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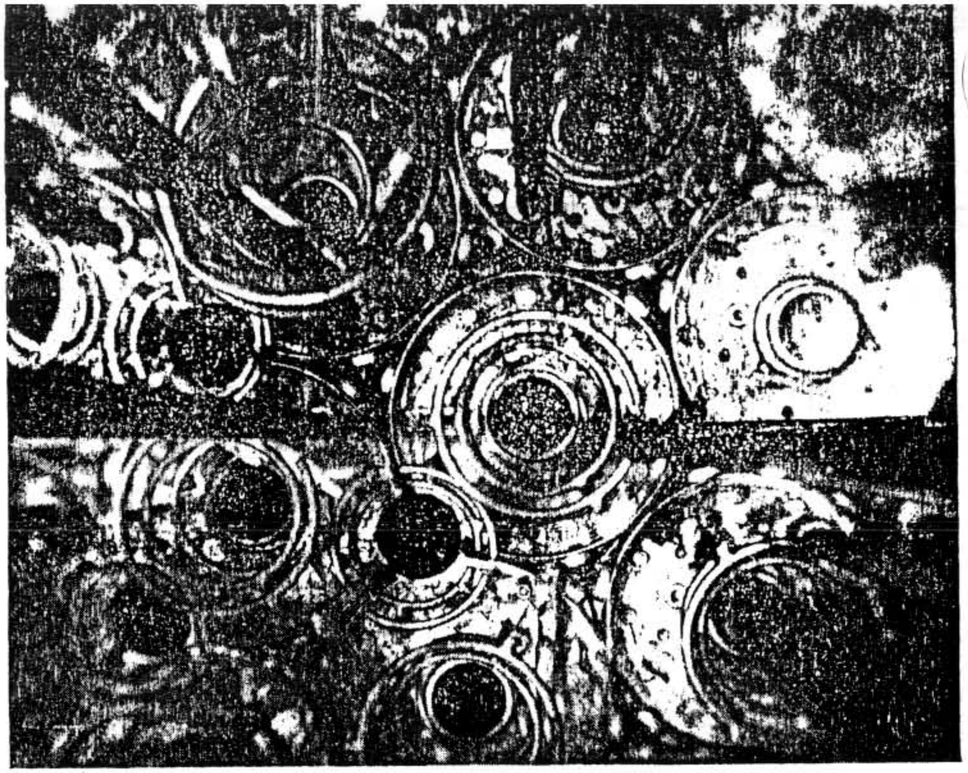

POST MORTEM VIEW of top of SRE core shows encrustation on snorkle tube vent (vertical tube) from center moderator can. Loose fuel slugs are strewn about on tops of other cans (top center). At time of picture core temperature was 325° F and radiation field below top shield 100 r/hr

# Coolant Block Damages SRE Fuel

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*A leak of organic material from an auxiliary cooling system into SRE's primary loop has subjected the SRE fuel to a much severer trial than anyone had bargained for. With the flow partially blocked in several channels by deposition of the material, temperatures got high enough to cause the stainless-steel clad to alloy with the uranium-metal fuel and, finally, to separate near the bottom end (NU, Dec. '59, 23). Here's the sequence of events as they appeared to SRE personnel operating the reactor.* —*Ed.*

On July 27, 1959, the Sodium Reactor Experiment (SRE) was shut down to determine, through viewing of fuel elements by a closed-circuit television system installed in the fuel cask, if there were obstructions that could explain rather wide temperature variations between fuel channels, which were preventing full-power operation of the reactor. As a result of this examination, twelve fuel elements out of the 43 fuel elements installed were discovered to be damaged. Preparations are now in progress to put SRE back in operation on a new second core of SS-clad Th-$U^{235}$ metal fuel around the middle of April. Individual trials of UC elements (which will probably make up the third core) will begin late in summer.

## Tetralin Leakage

The SRE had previously run a total of 2,409 Mwd; during this time it generated over $15 \times 10^6$ kwh of electricity in a series of operations designed to irradiate the alpha-rolled, beta-heat-treated unalloyed uranium which comprised the first core. The length of these power runs was determined by examining the fuel elements both destructively and nondestructively, for evidence of radiation induced swelling, and had varied from 150 to 300-Mwd fuel exposure per run. During the shutdown period preceding the power run of interest (Run No. 14) modifications had been made to the main primary system; the most significant of these was the replacement of the tetralin-cooled shaft freeze seal on the main primary pump. A NaK-cooled freeze seal was substituted.

This alteration, long contemplated, was effected because, during the preceding power run (No. 13) there had been evidence of tetralin leakage into the primary sodium system. Tetralin leakage was apparent from a characteristic odor in the vicinity of the pump, and, after shutdown, the appearance of napthalene and other decomposition products of tetralin in a vapor cloud over the reactor's top sodium pool. This vapor cloud, which was visible through a glass window inserted in the top shield after shutdown, was purged by sweeping with inert gas; approximately a pint of tetralin, napthalene, and other decomposition products were condensed out of the purged gas. After stripping hydrocarbons from the core with dry nitrogen gas introduced at the bottom of the core, no detectable hydrocarbons could be observed in the core cover gas. Some $4 \times 10^5$ ft³ of nitrogen were employed; the stripping operation was carried out with sodium at the normal shutdown temperature of about 375° F

Although some concern was felt

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concerning the presence of tetralin and its decomposition products in the primary system, previous experiments* had indicated the primary product would be amorphous carbon. Although carbon is a potential contributor to system carburization, it was not considered to be a short-term hazard. Examination of fuel had indicated that radiation-induced swelling was already sufficient to require removal of the fuel following power Run No. 14, and the effects of carbon on the thin-walled cladding were not significant for this period of time.

## Temperature Maldistribution

Upon start up of the reactor in a normal fashion, wide variations in temperature from individual fuel channels, as monitored by thermo-couples on the fuel hanger rods, were indicated. Analysis of temperature variations throughout the reactor indicated that a condition of unequal flow through fuel channels existed.

Similar temperature spreads had appeared following a shutdown in December 1958 during which system modifications had been performed and considerable oxygen had entered the system. At that time, clean up of the system using cold traps and increasing the reactor inlet temperature to 600° F had reduced temperature spreads to a normal pattern; following this full power operations with sodium-coolant temperatures as high as 1,060° F were performed with no indication of anomalous behavior.

The same procedure was followed in July, as oxygen had again been introduced into the primary system by pump alterations. This time, however, the temperature spreads were more persistent. The reactor was operated at power levels of 0.5–3 Mw, controlling on a maximum temperature differential between fuel-channel outlet and adjacent moderator-can coolant passages of 100° F. This temperature differential was established by stress considerations relative to the top head of the zirconium-clad graphite logs that form the SRE moderator. Increasing the inlet temperature to the reactor, by operating on an air-blast heat exchanger instead of the steam generator, did not appear to be helpful in reducing the temperature spread, as had been the case during December.

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In addition, some anomalies in reactivity occurred which were attributed at the time to the passage of gas bubbles through the core, postulated to have been due to the organic decomposition products. One of these reactivity transients prompted a manual scram. Reconstruction of control-rod positions during the period of operation also indicates a small reactivity decrease, occurring from day to day in sufficiently small amounts as to not be readily apparent. The cause of this gradual decrease in reactivity has not been determined at this date; neither have the reactivity perturbations experienced during operation been unequivocably explained.

During two weeks of this low power operation it was noticed that if some of the fuel elements were moved slightly, the exit coolant temperature decreased significantly. A possible explanation of this phenomenon was considered to be the dislodging of oxide (and possibly carbon) particles which had collected on the orifice plates installed at the bottom of the fuel elements. Accordingly, it was decided to shut the reactor down and inspect representative elements, to determine the nature of these deposits if in fact they did exist.

## Fuel-Element Inspection

On July 27 the reactor was shut down and a fuel element withdrawn into the fuel handling cask, into which a closed circuit television camera had been incorporated. The first two elements so inspected showed no anomalies. The third element inspected, however, appeared to have a crack in the cladding, although the element itself was intact. It was then decided to examine a fourth element which, when removed, showed that the bottom third of the element, including the bottom hardware, was missing. The separation of the seven rods, which make up the element bundle was approximately at the same level and was apparently complete, even including the spiral wire wrap attached to the top and bottom of the fuel rod.

A program for inspecting the remaining fuel elements was immediately initiated. As damaged elements were discovered, they were removed from the reactor and placed in storage. Ten additional damaged fuel elements out of a total of 41 inspected were discovered by this means. Two additional elements appear to be securely lodged in their process channels and are therefore assumed to be damaged.

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The original fuel cask does not contain a provision for handling fuel elements in which wires and hardware are widely spread out; the chain hoist mechanism became fouled by projecting portions of the 34th element removed. After several days of manipulation in the cask containing this damaged fuel element (during the course of which at least three fuel slugs and numerous pieces of cladding were disloged into a shielded cavity located below the cask) further efforts to free the cask operating mechanism were suspended. Assembly of a second cask, originally designed for handling moderator cans and/or fuel elements, was commenced; this cask was used to remove the remaining elements, except for the two apparently lodged in the core.

## Causes of Damage

Examination of the fuel slugs recovered from the handling cask indicated that cladding failure apparently was responsible for the separation of the fuel element. Sections of .010 in. stainless-steel cladding adhered to the slugs; the intimate contact suggested that an iron-eutectic had formed. Chemical analysis of sections of cladding and wire wrap recovered confirmed this indication; uranium contents as high as 10% were determined to be present in cladding sections analyzed. It is postulated that overheating had occurred in at least some of the channels, permitting fuel surface temperature to rise at least to the 1,340° F necessary to form the Fe-U eutectic.

The thermocouples that monitor exit-flow temperatures for each channel at no time read higher than 900° F and thus gave no clue to the excessive surface temperatures. Apparently, under the restricted flow conditions (which caused the hot channels), the thermocouple readings were thrown off by thermal contact with the sodium pool above the core.

Altogether, an estimated 5,000–10,000 curies was released at the time of the damage, 80% of which was less than one day in half-life.

An examination of the circumstances surrounding fuel-element damage was commenced immediately on discovery; deposits of a viscous, tar like substance were identified on hot-cell examination of a damaged fuel element. Deposits were observed on the top spider which supports the fuel rods and on the moderator can hold-down tube which is installed immediately above the fuel elements. Samples of this deposit were analyzed; they proved to be carbonaceous materials containing varying amounts of hydrogen. These were apparently decomposition products of tetralin. It is reasonable to assume that such carbonaceous materials were deposited at points of flow restriction and may be the primary cause of decreased coolant flow in those channels which contain damaged fuel elements.

The point of tetralin entry into the system was determined to be the main primary-coolant-pump-shaft freeze seal. A metal-sprayed layer in the vicinity of the tetralin-cooled shaft freeze seal, originally put on to build up shaft diameter where excessive wear had once occurred on the pump shaft, had apparently come loose and abraded the shaft-seal cooling chamber to a point where tetralin was admitted directly into the sodium stream. No excessive tetralin consumption had been observed; there are constant losses of tetralin due to evaporation in the cooling tower and occasional piping leaks outside the reactor area. Examination of tetralin make-up did not indicate excessive consumption during the preceding power runs; it is believed that no more than two barrels of tetralin were introduced into the system, and quite probably considerably less.

## Future Plans

Development of fishing tools based on possible conditions in the lower end of the fuel channels containing damaged elements was initiated immediately. It is known that the bottom hardware of the fuel element would come to rest, after a drop of some 10 in. from its normal position, against the stainless-steel pedestal on which the moderator can is mounted. Therefore, the remaining sections of damaged fuel elements would not fall into the bottom plenum below the core. Grappling tools that attempt to engage the hardware below the fuel rods, and bring the damaged section of fuel element up through the fuel channel as a unit were devised and tested in full scale mock-ups. The degree of fuel swelling, deposits of carbonaceous material, and degree of damage to the bottom section of the element, is not known at this time; the efficacy of recovery procedures in an actual channel is yet to be demonstrated. It is, however, expected that each channel will present somewhat of a different problem, the magnitude of which will be at least partially established by observation with a borescope specifically constructed for in-core examination. This borescope contains its own illumination and cooling system, and is capable of being inserted completely through the core if necessary. It also contains provisions for inspecting the under side of the grid plate on which the core is mounted.

Several facets of reactor operation must be covered prior to restoration of the SRE to full power operation with its second core loading of thorium-uranium fuel:

- First, of course, is the removal of fuel, its examination, and verification of the cause of damage.
- Second is an inspection of the core channels by borescope for obvious evidence of damage to moderator cans.
- Third, it is planned to survey the core using the neutron source in a fuel channel and observing this source with detectors in adjacent channels to determine, by neutron absorption, if sodium has been introduced into any of the graphite moderator logs.
- Fourth, any carbonaceous material remaining in the system, particularly in the vicinity of the heat exchangers, must be removed as completely as possible. Numerous schemes have been proposed; these will depend on observations of the nature of the deposits. It is currently planned to examine visually the intermediate heat-exchanger primary (tube) side, inasmuch as this exchanger showed a loss of heat-transfer capacity toward the end of the power run previous to the one during which fuel element damage was discovered.
- Fifth, the new fuel elements are being modified to contain thermocouples further down in the element, where they will be less affected by sodium-pool temperature. Additional fuel elements will be provided with thermocouples.
- Sixth, revision of the coolant systems to remove what is now considered the underlying cause of fuel element damage: introduction of carbonaceous material. Coolant systems which do not involve materials incompatible with sodium will be installed.

Upon completion of these steps, SRE will be returned to power with a loading of thorium-uranium fuel, to continue to provide high-temperature irradiation of reactor fuels and further information on high-performance liquid-metal-cooled reactor systems.