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Anxious history: The High Flux Beam Reactor and Brookhaven National Laboratory

THE HIGH FLUX Beam Reactor (HFBR) was one of the key instruments in the history of Brookhaven National Laboratory and of neutron physics. Its story intersects with many others—not only with changing scientific directions, the history of the lab, and the history of its funding agency, the Department of Energy (DOE), but also with local and national politics, local and national anti-nuclear groups, public perceptions of science, and more. These different intersecting stories make it hard for participants and historians to say where one story ends and the others begin. The result might be called "anxious history."

1. A CAREFREE DECADE

No such anxiety surrounded the HFBR's design and construction phase because Brookhaven's objectives motivated the reactor. One of the first three national laboratories, Brookhaven had been founded in 1947 for forefront research facilities, specifically reactors, too big for single universities to afford.[1] The initial plans formulated at the end of 1946 called for two reactors: "Pile #1," which would become the Brookhaven Graphite Research Reactor (BGRR), was to be built quickly on the model of Oak Ridge's X-10; "Pile #2," with a more advanced design, would follow after further research by the new lab's reactor engineers.[2] But in the excitement and distractions of Brookhaven's startup, little thought went to this second

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The following abbreviation is used: BNL #, Brookhaven National Laboratory publishes a series of reports identified by number; thus, BNL 940 refers to Brookhaven Report 940.

1. Robert P. Crease, *Making physics: A biography of Brookhaven National Laboratory 1946-1972* (Chicago, 1999); Alan Needell, "Nuclear reactors and the founding of Brookhaven National Laboratory," *HSPS, 14:1* (1983), 93-122.

2. Program of Brookhaven National Laboratory, 15 Dec 1946, Director's Office series, Historians office, appendix 1.

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reactor before 1954, when Donald Hughes, the dean of Brookhaven's nuclear physicists, experiencing growing competition with accelerator-based sources in his cross-section work, began agitating for a higher flux reactor. Lab director Leland Haworth appointed a reactor study group in 1956. A proposal based on a novel design by Jack Chernick was submitted to the AEC in mid-1957.[3] Chernick and his associates later patented the design.[4]

Whereas all earlier research reactors, including the BGRR, were designed for general purposes, the HFBR was optimized for experimental beam research. Conventional reactors thermalize fast fission neutrons by a moderator placed between the uranium fuel elements. Chernick instead placed all the fuel elements close together and immersed them with a vat of heavy water. The fast fission neutrons entered the heavy water moderator, where they slowed down before some returned to the core to sustain the chain reaction. The neutron flux therefore peaked outside the core, where the researchers could use them. A second design innovation, suggested by experimenter Julius Hastings, mounted the beam tubes tangentially, which reduced the high-energy neutron background.[5] By contrast, Oak Ridge's HIFR, designed about the same time, trapped the maximum flux in the dead center of the reactor, to optimize it for isotope production.[6]

The HFBR's proposal (and HIFR's) languished at first because of AEC belt-tightening, but after Sputnik the U.S. Congress, worried about declining U.S. superiority in science, placed extra, unasked-for money in the agency's budget that launched the HFBR and HIFR.[7] The HFBR began construction in earnest in spring 1962 and went critical on October 31, 1965. (Oak Ridge's HIFR had gone critical that August.) It cost $12.5 million. Like any large instrument it required a shakedown period. The machine reached its design power of 40 MW in 1966.

The HFBR had an important and clear-cut role: it was and remains the only high flux American reactor specifically designed for neutron beam research.[8] Donald Hughes, the first and principal proponent of the machine, intended to use the higher flux for traditional nuclear physics research such as measuring cross-sections. No anxiety there. But accelerators grew ever more competitive in this work, Hughes died in 1960, and the field of neutron scattering became fashionable. Neutron scatterers took over HFBR, making it a classic case of an instrument built for one purpose and used for another.

3. Lawrence Passell, "High flux at Brookhaven" IN G.E. Bacon, ed., *Fifty years of neutron diffraction* (Bristol, 1986), 120-128.
4. J. Chernick et al., "High flux beam reactor," Patent # 3,143,478, U.S. Patent Office, patented 4 Aug 1964.
5. Jack Chernick, *Selected papers* (Brookhaven National Laboratory, Upton, New York), 70-74.
6. J.W. Cable, "High flux at Oak Ridge," in Bacon (ref. 3), 128-135.
7. U.S. Atomic Energy Commission, Construction Project Description FY 1960, Project 562-60, "High flux research reactor," Jul 1958.
8. Crease (ref. 1), chapt. 12.

HFBR had nine holes, some subdivided into two or more stations, one hole or station for each department or research program. Decisions about the experimental program were made without formal proposals, and outsiders who wanted to work at the facility would talk to the key experimenters to work out arrangements.[9] Vance Sailor's nuclear cryogenics group occupied hole one (H-1); the nuclear physics cross-section group originally run by Hughes but then headed by Harry Palevsky and then Robert Chrien occupied H-2; and the nuclear structure group originally headed by the Goldhabers, H-3. All these programs derived from work at the BGRR. By the late 1960s and early 1970s, much forefront nuclear physics work required higher energies than obtainable from reactors and did better at newly developed pulsed neutron sources like ORELLA at Oak Ridge. By the end of the 1970s, the three programs had been abandoned.

Holes four-eight went to neutron scattering, then booming: owing to instrumental innovations like the triple axis spectrometer and a maturer theory of key processes. Inelastic neutron scattering looked particularly promising.[10] The neutron scatterers had five of HFBR's nine holes at the outset and took over others as their research programs ended.

For six years after its commissioning, the HFBR was the only reactor in the world optimized for beam research, and the only one with an undermoderated core. In 1972, the ILL (Institut Laue-Langevin) reactor came on line in Grenoble.[11] It had an undermoderated core, a power (57 MW) similar to HFBR's, and it, too, was optimized for beam research. But for awhile, HFBR remained the facility of choice. It had a strong in-house research community welcoming to outsiders; a newcomer joined a network of researchers with extensive experience. Another positive factor was Brookhaven's theory group, whose principal members (George Vineyard, Martin Blume, and Victor Emery) interacted closely with the experimenters. Brookhaven had a more flexible and informal atmosphere for experimenters than the ILL, where all experimenters had to submit proposals before a review board. Changes in response to new developments or technologies could be made quickly and informally.

Plans in the mid-1970s called for upgrading the HFBR to 60 MW and building several new major instruments. At H-2 the neutron physics group that carried on Hughes's work shifted its focus and wanted to install an isotope separator called TRISTAN, which had spent twelve years at the Ames Laboratory Research Reactor (ALRR) in Iowa. DOE planned to shut down ALRR at the end of 1977 and sought a new home for its reactor-based on-line isotope separator. TRISTAN had a small (about 5 gram) target of U-235 placed directly in a neutron beam in a vacuum. The

9. Users had insisted on preserving this informality; Herbert Kouts to Charles Falk, 28 Jan 1963. An HFBR Experimental Facilities Committee though formally created was never used; Crease (ref. 1), 323.

10. "Symposium on Inelastic Scattering of Neutrons by Condensed Systems," BNL 940, 20-22 Sep 1965.

11. Bacon (ref. 3), 135-155.

uranium would produce a spray of ionized fission fragments that, after passing through a small linear accelerator, entered an analyzing magnetic field. The separated fragments fell on a mylar tape, then passed through an array of detectors that registered their spin states and other properties. TRISTAN was especially good for the study of short-lived isotopes far from the line of stability. It brought a different atmosphere to the HFBR floor because it was run more as a user facility than the equipment at other stations; individuals or groups from outside Brookhaven did not have to join an in-house group to learn how to conduct experiments. Many outsiders, from Ames and elsewhere, and their graduate students, came to work at the HFBR.[12]

Another planned and important new piece of equipment, a cold neutron facility at H-9, consisted of a foot-ball sized container of liquid hydrogen cooled from the outside, and located deep inside the beam tube.[13] Collisions with the low-energy protons cooled the thermal neutrons to low energies (<5 meV) and long wavelengths (>4 Å), making them suitable for high-resolution condensed matter research and for studying relatively large objects like biological tissues. A cold neutron source had been planned in the original design, but protracted safety studies that ate up construction funds and other setbacks delayed completion through the 1970s.[14]

Meanwhile, neutron scattering research made greater demands for reactor time. But the cost of new reactors soared and the federal government's enthusiasm for building them waned. Julius Hastings, who had helped design the HFBR and became the dean of its reactor experimenters, began to worry. In 1974, he issued a report that summarized "the generally-held opinions of the community of neutron beam experimenters." The AEC, it noted, had built up an excellent, balanced range of facilities for neutron research used in fields as diverse as nuclear physics, condensed matter science, and biomedicine. But these facilities were becoming obsolete for "frontier experiments" and faced a growing demand in conventional applications. More intense sources were needed for application of neutron scattering techniques to areas of research, particularly determining the structure of biological molecules. Other countries were responding to those imperatives. The report warned that if the U.S. delayed, "we are likely to witness an inability to meet new demands which may peak in the next decade." It recommended that the AEC establish a program to develop "novel, intense, and flexible neutron sources for research;"

12. On the design of TRISTAN see W.L. Talbert and D. Thomas, "Design considerations for a system to investigate short-lived nuclei produced at a reactor," *Nuclear instruments and methods, 38* (1965), 306-311. A good summary and description done at the time of the move to BNL, with a complete set of references, is given in W.L. Talbert, "TRISTAN I-techniques, capabilities and accomplishments," in R. Chrien, ed., Isotope Separater On-Line Workshop, *Proceedings*, 31 Oct-1 Nov 1977, BNL 50847.
13. J.W. Dean and J.E. Jenson, "Direct cooling of the cold neutron moderator by helium," 5 Jan 1973; rev. 13 Jan 1973, Historian's office, Cold Neutron source drawer.
14. Crease (ref. 1), 343-345.

begin work on a new pulsed (accelerator-based) neutron source and a new steady-state (reactor-based) one; beef up support of existing programs; "start a national users' group to promote national and international co-operation;" and establish an AEC advisory committee on policy relating to neutron research.[15] The AEC took none of these steps although demand continued to climb and new studies of the field reaffirmed the conclusions of Hastings report. The National Research Council recommended in 1977 that existing capabilities be broadened by the development of a high flux spallation source, a facility whose existence would answer many of the concerns expressed in the Hastings report.[16]

That year, Brookhaven's lab director George Vineyard spelled out the differences between HFBR and ILL. "In contrast to Brookhaven, and of particular importance, the initial scientific management principles established at ILL emphasized outside users with an in-house staff mainly devoted to the design and operation of the various instruments." This, Vineyard continued, had two consequences for ILL, one good and one bad. To the good, a state-of-the-art set of spectrometers, "especially those devoted to high-resolution experiments." The contrast with BNL was striking: in 1977, BNL spent $400,000 on new instrumentation at HFBR, most of it in connection with the upcoming power upgrade, while ILL spent $2 million. The bad consequence was the ILL management system, which required formal proposals for all research, "a rather inflexible scheme of scheduling" that fragmented the research programs and encouraged "measurements rather than experiments." Vineyard concluded that HFBR's advantage over ILL "is fragile and is being eroded rapidly." He urged the DOE to help maintain the forefront position of HFBR not only through "strong direct support of the scientific staff and their programs," but also by launching "a vigorous effort to increase outside user participation."[17] The need to increase user participation proved far more significant to the future of the HFBR and U.S. neutron science than anyone could have known at the time. The larger the community of users a facility had, the broader its base of support. This consideration was critical for a facility as expensive, and politically controversial, as a research reactor.

Despite the waning Federal support of reactors, HFBR stayed a centerpiece in the U.S. neutron research program. Brookhaven took pride in it and featured it on weekend public tours. Visitors would be taken down to the spent fuel pool to marvel at the blue color caused by Cherenkov radiation, up to the experimental level to see the beam lines and instruments, and then to the top to see the control room

15. J.M. Hastings to J.M. Teem, 25 Oct 1974, Historian's office, HFBR drawer.
16. NRC Solid State Sciences Committee, *Neutron research on condensed matter: A study of the facilities and scientific opportunities in the United States* (Washington, D.C., 1977), p. 1, called for a comprehensive program to meet "the future challenges and opportunities that lie open to this area of science." The study recommended complementing existing steady-state neutron facilities (research reactors) with a new high-flux pulsed spallation neutron facility.
17. George Vineyard to James S. Kane, 10 Aug 1978, Historian's office, HFBR drawer.

and the operators. This public accessibility reflected and reinforced the comfort that the community felt about the presence of a nuclear reactor in its midst.

The future looked bright for HFBR in 1982, when it began to run at 60 MW, which increased the flux by fifty percent. Another promising development, which wove the reactor still more deeply into Brookhaven's research programs, was the commissioning of the National Synchrotron Light Source (NSLS) at about the same time. The NSLS, an applied and basic research user facility that routinely hosted interdisciplinary collaborations, had a huge impact on Brookhaven. It drew in outside users in abundance. It complemented the HFBR's scattering capabilities, boosting the lab's position as a center of materials science, and opened the way for research programs that would cross over between neutrons and photons. The co-location of neutron and synchrotron radiation sources would become a model for the future. But the opening of the NSLS led to greater formalization of the experimental program. Participating research teams (PRTs), consisting of BNL scientists and regular users from other places came into existence; one quarter of NSLS's operating time was set aside for outside general users on a proposal-based, peer-reviewed system. This system was also implemented at HFBR, not without resistance.

2. REACTOR ANXIETY

The first decade of HFBR's life displayed little anxiety. Although caught up in neutron research and its changing directions, it had a clear and undisputed role at the laboratory and in the U.S. Science Program. Anxiety began to enter in the mid-1970s. A main cause was an important change in the principal funding agency for the laboratory with the creation of the Department of Energy (DOE) in 1977. The DOE differed greatly from the AEC (and the short-lived ERDA) in scale, organization, and political profile. Whereas the AEC had focused on accelerators and reactors, DOE had many competing and conflicting mandates. It had been cobbled together out of many opposed or disconnected bureaucratic pieces. The cabinet-level DOE Secretary was politically much more visible than the head of the AEC. Bureaucracy can play a positive role by keeping important decisions mid-range and out of politics. The new high political profile of the department's secretary now opened the possibility his or her decisions could be political footballs. Consequently DOE tended to be cautious about potentially controversial research reactor construction projects and even upgrades of existing instrumentation. As the 1970s ran out, neutron researchers became convinced that the DOE was not taking adequate care of their field.

Another important factor was the increasingly negative public perception of reactors fostered by powerful national organizations. A local instantiation of this national development took shape in opposition to the Shoreham Nuclear Power Plant on Long Island. In 1965, the same year HFBR came into operation, the Long Island Lighting Company (LILCO) announced plans to build a nuclear power plant in the town of Shoreham. It applied for a construction permit in 1970 and public hearings began that September. The public obtained a separate and substantial voice in now open licensing proceedings that often seriously delayed and ultimately killed reactor projects. LILCO received its permit in 1973 and set up the reactor pressure vessel in December 1975, amid an increasingly organized and vocal opposition.[18]

The Shoreham opponents eventually turned their attention to HFBR. In December 1975, an official of the New York City Health Department of New York City, fearing daily shipments of spent fuel rods through the future Shoreham plant, proposed to ban them. The New York City Council adopted the proposal. Transport via an alternate route, using the Orient Point Ferry to New London met with protests, media coverage, and political posturing. Protestors handed out leaflets and carried placards bearing portraits of mushroom clouds and skulls and crossbones. A Suffolk County (New York) assistant district attorney called the shipping of a cask of spent fuel, whose surface radiated with an intensity a hundredth of a dental x-ray, an act of "genocide."[19]

To the scientists, the apocalyptic signs and flyers addressed issues irrelevant to HFBR and especially to shipment of its spent fuel. The protesters made a category error in equating a research reactor like the HFBR with power reactors and nuclear weapons. But abolishing distinctions between types of reactors and radiation-emitting man-made things was a crucial element of the anti-nuclear movement. The smudging was more easily accomplished because of the AEC's mendacity about accidents and exposures of the public to radiation in the 1950s and the intrinsic human fear of things nuclear.[20]

The negative public perception of reactors, and the sometimes heavy-handed actions of the DOE, began to intersect early in 1979 after the partial meltdown at the Three Mile Island Nuclear Power Plant. Though an insignificant amount of radiation was released, the accident inspired public fear, and galvanized the anti-nuclear groups. Protestors staged demonstrations at nuclear power plants around the country. In June, demonstrators at the Shoreham plant nearing completion scaled the walls and damaged some property. The head of BNL's Reactor Department, fearing that the demonstrators might turn on the HFBR, asked the guards what their instructions were should protestors try to enter the building. "Shoot to kill." He ordered the doors welded shut; no demonstrators appeared. The lab began to give HFBR a lower profile, downplayed its press releases and dropped it from many tours.

18. David McCaffrey, *The politics of nuclear power: A history of the Shoreham Nuclear Power Plant* (Dordrecht, 1991); Joan B. Aron and E. Leo Slaggie, *Licensed to kill? The Nuclear Regulatory Commission and the Shoreham Power Plant* (Pittsburgh, 1998).
19. Robert P. Crease, "Conflicting interpretations of risk: The case of Brookhaven's spent fuel rods," *Technology, 6* (1999), 495-500.
20. Barton C. Hacker, *Elements of controversy: The Atomic Energy Commission and radiation safety in nuclear weapons testing 1947-1974* (Berkeley, 1994); Spencer Weart, *Nuclear fear: A history of images* (Cambridge, 1988).

Although the Three Mile Island facility was privately owned, the accident provoked the DOE to create a committee to review DOE reactors. The committee required quality assurance in reactor operations; paper trails had to be adequate for tracing claims about materials used and procedures followed. This introduced a much greater formalization into HFBR's operations and presaged more.[21] It also caused the operating costs of the reactor to skyrocket.

Meanwhile, another set of developments forced an overhaul of security at HFBR. In 1979, Lt. Col. Edward J. McCallum, who had seen thirty years of military duty including Special Forces assignments in Europe and Southeast Asia, because Director of the Safeguards and Security Division at the DOE's Chicago Operations Office, which had jurisdiction over Brookhaven. McCallum's head, which would roll a decade later as a result of his loud claims of lax security at DOE, took security and defensive readiness extremely seriously. In the early 1980s, he dedicated himself to tightening up security at DOE facilities. Brookhaven managed to fend him off until 1983. Security at HFBR, in informal Brookhaven style, amounted to a secretary who sat behind a desk just inside the reactor building. This changed after October 1983, when a truck loaded with explosives broke through security barriers at a U.S. Marine Corps barracks in Beruit, Lebanon, killing 251 military personnel. McCallum obliged Brookhaven to conduct an evaluation of HFBR's readiness for two sorts of terrorist actions. It failed the test. In the fall of 1985 the DOE made Brookhaven shut down the reactor.[22] Anxious to turn its reactor back on, HFBR made extremely conservative assumptions about potential threats, which showed a need for additional defenses. McCallum ordered fortifications against terrorist assault. A retina scan was required to enter the operations level. Armed guards behind cinderblocks, sandbags, and protection against light anti-tank weapons, and fortified with machine guns, hand grenades, and sticky foam to immobilize intruders, controlled access to doors and elevators. The reactor came back on in January 1986.

These measures hampered operations. Routine operations like fuel delivery became day-long procedures involving among other things an inspection by guard dogs of the entire building for possible saboteurs. New orders allowed little spare fuel, so the reactor operations and fuel delivery had to be carefully synchronized in advance. Delay in delivery could disrupt experimenters. They often had little warning of deliveries; DOE security did not want the operations schedule published lest it cue terrorists to the delivery of new fuel shipments.

21. Philip L. Cantelon and Robert C. Williams, *Crisis contained: The Department of Energy at Three Mile Island* (Carbondale, IL, 1982).
22. One scenario involved terrorists sabotaging the vessel in a way that dropped the coolant water to uncover the core. Fission materials might be released into the building, and then to the outside if the terrorists blew a hole in the building when the wind came from the right direction. The other scenario involved terrorists taking out recently discharged fuel rods from the spent fuel pool and placing them on the floor, then blowing a hole in the reactor with the wind blowing right.

These restrictions remained in place until 1992, when one member of the Reactor Division became so outraged by the requirements that he redid the old conservative evaluations in a more realistic way and showed that most of the security measures were unnecessary.

That did not stop the local community from worrying about the laboratory as a potential environmental polluter. In 1984, inspectors measured slightly elevated levels of tritium in an offsite monitoring well. A tritium-containing water had been emptied by mistake into the lab's sanitary sewage system; it had nothing to do with HFBR operations. Although the contamination did not exceed Federal guidelines, the lab made a point of publicly releasing the information. The news was given wide coverage. The lab's profile as an environmental hazard intensified in 1989 when the Environmental Protection Agency put it on the National Priorities List, frequently referred to as the "Superfund" list (The designation was incorrect because DOE, rather than the Superfund set up by Congress as a tax on industry, would pay the cleanup costs).[23]

The reactor accident at Chernobyl in April 1986 prompted DOE to order another review conducted by a committee of the National Academy of Sciences.[24] One of its major recommendations transformed oversight for the reactor. Previously the onsite office, subject to an annual audit of the Chicago DOE area office, oversaw reactor safety. The NAS report recommended a centralization of safety oversight. The DOE's Office of Nuclear Energy in Washington took on the role. The onsite office was enlarged to put HFBR's operators in almost daily contact with the Washington DOE.

Another of the NAS committee's recommendations resulted in a two-year shutdown of the reactor. Initial safety tests conducted in 1963 at 40 MW had included a study of the consequences of a low-probability, worst-case pump failure. So-called flow reversal would circulate the water after an interim period of stagnation. Additional DC motors were installed to control the coolant flow for the 60 MW upgrade. A small amount of fuel damage could occur during the stagnation, an undesirable but not necessarily unacceptable state of affairs. The NAS committee, however, questioned whether DOE should permit fuel damage as an "allowable consequence" of an accident. Brookhaven scientists tested the scenario and concluded that on their very conservative assumptions, there might indeed be a little fuel damage. In March 1989 they shut the reactor down, brought the issue to the attention of DOE, and asked permission to restart at 40 MW—a level known to be safe—pending further study of the danger, if any, of fuel damage. But DOE's Advisory Committee for Nuclear Facilities Safety, which had recently shut down HIFR for an extended period, refused and ordered a thorough review. The reactor did not come on again until May 1991, and then only at 30 MW. Meanwhile,

23. National Priorities List, 12 Dec 1989, announced at BNL in: R.P. Miltenberger, B.A. Royce, and J.R. Naidu, *Site environmental report for calendar year 1990*, BNL 52322.
24. National Academy of Sciences, *Safety issues at the DOE test and research reactors* (Washington, 1988).

studies expected to be positive began at Columbia University's heat transfer lab to demonstrate that there would be no fuel damage at 60 MW.

Yet another of the NAS committee's recommendations brought about yet another shutdown. It recommended that DOE have Probabilistic Risk Assessments (PRA) carried out on their research reactors. Probabilistic Risk Assessments grew out of a reactor safety study conducted in 1975 in connection with commercial reactors. Until then, reactor safety studies usually looked at the worst-case scenario, or "maximum credible accident," assuming that a reactor could withstand anything less dire than that. But the NRC became interested in a study method that looked at the systems designed to prevent the core from melting, and devised extended tree analyses that modeled the probability of each of the thousands of kinds of accidents that could take place. These complicated analyses had two stages: Level 1 PRA, to determine accident frequency, and Levels 2-3, to determine the effect of releases into the building and doses to the public. The entire procedure took years to perform. After the Three Mile Island accident, which followed a scenario anticipated in the PRA, PRAs ranked high as tools for determining the weak points of power reactors. They were not applied to research reactors, which were much simpler devices.

The NAS panel, however, called for PRAs on research reactors. From 1989 to 1991, Brookhaven's Reactor Division in collaboration with its Department of Advanced Technology carried out the PRA Level 1 (internal events). In 1991, they began to look at external events, such as flooding, earthquakes, and aircraft impacts. When they got to earthquakes in the fall of 1992, they discovered that the sophisticated seismic analyses of the 1990s picked up certain dangers that the cruder methods of the 1970s had not. They discovered that a tank known as the poison water tank, which sat on a stand, was vulnerable to "side sway" in the event of an earthquake. The poison water tank contained water to which cadmium nitrate had been added. In the event the reactor lost power in the forced cooling system, water from this tank would be added to the coolant, and the cadmium would absorb enough neutrons to help kill the reaction. The operators shut down the reactor in November 1992, telling the DOE that they had an "unreviewed safety question." With the addition of another tank, affectionately called Secondary Poison Water Addition Method, or SPAM, the reactor started up again in June of 1993.[25]

The following March, an electrical malfunction at TRISTAN ignited a piece of plexiglass serving as an insulator and vacuum seal. With the vacuum lost, fission products oxidized and escaped to the interior of the HFBR building. Some went up the stack. The release offsite corresponded to about a second's exposure to natural background. Brookhaven officials downplayed the event, but local newspapers treated it as front-page news. The episode highlighted a growing gap between the technical evaluation of a threat and public and media perceptions.[26]

25. Proposal to restart the HFBR following shutdown due to unreviewed safety question determination, 18 Mar 1993, Historian's office, HFBR drawer.
26. HFBR OR #1994-0005; U.S. Department of Energy, Chicago Operations Office, "Type

In 1996, the lab announced that some nonradioactive contaminants, mostly volatile organic compounds such as carbon tetrachloride and all having nothing to do with HFBR's operations, had been detected offsite. Although hydrologists from both the laboratory and the county felt fairly certain that no one was drinking contaminated water, the DOE offered public water hookups (valued about $1,500 each) to residents to the south of the laboratory, in what its site manager called an effort to be a "good neighbor." The effort backfired. Residents did not see this as a neighborly gesture. The offer seemed to verify that the water had been contaminated and all but invited demands by other community members for similar treatment. At a traumatic meeting, scientists proved almost wholly unable to calm the fears of residents and even wound up exacerbating them. The episode highlighted Brookhaven as a potential local polluter and put it on the local political map.

From the mid-1970s to the mid-1990s, HFBR's story intersected with those of the anti-nuclear movement, growing local environmental safety concerns, and national security issues. That was not all.

3. THE NEUTRON CRISIS

The NRC study of 1977 recommending development of a major spallation neutron facility had been predicated on an expansion of DOE funding in that area. This did not materialize, though work began on two small-scale spallation sources, one at Argonne (IPNS-1) funded by DOE's Office of Energy Research and one at Los Alamos (WNR/PSR) funded by DOE's Division of Military Application. In 1980, the DOE appointed a panel, headed by William Brinkman of Bell Telephone Laboratories, to review neutron scattering research and the priority of a major spallation facility under the constraint of a constant level of funding. The Brinkman report's conclusion was bleak. Neutron scattering research "provides *essential* and *unique* information about the microscopic nature of a broad spectrum of phenomena occurring in fields as diverse as materials science and biology." Yet although the U.S. made the first major contributions to neutron scattering research, it had fallen far behind the rest of the industrialized world. The U.S. spent less than West Germany, England, and France, taken separately, and one-eighth of their total amount when measured as a fraction of gross national product. The report's dramatic Table 1, "Seminal and milestone contributions," showed that, while the U.S. made most of the key contributions until the 1950s, by the 1970s they were being made mainly at the ILL. The Brinkman report noted that, realistically, a major spallation source was far off, and that the two existing research reactors built in the 1960s—HFBR and HIFR—"will be the mainstays of our neutron scattering research programs for at least the next decade," that is, into the 1990s. But it also noted that "the constant level of funding of these two facilities during the 1970s has not

B investigation of the March 31, 1994 fire and contamination at the Tristan Experiment, high flux beam reactor, Brookhaven National Laboratory, Upton, NY," 29 Apr 1994, Historian's office, HFBR drawer.

allowed the kind of instrumentation and innovation necessary for continued vitality." Thus, "we assign first priority to *increased* support of the two reactor facilities." The report called for the DOE to respond more forcefully to the needs of neutron scattering research:[27]

> The major responsibility for neutron scattering research resides in the DOE because of its long-term involvement in the development of reactor and accelerator technologies and because national laboratories have been the natural settings for large intense neutron generators. *It is imperative that the Department of Energy continue to take the major responsibility for the strength and development of neutron scattering research in this country.* Much of the information learned from neutron scattering research in materials science provides a vital part of the technology base for future energy-related developments. Thus, the more general responsibility of the DOE for neutron scattering research is commensurate with its goal of research related to energy.

Inspired by the Brinkman report, Brookhaven proposed an upgrade of the HFBR's facilities. It centered on an extension of the building to create a guide hall for the beams from the cold neutron source. This was the first of four efforts to upgrade HFBR. All received favorable reviews, some made it into the DOE budget, but all collapsed when the money never materialized.

Three years after the Brinkman report, the Office of Science and Technological Policy (OSTP) asked the NRC to establish priorities for major facilities for materials research. The NRC created a committee co-chaired by Frederick Seitz of Rockefeller University and Dean Eastman of IBM. The following year it sent OSTP head George Keyworth a careful plan that separately ranked proposed new facilities and proposed new capabilities at existing facilities. The ranked proposed new facilities were: 1, A 6 GeV X-ray source (now at Argonne); 2, an Advanced Reactor Source (to be built at Oak Ridge); 3, A 1-2 GeV ultraviolet source (at Berkeley); 4, A future spallation source. The ranked proposed new capabilities or upgrades were: 1, New guide halls and instrumentation for the cold neutron sources at Brookhaven's HFBR and at the National Bureau of Standards reactor; 2, Insertion devices at existing synchrotron radiation rings; 3, An experimental hall and new instruments at Los Alamos; 4, Upgrading of the National Magnet Laboratory; 5, Enriched spallation targets.[28] The committee pointed out that there were "six fully instrumented cold neutron guide halls either completed or under development in Western Europe" and none in the U.S., and that only two cold-neutron sources existed in the U.S., one operating at Brookhaven and the other under development at the National Bureau of Standards (run not by the DOE but by the Department of Commerce).

27. Report of the Review Panel on Neutron Scattering, 22 Oct 1980, underlining in original, Historian's office, HFBR drawer.
28. National Research Council, Major Materials Facilities Committee, *Major facilities for materials research and related disciplines* (Washington D.C., 1984).

The HFBR guide hall made it into the DOE budget but was eventually withdrawn; the NIST reactor, however, received one. Told by the DOE that the HFBR external guide hall was too ambitious, Brookhaven modified its proposal to take the cold neutron source (CNS) lines not outside, but to the edge of the current building.[29] This second proposed upgrade was strongly supported by another committee (the Pincus Committee) in 1988. DOE provided some money for upgrading instruments, though ones with no connection to the cold-neutron source. BNL then developed a third upgrade proposal was then developed to improve its instrumentation.[30] Meanwhile, the field of neutron scattering grew despite the lack of new major facilities and the stagnation of support for existing facilities and instrumentation.[31]

In 1992, the ILL reactor became inoperable when a plate inside the vessel controlling the coolant flow broke. The laboratory had the choice of repairing the plate or replacing the entire vessel. It chose the second option, which cost little more than the first and provided the opportunity for significantly prolonging the life of the reactor. Brookhaven reactor scientists proposed doing the same at HFBR. Changing the vessel would allow the cold-neutron source to be moved closer to the core, which would give HFBR capabilities comparable to ILL's. Also, the ILL experience provided a good estimate of costs and potential problems. The expanded cold neutron capability would also tie in well with research at NSLS. Plans for this fourth upgrade went forward.

In 1994—on the heels of the termination of the Superconducting Supercollider —the U.S. Congress also terminated the Advanced Neutron Source at Oak Ridge. DOE then created two subpanels to study the future of neutron scattering facilities. One, chaired by Robert Birgeneau, considered upgrades to HFBR at Brookhaven and HIFR at Oak Ridge with a budget of about $200 million, while the other studied improvements of the Los Alamos and Argonne spallation sources. The Birgeneau report recommended $150 million for HFBR, and $50 million for HIFR. The HFBR proposal, involving the renovated cold-neutron source and a new guide hall, would make the facility viable beyond 2025, and "would more than double U.S. capabilities in the all-important area of cold neutron research and would make us competitive with Western Europe."[32]

Annoyance with the DOE's stewardship of neutrons grew with the wide dissemination of the knowledge that the operating cost of the NIST research reactor, run by the Department of Commerce, fell far below that of similar DOE facilities. In 1996, the president of the Neutron Scattering Society of America (NSSA), Samuel

29. BNL, *High flux beam reactor: Beam lines and facilities upgrade* (Upton, NY, 1987).
30. BNL, *High flux beam reactor neutron beam lines and facilities upgrade* (Upton, NY, 1994).
31. J.D. Axe, "Neutron scattering: Progress and prospects," *Science, 252* (1991), 795-802.
32. Report of the Basic Energy Sciences Advisory Committee on Neutron Source Facility Upgrades and the technical specifications for the spallation neutron source, *Report* (Washington, D.C., 1998).

A. Werner, wrote a letter to Congressman Robert S. Walker, Chairman of the U.S. House of Representatives Committee on Science, expressing rather directly the "deep concern and frustration with the DOE's stewardship of facilities for neutron research in the United States" felt by many of his peers:[33]

> Four major DOE laboratories—ANL, BNL, LANL and ORNL—have made countless proposals over two decades to remedy the situation and received essentially no real support from the DOE commensurate with providing American scientists with internationally competitive facilities. This disheartening result is in spite of a number of exhaustive studies, including several sponsored by the National Academy, over the past two decades detailing the need....After surrendering our lead in the exciting field of high-energy physics (demise of SSC), we are about to close down an enterprise with obvious and tremendous actual economic impact—neutron scattering research.

Werner's letter annoyed many in the DOE and also neutron scatterers who feared having their anger and pessimism aired. Amid the pessimism, HFBR's proposed upgrade, which looked underway, offered a positive sign. This upgrade proposal, the fourth, would have had a significant impact on HFBR by vastly increasing the number and spectrum of users and by demonstrating DOE's determination to maintain the facility. HFBR researchers were excited by it, and by the prospect of 60 MW.

Former Brookhaven director John H. Marburger once described what happened at Brookhaven in 1997 as a catastrophe in the engineering sense of the word. A complex system grows out of synch with its environment so that it takes only a tiny, apparently insignificant event to bring it crashing to a halt or force it into a dramatically new mode. HFBR fell out of synch because of the intersection of the Shoreham episode, local activism, national activism, politics, the DOE, and so forth. The apparently insignificant event was a tiny leak of tritium-containing water, which posed no health risk, from the spent fuel pool of the reactor. The resultant wild events—which, in a novel would be considered hopelessly crude attempts at irony—prompted a media firestorm and political intervention. Lab director Nicholas Samios resigned and the DOE fired the lab's contractor, Associated Universities, Inc.[34] A frantically short competition for a new contractor followed. Meanwhile HFBR stayed idle.

In June 1997, the then-Republican, then-congressman Michael Forbes said he would support a restart if the reactor were proven safe. In July 1997, the DOE's Basic Energy Sciences Advisory Committee (BESAC) strongly endorsed the restart at 60 MW and momentum began building for it.[35] But the relatively small size of the user community, its dispersion, and its emphasis on basic research, proved

33. Samuel A. Werner to Robert S. Walker, 12 Mar 1996, Historian's office, HFBR drawer.
34. Andrew Lawler, "Meltdown on Long Island," *Science, 287* (25 Feb 2000), 1382-1388; "NY legislators want reactor closed," *Science, 277* (5 Sep 1997), 1431.
35. John Stringer to Martha Krebs, 22 Nov 1997, Historian's office, HFBR drawer.

handicaps. Had the major upgrades succeeded, the resultant bigger and more powerful user community might have been mobilized. Also that summer, a celebrity-stocked, anti-nuclear group called STAR came into being with a high media and political profile and much influence.

In September 1997, Forbes and Senator Alphonse D'Amato introduced an amendment to a House Appropriations Subcommittee bill that would mandate closure (later amended to non-funding of a restart) of HFBR. This amounted to a gauntlet thrown at the DOE. To program officers who were trying to draw up budgets for submission to Congress, it signaled that any project that depended on the HFBR restart would surely bring on a bitter fight. The legislation meant, effectively, that any attempt to restart HFBR would require extremely active and aggressive moves at the very highest levels of the DOE itself—from the Secretary's office.

That did not happen. DOE Secretary Federico Peña took what looked to be a safe way of postponing the decision by ordering an Environmental Impact Statement (EIS) as a condition for the restart. Although an EIS was unnecessary, for the operation of the reactor had nothing to do with the tritium plume, both proponents and opponents of the restart regarded the suggestion as a positive step. Scientists who knew the reactor and wanted it restarted anticipated that an EIS would come out satisfactorily. Also, the proposed upgrade—and perhaps even the increase to 60 MW—would require an EIS; the opportunity could be used to get this lengthy process out of the way. Activists who wanted the reactor terminated also favored an EIS, for they knew its bureaucratic consequences. Because the EIS, like licensing hearings, is open to the public, it can become an effective vehicle for delaying large projects, forcing them to use up money, and eventually killing them.

The EIS was a major factor in HFBR's eventual termination—and also the final moment when it might have been saved. But that would have needed strong leadership at DOE. The environmental issues could have been addressed and many forces could have been brought to play, including the scientific community, LI businesses, and scientists. Even local politicians needing environmental credentials would have found it difficult to maintain their opposition.

The delay brought about by the EIS hurt for three reasons. First, it gave local activists more time to mobilize opposition to the reactor. STAR exploited this opportunity. Second, it gave other scientists whose facilities competed for money with HFBR within DOE's Office of Science (OS) budget time to mobilize. These included supporters of the Spallation Neutron Source at Oak Ridge. Third, the delay became an argument in itself. The longer the process took, the more persuasive grew the argument that it would become so protracted and eat up so much money that it would be better to invest OS resources into operations more likely to bear scientific fruit.

Predictably, the EIS process encountered delay after delay. DOE's bureaucracy was effectively paralyzed as it agonized how best to proceed, dreading the inevitable controversy that would follow completion of the process. And the House

Subcommittee's amendment did not help speed expeditious processing. The vice-presidential aspirations of the new DOE Secretary Bill Richardson, who succeeded Peña as the new DOE head in July 1998, created another difficulty. STAR's board included high-profile fund-raisers for the Democratic party including movie star Alec Baldwin and supermodel Christie Brinkley. The original date for release of the draft EIS passed, unmet, in August 1998, as did the original date for release of the final EIS in November 1998.

Meanwhile, HFBR remained on DOE's list of key neutron facilities for the U.S. program, repairs were underway, and the approval process for the upgrade to 60 MW prospered. But the opposition grew stronger with each delay of the EIS. In February 1999, Richardson met with STAR board members and agreed to extend the public comment period after release of the still-unreleased draft EIS. In April a draft EIS concluded "that the environment and public health and safety would be protected under any of the four reasonable alternatives for the future of the HFBR," but the DOE did not release it. In October 1999, Richardson met again with STAR board members. According to an account of the meeting in *George magazine*, clearly based on lengthy interviews with several participants, Brinkley "reminded Richardson that his aspiration to be Al Gore's running mate—a job he hadn't been coy about lobbying for—would be seriously compromised if he didn't acquiesce;" in response to which "Richardson's jaw dropped." The article continued, "Richardson didn't savor the idea of going up against a group supported by New York's media elite and spearheaded by a bunch of local celebrities."[36] Hearing of this meeting, Julius Hasting called Richardson's office and asked for an appointment. He was rebuffed.

Less than a month after the meeting with STAR, on November 16, 1999, Richardson announced the permanent closure of HFBR, citing the cost and time it would take to restart the reactor as well as his view that its science could be done at other facilities.[37] Lab officials heard about the decision from the news media. Richardson had aborted a carefully planned restart process; the EIS was still not yet released. The lumbering behemoth bowed to the reality that it had helped create. Brinkley then appeared on talk shows claiming that STAR had been responsible for shutting down HFBR.[38] Richardson came to Long Island to accept an award from STAR from Brinkley herself at a pop concert.[39]

HFBR was terminated not because it was unsafe, but because it was vulnerable. Various subplots contributed in different ways to create this vulnerability. One of the lessons of the HFBR story is the many ways in which, and reasons for which, large scientific projects can become easy targets for various interest groups.

36. *George magazine*, Aug 2000, 81-84, 111-113,
37. *DOE News* (press release), 16 Nov 1999.
38. Barbara Walters, "The View," ABC (6 Aug 2001).
39. *Newsday* (20 Aug 2001), B9.