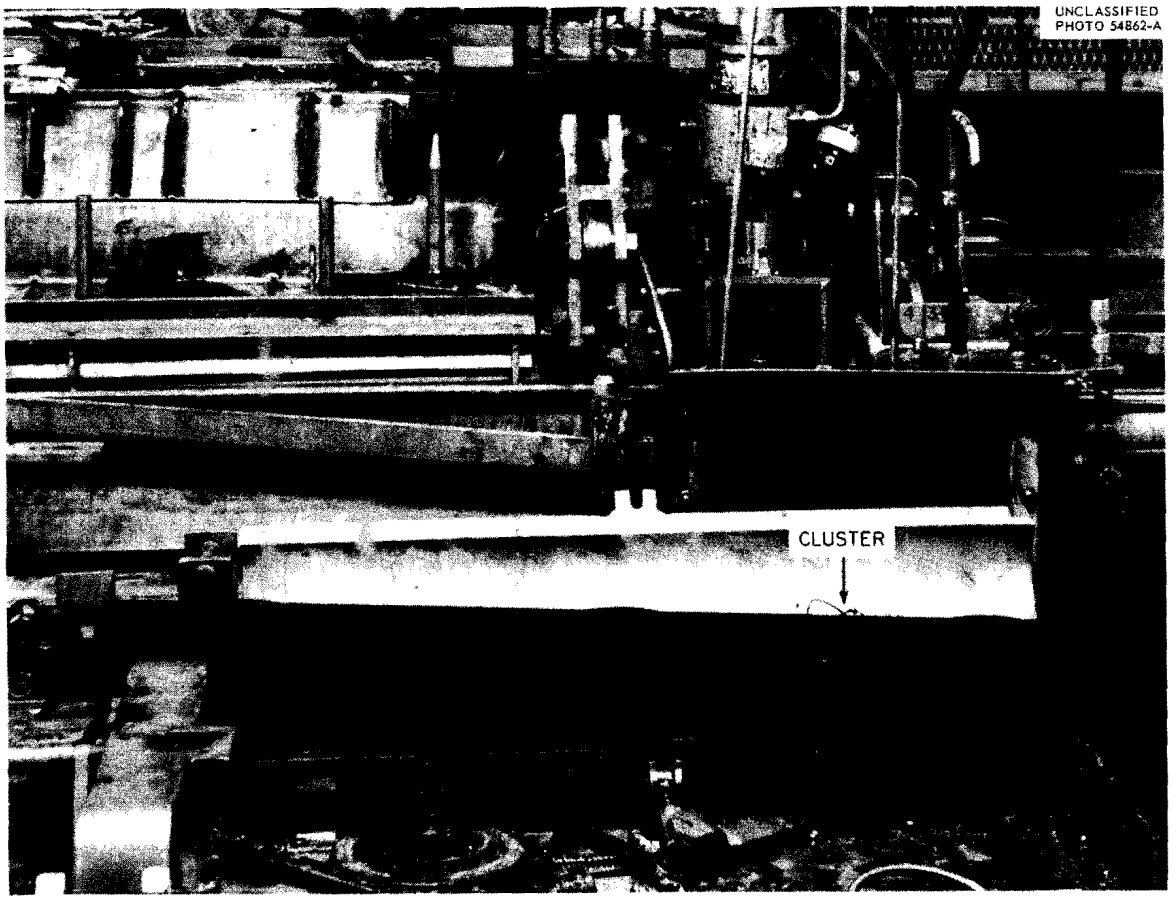

Fig. 5. SRE Core 1 cluster in saw trough preparatory to removal of inert ends by abrasive disk sawing. Hydraulic dejacketing unit in background.

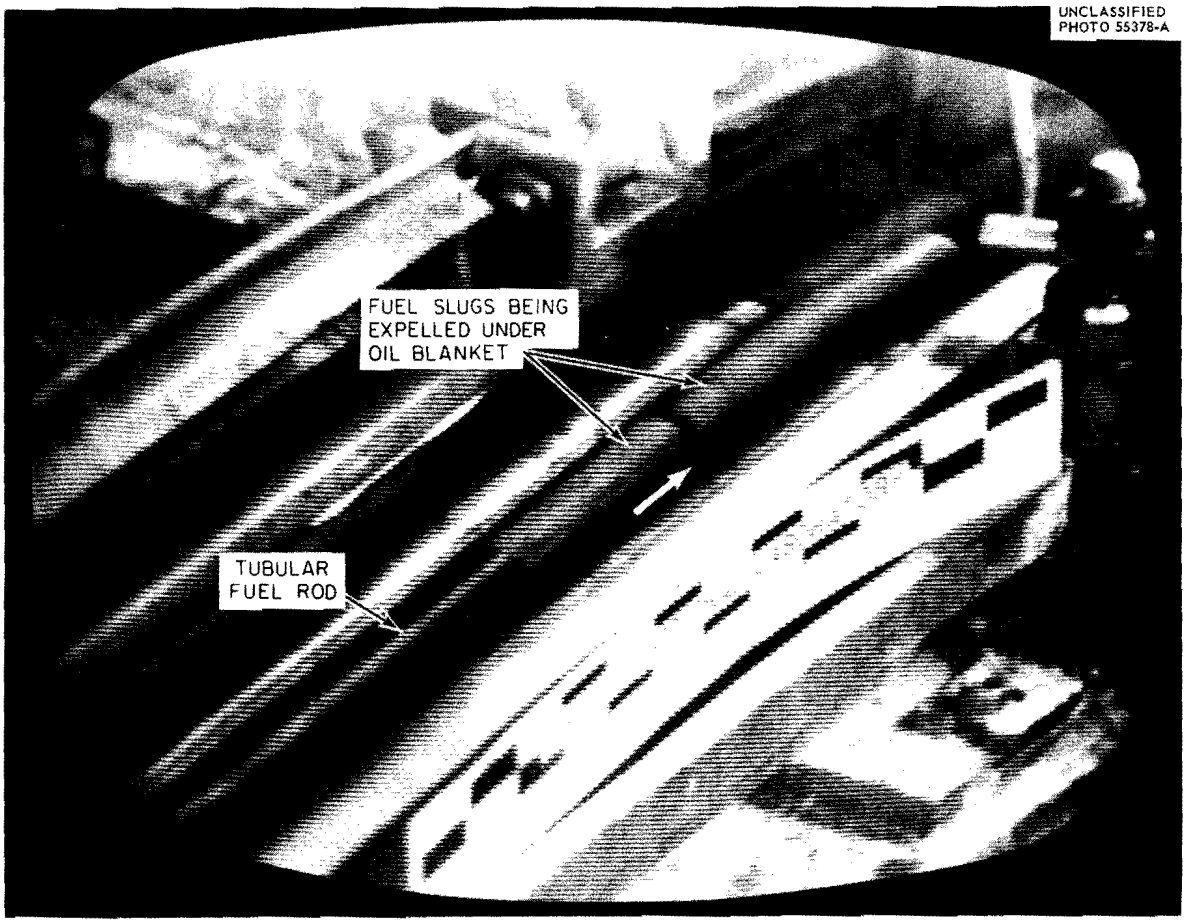

Fig. 6. Expulsion of SRE Core 1 fuel slugs from stainless steel tubular fuel jacket by an internal mechanical screw (photograph from television screen).

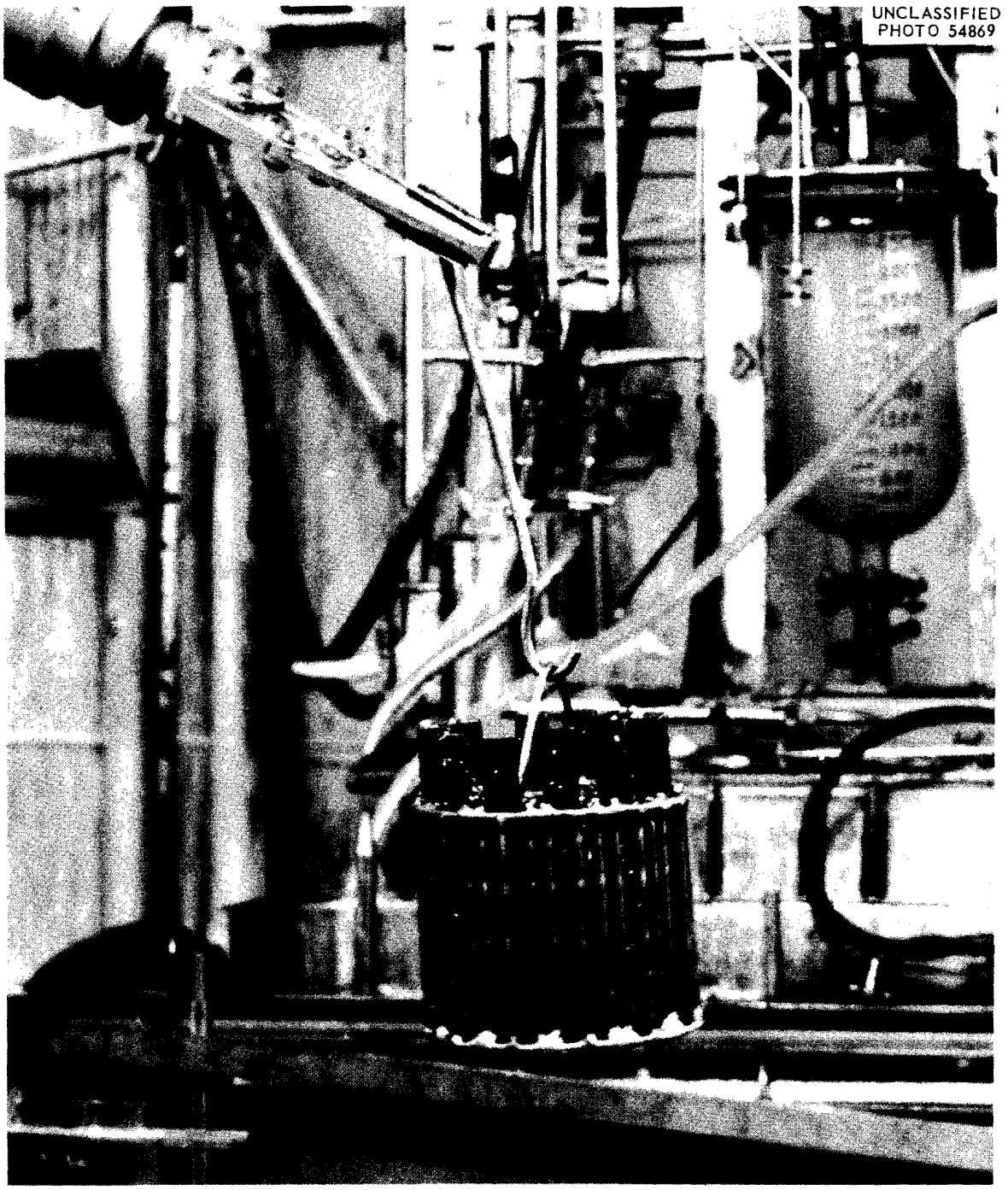

Fig. 7. Slugs from one SRE Core 1 fuel rod being transferred to steam cleaner. Note globules of NaK clinging to oily surfaces of uranium slugs.

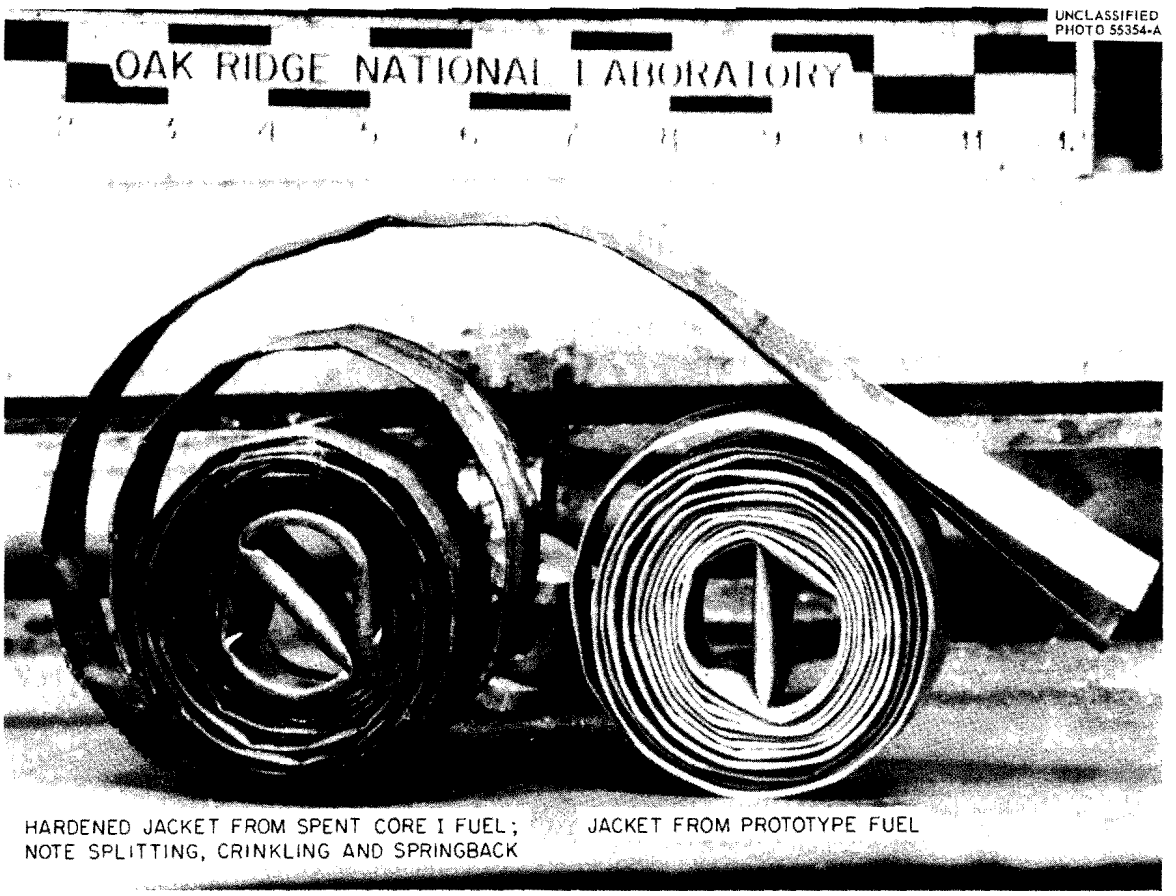

Fig. 8. Comparison of a 304 stainless steel jacket processed from SRE Core 1 fuel with a more ductile prototype jacket.

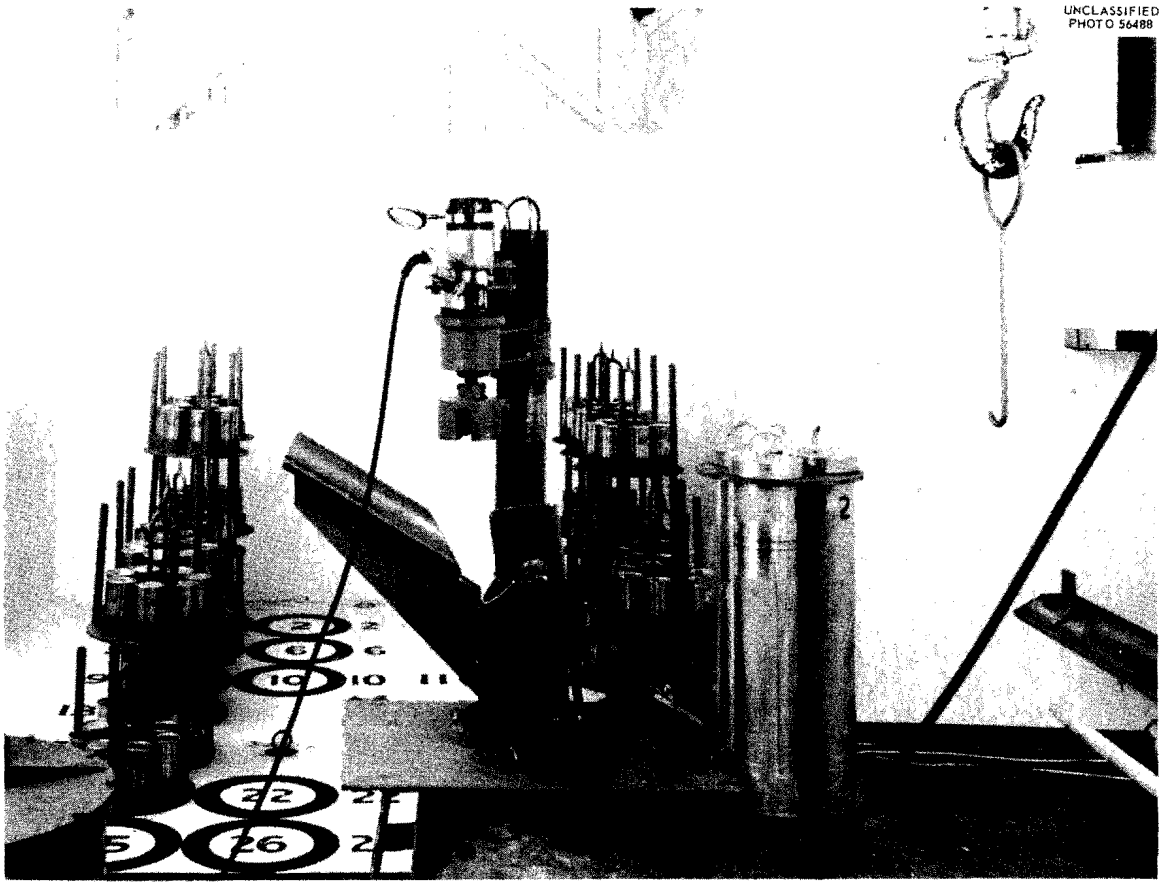

Fig. 9. Dejacketed, cleaned, canned, and stored fuel slugs in critically safe storage racks awaiting shipment in canisters (in foreground) to processing site.

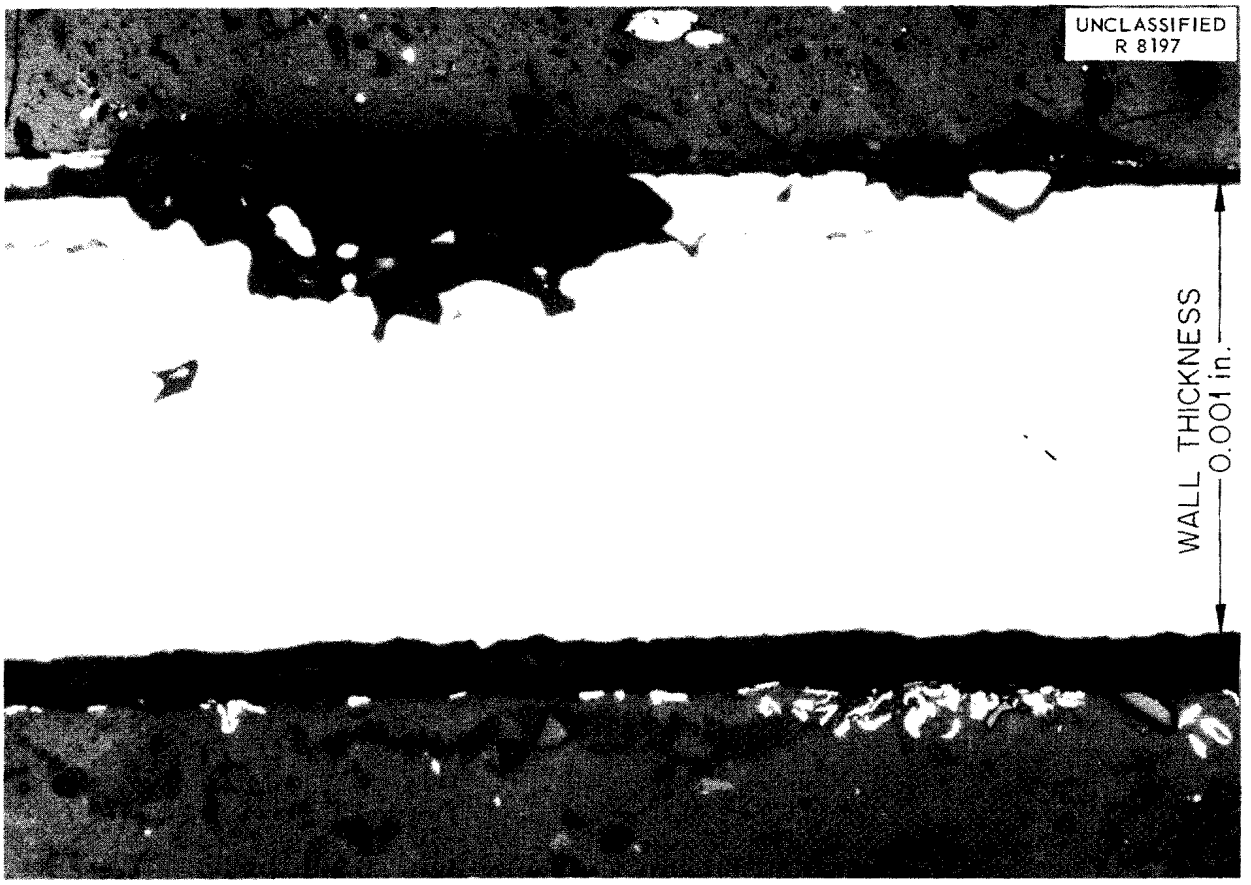

Fig. 10. Top portion of type 304 stainless steel fuel jacket showing intergranular attack.

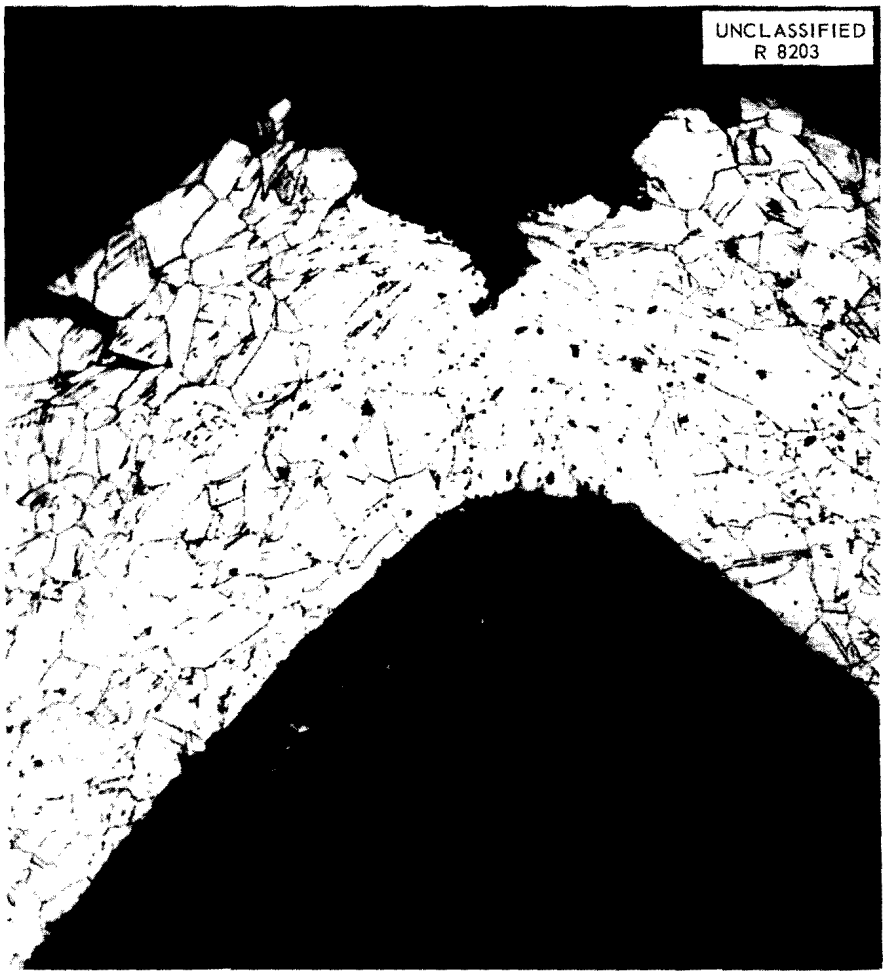

Fig. 11. Bend specimen from type 304 stainless steel fuel jacket taken from area showing sensitization, intergranular attack, cold working, and hardening.

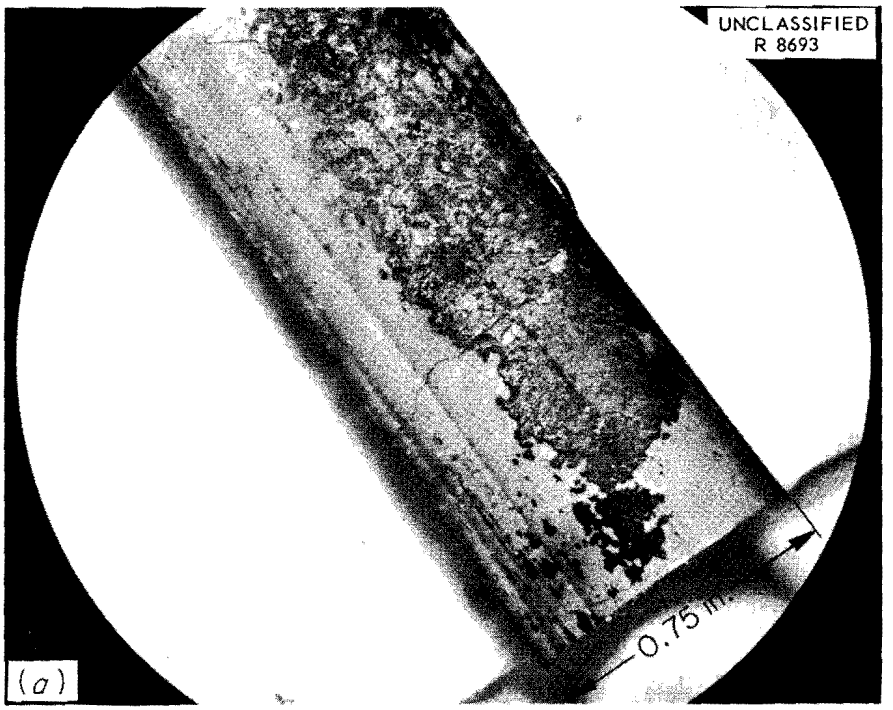

Fig. 12. Stainless steel uranium eutectic on interior surface of type 304 stainless steel jacket.

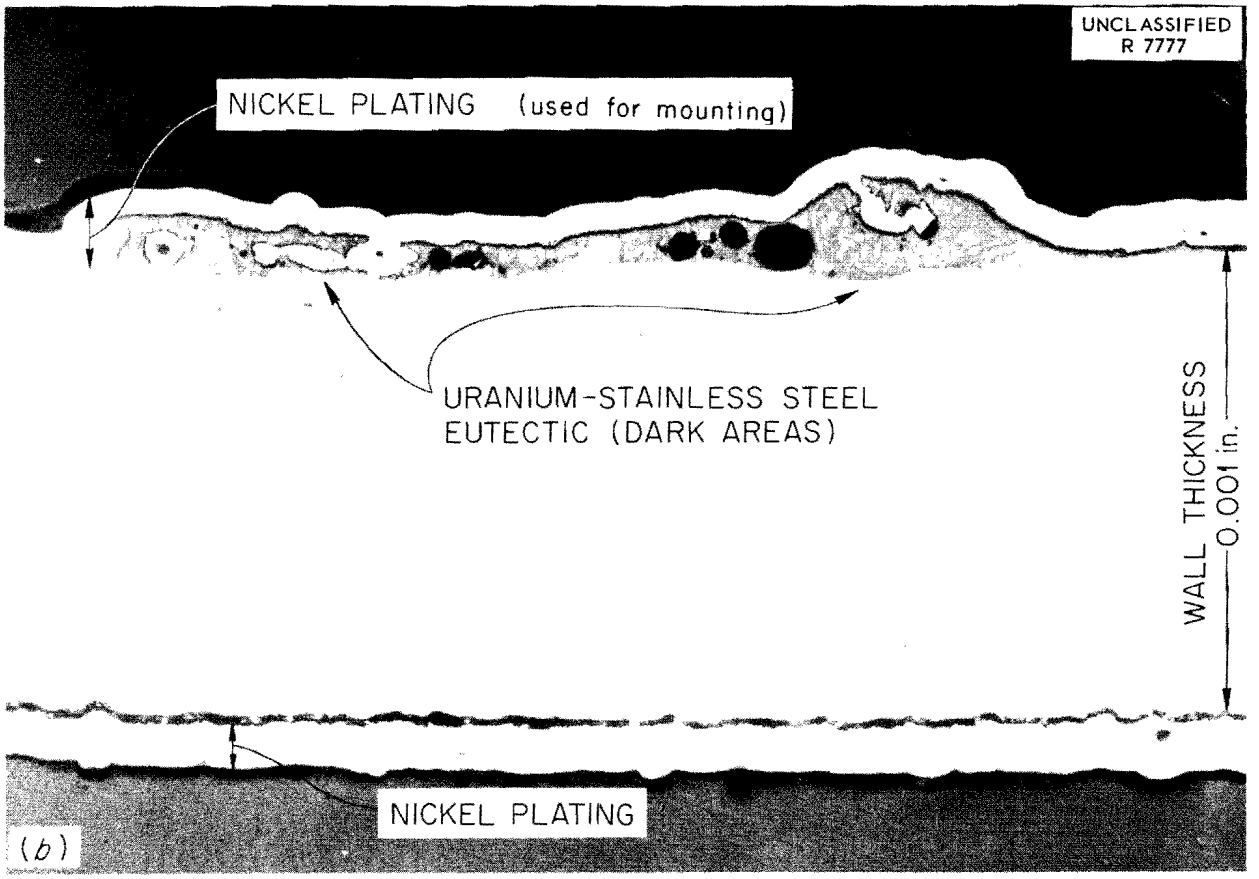

Fig. 13. Cross section of jacket with eutectic.

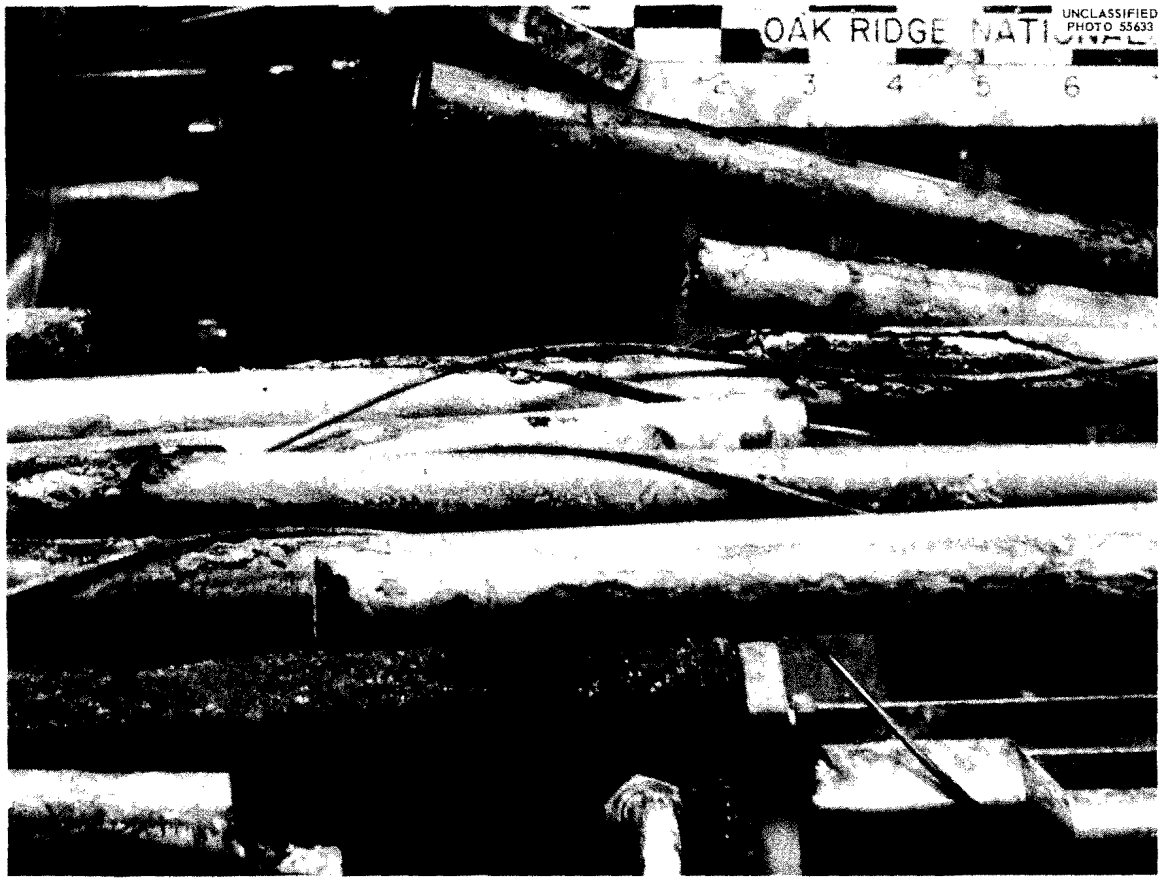

Fig. 14. Cluster of badly damaged SRE Core 1 fuel.

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