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UPGRADING OF TREAT EXPERIMENTAL CAPABILITIES

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ABSTRACT

The TREAT facility at the Argonne National Laboratory site in the Idaho National Engineering Laboratory is being upgraded to provide capabilities for fast-reactor-safety transient experiments not possible at any other experimental facility. Principal TREAT Upgrade (TU) goal is provision for 37-pin size experiments on energetics of core-disruptive accidents (CDA) in fast breeder reactor cores with moderate sodium void coefficients. This goal requires a significant enhancement of the capabilities of the TREAT facility, specifically including reactor control, "hardened" neutron spectrum incident on the test sample, and enlarged building. The upgraded facility will retain the capability for small-size experiments of the types currently being performed in TREAT. Reactor building and crane upgrading have been completed. TU schedules call for the components of the upgraded reactor system to be finished in 1984, including upgraded TREAT fuel and control system, and expanded coverage by the hodoscope fuel-motion diagnostics system.

INTRODUCTION

Current TREAT experiments at the 1-7 pin level have provided important data on transient fuel failure thresholds and mechanisms, on the phenomena of accident shutdown by fuel dispersal, and on related CDA phenomena. These experiments, despite their limitations, have been highly successful in providing accident energetics data in support of FFTF and CRBR licensing. At this stage in fast reactor technology, two problems related to experiment size have become apparent: First, direct application of these post-failure movement data to an LMFBR subassembly geometry is limited because of thermal hydraulic constraints arising from the small number of test pins. Size-related effects are sources of uncertainty in early fuel dispersal, fuel sweepout, and plugging at the ends of subassemblies. A comprehensive review of LMFBR test facility needs[1] concluded that an increase in the test bundle size to 37 pins would provide significant improvement in the ability to model post-failure movements in actual subassemblies. Although 37 pins is not large enough for direct simulation, it does make possible a significant decrease in the degree of analytical extrapolation to full-size bundles. This may be illusrated, using the ratio of internal pins to total number of pins in a bundle as an index. For one pin, this ratio is 0, for 7 pins it is 0.14, for 19 pins it is

0.37, and for 37 pins it is 0.51. Second, the non-prototypic scale of current experiment sizes limits severely the development of data on the transition phase following initial disruption. Thus, a capability for 37-pin size tests appears to be essential to confirm or adjust the range of possible CDA issues relevant to forthcoming LMFBR licensing reviews.

Although the upgraded TREAT retains the capability for small size experiments of the current types, TU will provide somewhat greater experimental flexibility than current TREAT for seven-pin-size experiments.

In order to exploit these improved test sample capabilities, the TU has provided final designs of an Advanced TREAT loop (ATL),[2] and of the full system of support equipment for handling and operating ATL-size loops.[3] The upgraded TREAT building, which permits a corresponding increase in experiment loop capability over that available previously, will be described briefly in this paper.

The approach chosen for the TREAT Upgrade is the expansion of an existing facility rather than construction of a totally new one. This approach offers two significant advantages over the "new facility" route: First, it is cost effective by utilizing existing equipment and construction, and second, it provides a high degree of confidence on technical performance by utilizing well-proven capabilities.

FUNCTIONAL REQUIREMENTS

TREAT Upgrade Functional Requirements, based upon the Energy Research and Development Administration (ERDA)-commissioned Reference 1, were issued by ERDA. Subsequently, Functional Requirements were prepared for the accommodation in TU of current loops of the Mk III and Single-Pin Test Loop (SPTL) type. The top level Functional Requirements are summarized in Table 1. Summary Requirements 1 through 5 are discussed further below.

Summary Requirement No. 1 is the basis for detailed design requirements for the TU Reactivity Control System (RCS). Although the details of power vs time profiles for CDAs postulated in LMFBRs are design- and accident scenario-dependent, this requirement broadly specifies the need for a flexible, progammable reactor control system that will produce shaped TU power transients which will include high power bursts having controlled reactor periods in the range of 100 msec to ~15 sec. See Fig. 1 for a generic transient shape definition.

Requirement No. 2 leads to an expansion of the TREAT fast neutron hodoscope[4] in order to provide coverage of the expanded experiment size, and requires that the core accommodate the hodoscope.

Requirements No. 3 and 4 are the bases for the detailed design requirements for the ATL final design.[2] Thus, these requirements are the (indirect) bases for the building expansion and for the final design of the experiment support equipment.[3]

Requirement No. 5 is the basis of the design of the modified TREAT converter fuel elements, being provided as part of TU.[5]

Table 1. Summary of TU Functional Requirements

1. The TREAT upgrade shall provide the capability to expose fresh and preirradiated test fuel to irradiation transients which simulate LMFBR CDA accident ramp rates from less than 50¢/s to slightly greater than 6$/s at failure.

2. The facility will include the capability to detect and diagnose the details of test fuel motion during and subsequent to an experiment.

3. The facility shall be capable of simulating the thermal hydraulic conditions for the fuel under test.

4. The facility shall be capable of accepting a variety of sample fuel designs (both fresh and irradiated) whose dimensions are within the dimensional envelopes given in Table 1 of Ref. 4. The facility will also be capable of accepting for testing at one time a minimum of 37 Pu-bearing preirradiated test fuel pins of a design which fits within the specified envelopes.

5. The TREAT reactor shall be capable of depositing energy in the sample fuel as summarized by the envelope in Table 2.

6. The capability shall be retained to reload TREAT to obtain the existing transient irradiation capability without degradation.

7. The current capability of the TREAT reactor to operate at low power for extended lengths of time for calibration and radiography must not be degraded by the TREAT Upgrade modifications.

Table 2. TU Sample Energy Envelope

Case	Cluster Averaged Sample Energy at Core Midplane (including contingency)
37 highly-enriched pins in ATL	2840 - 3250 j/gram
7 prototypic-enriched pins in Mk III loop	3200 - 4000
Single prototypic-enriched pin	5700 - 8000

Taken as a group, the summary Requirements require a broad flexibility in TU capabilities. For example, a TU core nuclear design narrowly optimized for experiments on a single test pin could give unacceptable performance for a full cluster of the largest pins specified. Conversely, a core design narrowly optimized to a 37-pin bundle of the largest pins specified could give unacceptable performance for a few-pin experiment. Further, it must be emphasized here that the energy values given in Table 2 are enveloping ones, representing the energy requirements for the most demanding experiments. Many specific experiments will require significantly less energy than the Table 2 envelope and the detailed individual experiment goals may involve a trade-off of unneeded energy for increased power flattening across the test sample.

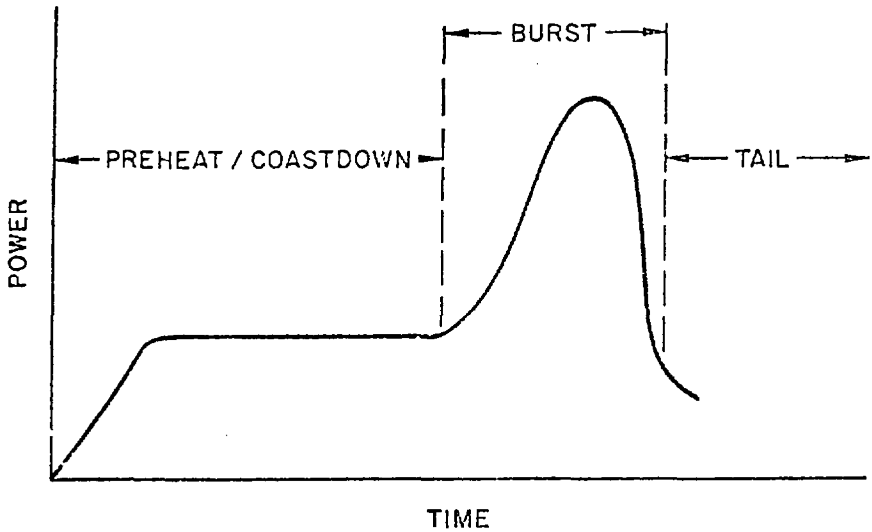

Fig. 1. Transient Shape Definition

Preheat/coastdown phase establishes pre-burst thermal and hydraulic conditions; and for TUCOP* simulations, it is during this phase that the flow coastdown also occurs.

Burst phase simulates the thermal conditions of the LMFBR power transient being simulated.

Tail follows each burst. The power tail may be adjusted to meet specific experiment requirements.

BRIEF DESCRIPTION OF UPGRADED CORE

The TU core consists of a modified high-temperature "converter" within the central 11-element x 11-element region of the nominal 361-element core. The high-temperature, inconel-clad converter elements contain urania loadings which are graded to optimize the neutron flux in the test regions and which

*Acronym for transient undercooling-driven overpower accident.

are greater than those in the present core. The present TREAT zircaloy-clad, graphite-urania fuel elements are retained as the "driver" region outside the converter. The converter elements are restricted to clad peak temperatures just under 900°C (except for the outer row of elements that are operated at lower temperatures to protect the driver elements). Given all of the constraints, this design provides the best cost-effective means of upgrading the capabilities of the TREAT reactor.

The converter fuel loadings have to be matched neutronically and geometrically to the test loops to produce optimal performance in the tests. Since a number of different loops having a range of experiment neutron "filters" is specified to be accommodated in the upgraded reactor, the design was aimed towards optimizing the core performance for the ensemble of test loops. The design solution to the problem was to have the bulk of the modified core optimized for the ensamble of tests and have 5 x 5 fuel assembly "inserts" that were specifically optimized for the two main test loops of interest -- viz the 37-pin ATL and the 7-pin Mk III loop. A variant of the latter contains an unfueled inner ring of assemblies and is used for some Mark III tests and all single pin tests.

The kinetics behavior of the TU reactor is altered relative to TREAT because of the decreased magnitude of the negative temperature feedback reactivity (by about 60%) and shortened prompt neutron generation time (by about 50%).

The TU reactor is very tightly coupled neutronically, which makes the use of point kinetics model of the core adequate for the study of the reactor kinetic behavior. This fact was confirmed by explicit space-time kinetics calculations using the FX-2 code. Using the point kinetics model and neutronics data generated from detailed TU core models, it was demonstrated that the complex power time shapes desired by the experimenters could be easily achieved. Furthermore, explicit calculations established that the transient operation of the TU reactor in the feedback control mode is stable using the transient rod drives that are identical to those in the present TREAT reactor.[6]

The control system of the reactor has been upgraded for enhanced experimental flexibility and reactor safety. Three independent sets of control rods and static control methods provide for safe operation and yield the flexibility to operate the reactor with widely different loop/neutron filter characteristics. One consequence of the enhanced experimental capability in TU is the need for a Plant Protection System (PPS) to terminate low-probability reactivity accidents. Extensive analyses have shown that reliable PPS protection is achievable with commercially available control hardware and electronics.

NUCLEAR CAPABILITIES

The upgraded nuclear capabilities of the TU reactor fall under the following classifications: statics, kinetics, and accommodation of fuel motion diagnostics.

Statics

The static capabilities of the TU reactor refer to the test sample energy deposition and the radial power profile within the test cluster, both determined at the axial midplane of the test cluster. Both of these parameters are strongly dependent upon specifics of the test fuel (fissile enrichment, pin size) and of the surrounding environment (test vehicle design, use of neutron filters) in addition to the basic effects of the core design. Computation of these parameters by deterministic methods is complicated by the difficulties in generating suitable temperature-dependent neutron cross sections in the spectrally non-asymptotic region composed of discrete pins. Probabilistic (Monte Carlo) methods using continuous energy formulations are better suited for the calculations and were used despite the uncertainties introduced by the necessity of running a limited number of histories from cost considerations. The method used employs the VIM code[7] and has been compared against experimental results obtained in TREAT. Both the flatness and energy deposition values were found to agree with measurements to within statistical uncertainties.

The calculations showed that the functional requirements on energy deposition and flatness are easily met. The statistical uncertainty on the computed energy values is of the order of 5%. However, effects of possible hot spots in the core, and the operational constraints related to instrument calibrations introduce additional uncertainties in the computed TED values. The best estimate values of the total uncertainty in the computed energy estimations is ± 12% The requirements on the radial power profiles in test clusters are easily met, even considering uncertainties.

Some specific results for test samples of relatively near-term interest are discussed below.

- A 37-pin ATL which containing 37 mixed oxide FFTF-type pins, having 10% burnup and uranium enrichment graded to achieve near optimization of sample power both in the FFTF (reflector) irradiation position and in TU, is calculated to have a cluster-averaged sample energy capability of 4300 j/gram of sample fuel on the core midplane. Subtracting an estimated 12% uncertainty to accommodate operational and design contingencies, a capability of 3780 j/gram is predicted.

Approximately 1300 j/g is required to carry oxide fuel adiabatically to its liquidus. Thus, over 2700 j/g is available to be used to establish proper prefailure thermal conditions and to meet specific power-time history requirements. The calculations also show that a uniform enrichment 37-pin test cluster composed composed of large (0.658-cm o.d.) advanced oxide pins irradiated to a 10 a/o burnup would have energy deposition capability of 3350 j/g, with the 12% decrement taken as above and a radial intra test power profile characterized by a ring averaged maximum-to-average value of 1.10. In this case over 2,000 j/g is available for establishing prefailure thermal conditions and for specific power-time history requirements. For example, a total of 3350 j/g energy capability is more than adequate to provide an accelerated flow coastdown with a TREAT burst "preheat" power shelf which will produce fuel bundle and outlet temperatures typical of those for a real time LMFBR flow coastdown with postulated loss of scram. Proper downstream test thermal conditions at the time of inception of the high-power burst are essential for testing and verifying models of LMFBR shutdown by fuel dispersal under CDA conditions. This capability for sample size and energy input may also be exploited for experiments on the development and phenomenology of the transition phase following the initial core disruption in a CDA.

- Including the 12% contingency decrement, a Mk III type loop which contains seven mixed oxide pins with 0.658-cm o.d., loaded with PFR outer zone fissile content and irradiated to 10% burnup, is calculated to have a cluster-averaged sample energy capability on the core midplane of:

  3250 j/gram with a radial pin-averaged maximum-to-minimum power ratio of 1.2 (fueled insert surrounding loop),

  4080 j/gram with a radial pin-averaged maximum-to-minimum power ratio of 1.3 (graphite insert surrounding loop).

  The two Mk III insert options provide experimenters with the capability to use energy vs radial power flatness criteria in planning TU experiments on seven prototypic enrichment pins. Both cases provide a flatter radial power ratio for these pins than the current TREAT value, which is in excess of 1.4.

It should be noted that this represents a major upgrade of the experimental capabilities in TREAT. The only method available in current TREAT to achieve better flatness is the use of neutron filters. For bundles of seven prototypic enrichment mixed oxide pins* in current TREAT, addition of a filter strong enough to cause a test sample energy capability to drop by more than a factor of two from the unfiltered value will not cause a change, outside uncertainties of measurements, in the pin-averaged maximum-to-minimum power ratio. This phenomenon is a consequence of the large near-thermal resonance in Pu-239. Thus, in current TREAT, the experimenter does not have a realistic capability to trade off horizontal power flatness against sample energy for prototypic enrichment mixed oxide pins. (This capability does exist for similar pins containing highly enriched uranium and was utilized routinely in the past to meet specific test goals for experiments with such pins.)

- Including the 12% contingency decrement, a single 0.658 cm. o.d. pin, as above with 10% burnup, contained in a Single Pin Test Loop (SPTL) is calculated to have a core midplane energy capability of 8360 j/g.

In the interpretation of the test energy deposition numbers, several important points should be borne in mind. As indicated earlier, subtracting the 12% contingency allowance from the best computed values provides an estimate of the lower limit of the band within which the performance values are expected to lie for these test pins. Higher energies would be available for more favorable experiment cases, i.e., smaller pins, lower (or no) burnup, or higher fissile content.

Kinetics

The TU core kinetics parameters are sufficiently similar to those of current TREAT that the transient behavior of the TU core is similar to that of TREAT. This similarity has the specific significance that there is a high degree of confidence in TU kinetic calculation results because the calculational techniques were validated against experimental data in TREAT. Explicit

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*Mixed oxide pins with fissile Pu content of about 25% of heavy metal atoms; and with the uranium fissile content in the range at-or-near-natural.

calculations showed that the desired power-time shapes (burst periods ranging from 100 msec to about 15 sec, initial preheat energies of about 1000 j/g, peak power of 8000 w/g of test fuel) could be produced. The only impact of uncertainties in the parameters is altered reactivity and reactivity insertion rates necessary to produce the desired shapes. Enough flexibility exists in the control design to permit adjustments to account for effects of such uncertainties, while meeting all of the TU kinetic requirements.

The design of the TU Reactor Control System (RCS) is a refined, state-of-the-art version of the current RCS, rather than a totally new concept. Refinements of importance to experimenters include: additional checks on transient power vs time shapes (provides greater assurance of meeting shape specifications), and decreased accident overenergy from postulated rod runaway accidents (reduces the safety-related restrictions upon experiment specifications). In addition, the transient rods in TU are ganged to move in parallel, rather than in sequence as in current TREAT (this feature will eliminate azimuthal power tilts in the reactor which can cause swings in the ratio between sample power and the reading of the ex-core power monitors during a transient).

The RCS is backed up by a safety grade Plant Protection System (PPS) which is activated by period, core power, or core energy in addition to core temperature. A multilayered protection concept has been used to ensure that accidents resulting from worst case RCS failures do not result in core damage and public hazard.

Accommodation of Fuel Motion Diagnostics

The TU core is designed with a row of slotted elements which extend from the central test position to the fast neutron hodoscope position.[4] The modified fuel element fissile loadings are graded azimithally to compensate for the presence of the slot.[5] Without this grading, the slot would produce an undesirable derating in test sample energy deposition capability, and would also cause a strong horizontal power tilt across the test bundle. Calculations have shown that special "shielding" modified elements do not have to be loaded behind the test position to block out background.

BUILDING UPGRADE

The TREAT building has been greatly expanded and upgraded in preparation for the reactor modifications. Figure 2 contrasts the current (TU) floor plan with the "original" floor plan prior to upgrading. the previous building consisted basically of a rectangular high bay, having the long axis in the north-south direction, and some low bay extensions on east and west sides. The new building has a larger south high bay beginning a few feet north of the reactor. Low bay service areas have been expanded, also. Prior to this building expansion, experiment hardware was brought in through the truck door in the north wall, and operations with this hardware were carried out in the multipurpose area north of the reactor. These operations were supported with a 15-ton bridge crane which also serviced the reactor. The operational capability in the north end of the building and the 15-ton crane have been retained in the current building. In addition, there is now a capability for once-through truck-transporter service through the south high bay, which is serviced with a 60-ton crane.

Figure 3 is a cutaway drawing of the current building. Two experiment-service mezzanines are shown to the east of the reactor. Note that both cranes provide coverage over the full reactor. At the south wall is shown the assembly tower structure which serves both as a storage location for the Loop Handling Machine (LHM) cask and as an experiment assembly facility. On the floor, extending from the west face of the reactor, is the radiography station. Just visable, extending out from the north reactor face, is part of the upgraded hodoscope facility. The combination of the new crane and the LHM provides the capability to handle large experiment loops that fit within a cylindrical envelope 50 cm in diameter by 8.2 meters long.

A series of experiment storage and operations pits is provided in the new high bay area. These provide a greatly expanded capability to assemble experiment loops, load radioactive fuel into the loops and perform loop checkout, and to perform some post-experiment operations such as removal of reusable secondary containment components.3 In addition, this area provides a capability for assembly and disassembly -- in a large floor pit -- of calibration assemblies used to measure the nuclear performance of experiment samples. Although these calibrations do not use previously irradiated sample fuel, these in-reactor calibration runs do activate the sample fuel and the calibration hardware. Thus, some shielding is necessary for the semi-remote handling operations required for the calibrations.

SUMMARY AND CONCLUSIONS

By adopting the approach of modifying an existing, highly productive experiment facility, the TU provides a cost-effective route with a high level of technical confidence of success for achieving a large increase in LMFBR safety experiment capability. The Functional Requirements, although demanding, appear to be achievable on a schedule that provides a useful support for forthcoming licensing actions.

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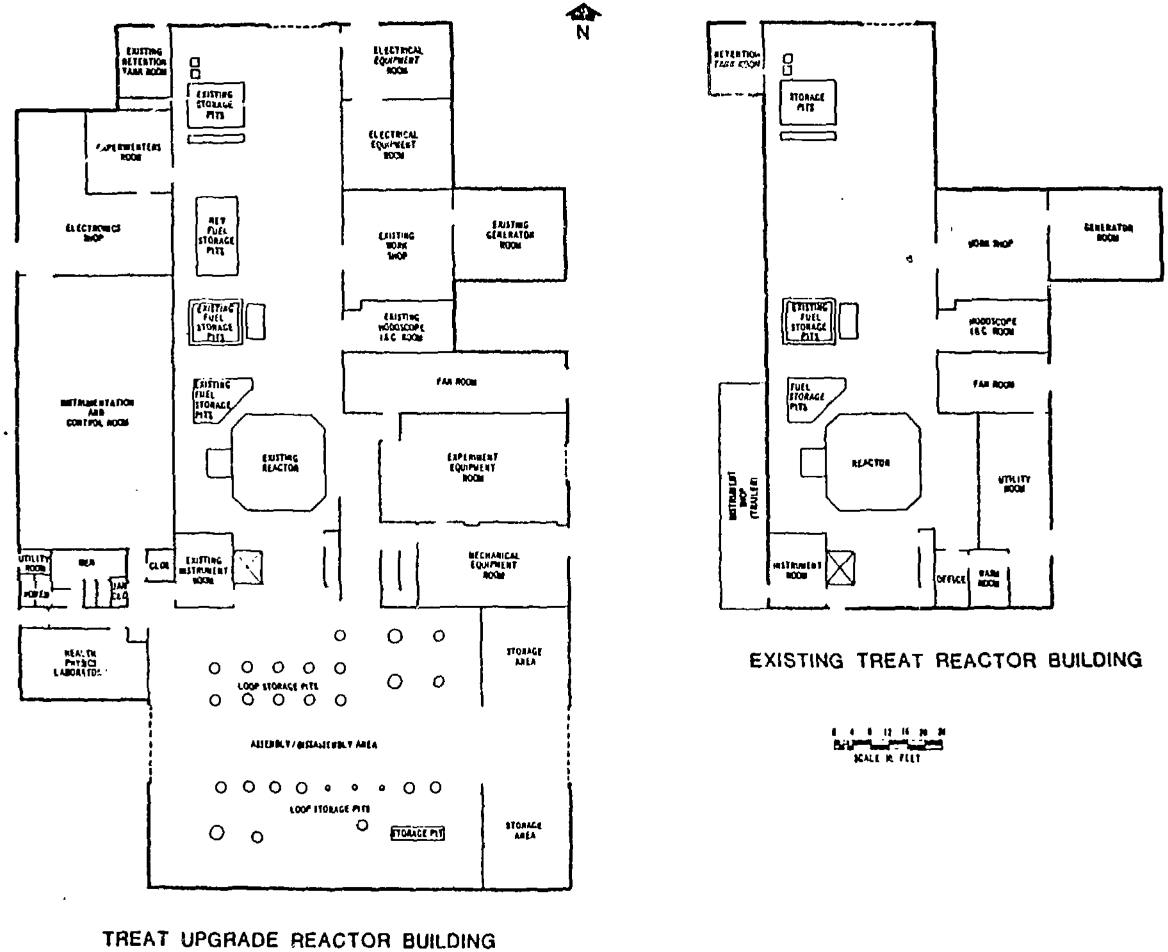

Fig. 2. Comparison of original and upgraded TREAT buildings

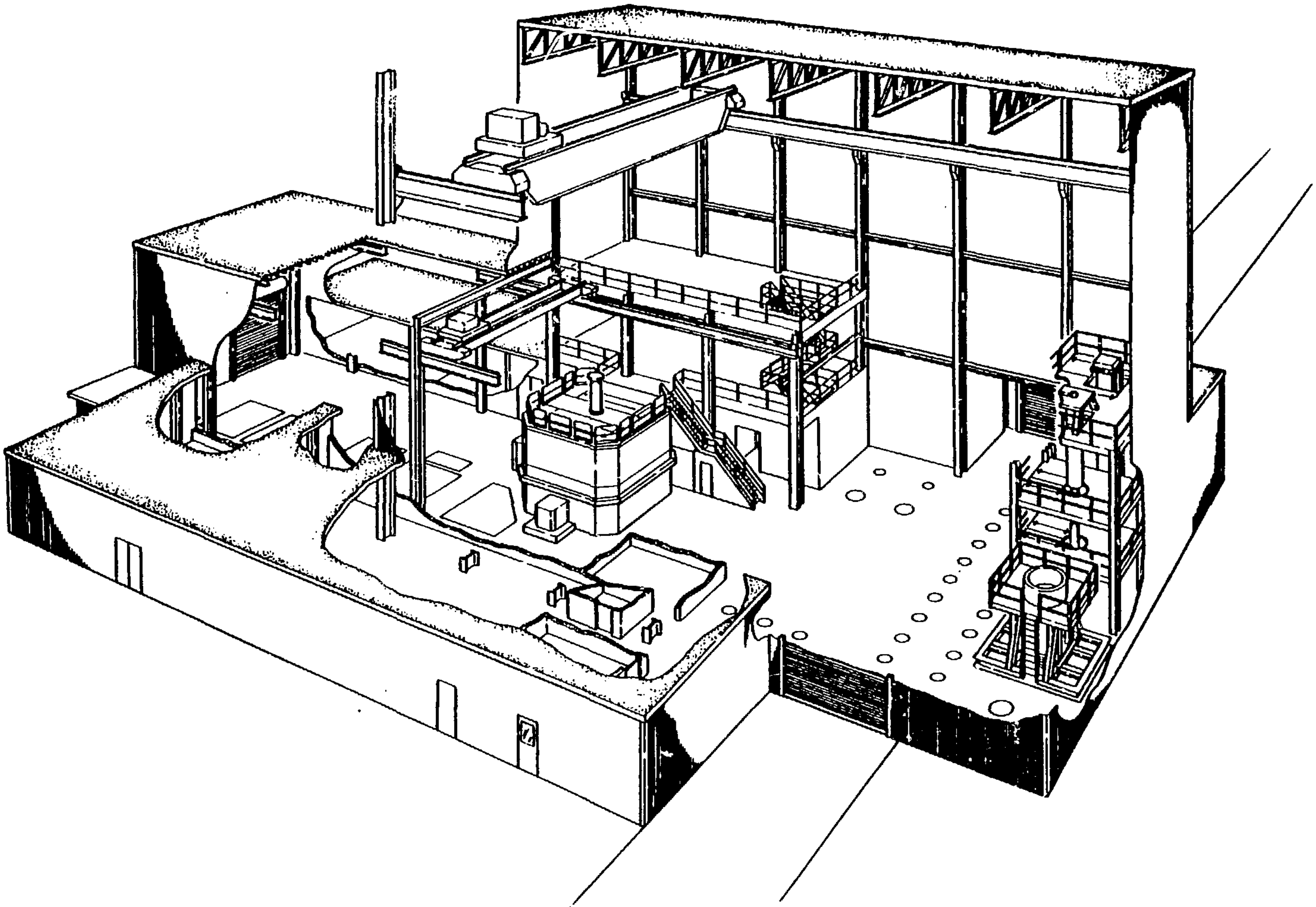

Fig. 3. TREAT Upgrade reactor building

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