UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of Commonwealth Edison Company (Dresden Station, Units 2 and 3)	)	Docket Nos. 50-237 50-249

TESTIMONY OF
J. E. DRALEY

Contention 7:

Corrosion

Testimony relative to Commonwealth Edison Company proposed changes to Operating License for Dresden Station Units 2 and 3 by J. E. Draley.

My testimony is in the form of general statements concerning corrosion and related reactions of the stainless steel/Boral storage rack tubes, followed by specific replies to Second Amended Contentions of the State of Illinois, as identified by the NRC Atomic Safety and Licensing Board in the Board's "Memorandum and Order of September 9, 1980." A statement of my professional qualifications is attached, as are the references which appear in this testimony.

GENERAL STATEMENTS CONCERNING CORROSION

A. Corrosion of Type 304 Stainless Steel

In pure water at storage pool temperatures, the uniform corrosion over the surface of austenitic stainless steels such as Type 304 is so slow as to challenge the ability of experimenters to measure it. In fact, I know of no accurate measurement of this corrosion rate. In my judgment the uniform penetration of 304 stainless steel is likely to be less than one ten thousandth of an inch in 40 years exposure to high purity water in Dresden spent fuel storage pools.

Under some circumstances, stainless steels, including Type 304, are susceptible to stress corrosion cracking.

However, there is considerable experience with stainless steel racks and pool liners. No stress corrosion cracking of either has been found in pure water, even in weld-sensitized and residual stress regions,[1] and none is expected to occur in the Dresden pools.

In sufficiently aggressive solutions such as those containing a high concentration of chloride ion, and especially in the presence of crevices, stainless steel has been known to suffer localized attack or pitting. This type of attack has not been observed in storage pool water and is not expected to occur for the lifetime of the Dresden pools.[1]

B. Boral

This product is manufactured by Brooks and Perkins, Inc., and for Dresden Units 2 and 3 consists of about 48% by weight of boron carbide (B_4C) particles embedded in a matrix of commercially pure (1100) aluminum. The size of the B_4C particles is given 60-200 mesh. This boron carbide-aluminum material is formed into a plate, clad with 1100 aluminum on both sides. The same aluminum alloy is inserted between the cladding plates at each end so that the resultant piece, after cutting for use in the racks, is covered on four of the six sides by 1100 aluminum; the side edges are left without cladding.

As in the case of stainless steel, the actual corrosion rates of aluminum alloys such as 1100 are so low

after an initial period of exposure to pure water as to have challenged the skill of experimenters to determine it. In fact our own observations for tests running nearly three years have shown that after an initial period lasting for several days the amount of corrosion increases only very slowly with further exposure times for temperatures of 50°C (122°F) and 70°C (158°F) in pure water. At 70°C, after the inital period, the amount of corrosion has been shown to vary with the logarithm of time for at least two years.[2] The logarithmic intercepts and rate constants published in 1967 by Draley, Mori, and Loess[3] indicate that for storage pool temperatures the amount of uniform corrosion of 1100 aluminum should not exceed one ten-thousandth of an inch in 40 years of exposure in high purity water.

There has been enough testing of the bare edges of Boral in which the aluminum-boron carbide core material and the 1100 aluminum cladding is exposed to show that little or no accelerated corrosion occurs in nearly pure water. For example, Weeks[4] reports no measurable deleterious attack in 19-1/2 years exposure in the Brookhaven Medical Research Reactor.

In nearly pure water such as that in the storage pools no stress corrosion cracking or significant pitting is expected of Boral.

C. Boral-Stainless Steel Couples

When dissimilar metals are held in electrical contact, the corrosion of the metal that is electrochemically more active is sometimes accelerated and the corrosion of the metal that is electrochemically more noble is sometimes retarded. The increased corrosion of the more active metal is known as galvanic attack. In the present instance, 1100 aluminum and the layered Boral product are anodic to or more active than the stainless steel jacket. In deionized water, essentially free of chloride ion, galvanic attack of aluminum coupled to stainless steel is very slight as long as the water purity remains high. Very long time data do not exist; it is judged that the depth of any sites of local galvanic attack that occurs will not exceed a few thousandths of an inch in the 40-year period considered. The explanation for this extremely limited attack is probably related to the limited conductivity of the solution between the cathodic stainless steel and the anodic Boral. It is necessary to have such ionic conductivity in the solution for local galvanic attack to propagate. The near absence of galvanic attack and the expected existence of oxide on the surface make it unlikely that a significant amount of boron carbide will be lost from the edge of the Boral.

REPLY TO CONTENTION

Contention 7: The Application does not adequately assess the possibility of general corrosion and galvanic corrosion in the racks in that:

(A) The life expectancy of the Boral tubes is unsubstantiated.

Reply

On the basis of the corrosion of Boral and Boral-stainless steel couples described above, the life expectancy of the Boral plates and the stainless steel encapsulating tubes is expected to be well in excess of 40 years.

(B) Swelling of the Boral in the tubes and its effect on removal of fuel assemblies have not been analyzed.

Reply

I am aware of two processes that could lead to swelling of the Boral within the stainless steel tubes. In the first, if the quality of the Boral is poor so that there is porosity, there could be a path for permeability of the core material by water. It would then be possible for reaction of this water with the aluminum at some internal place to produce hydrogen gas in quantities sufficient to expand the Boral, as by the formation of an internal blister. The location of such a blister might be some distance beyond that of the water that produced the gas, the hydrogen diffusing ahead of

the water. This type of swelling should be self-limiting, since expansion of the blister should deform the plate enough to allow release of the hydrogen pressure. Gas pressure should not develop inside the stainless steel tubes because of the venting. In the second mechanism some local corrosion of pitting might be induced by galvanic interaction between the aluminum of the Boral and the stainless steel tubes (where the plates are pressed together). The solid corrosion product has a greater volume than that of the corroded metal, and local swelling could result.

With respect to the first process, due to accidentally porous Boral, there has been no experience of this kind of swelling at pool temperatures of commercial grade good quality Boral either in the old formulation (see reference to the material in the Brookhaven Research Reactor above in Section B or in the new formulation, for which there is less extensive experience. It did occur in some tests run by Exxon Nuclear Company[5], using specimens of material, not used commercially, containing quantities of fine boron carbide, of the order of minus 300 to 350 mesh. It was at locations of such fine material that Exxon found the blisters to form. During mechanical testing of this type of material (not in contact with water or aqueous solution), Brooks and Perkins found areas of imperfect bonding between the core and cladding. Specifications for the boron chloride powder (size range) were then set at -60 + 200 mesh, and

no areas of poor bonding were discovered. This is the product that is used commercially. Because of universally good experience with the commercial product and the non-applicability of the Exxon results to such a product, no swelling of this type is expected in the Dresden pool.

Concering the second swelling mechanism, the extent of galvanic corrosion is expected to be limited by limited conductivity of the water or poor electrical contact between the Boral and the stainless steel, which might be caused by naturally occurring oxide films on either metal. If through some unpostulated mechanism galvanic corrosion is not so limited, it is conceivable that the entire thickness of the Boral might be converted to the aluminum corrosion product, a hydrated oxide, expected predominantly to consist of a crystalline form known as bayerite. Using the density of bayerite (2.42), it can be calculated that the corrosion product will occupy a volume some 3.2 times that of the aluminum from which it is formed. For a total Boral thickness of 0.082 inch, the maximum swelling would then be .262 inch, an amount that would not interfere with the movement of normal fuel within storage tubes, since the minimum total clearance in a tube is 0.496 inches. If a channeled fuel assembly is bowed by more than 0.23 inch, and there is a highly improbable local swelling of the type described above, there is a possible impediment to insertion or withdrawal of a fuel element, depending

on the location of the swelling. I have recommended that a periodic mandrel test of unfilled storage tubes be carried out to guard against this unlikely event.

Another possible swelling mechanism for unvented tubes, not involving the swelling of Boral, would be accumulation of entrapped gas between the Boral and the stainless steel tube. Assuming a leak near the bottom, access of solution to the aluminum and the production of some hydrogen as a corrosion product will be allowed. If the resultant gas (perhaps a mixture of the hydrogen and the air originally entrapped during the manufacture of the tube) nearly filled the free space between the Boral and the stainless steel tube, its pressure near the top would be in excess of that outside the tube by an amount that could bulge the stainless steel sheet. This is the mechanism believed to explain the swelling of some tubes in the spent fuel storage pool at the Monticello Plant in 1978. It should not occur at Dresden due to the use of vented tubes.

(C) The corrosion surveillance program will not assure detection of corrosion in the racks because the samples to be inspected will not be representative of the actual tubes in the racks, because the sample environment will not represent pool conditions in and near the racks, and because the program does not require a dummy fuel test shortly before placement of fuel in each tube.

Reply

With a near-zero probability of corrosion that would impair safe utilization of the racks, the surveillance program need not assure by individual accurate measurement or through the use of a dummy fuel element that each tube has suffered no damage at the time it is to be filled with spent fuel. However, I have recommended periodic mandrel testing of the tubes, as described above.

Testing and destructive examination of a number of small vented specimens fabricated of the same Boral as used in the actual storage tubes will show whether the predicted behavior is occurring in the specimens. The behavior of these specimens can then be used to judge the performance of storage tubes. Should circumstances warrant it, one or both of the two full length vented storage tubes suspended in the pool as specimens can be examined for additional information. The corrosion surveillance program is shown in Reference 6.

Experience in the maintenance of the purity of the water in the two storage pools indicates that there have not been extended periods of loss of water quality. It is therefore believed that water quality has been good at all storage locations and will remain that way for at least a great fraction of the time. On this basis, it is believed that the quality

of the water at the specimen location will be representative of storage locations in the same pool.

(D) There is no plan for steps to be taken should corrosion be discovered in the racks. (Am. Cont K; 2nd Am. Cont. 8).

Reply

Since damage to any rack, whether from corrosion or other causes will not be in the nature of a rapidly changing condition, a plan can be made at the time the damage is discovered. Fuel can be loaded in alternative locations if necessary while any problem with the racks is resolved.

REFERENCES

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2. J. E. Draley, Shiro Mori, and R. E. Loess, The Corrossion of 1100 Aluminum in Oxygen-saturated Water at 70°C, J. Electrochemical Society, 110, pp. 622-627 (1963).

3. J. E. Draley, Shiro Mori, and R. E. Loess, The Corrosion of 1100 Aluminum in Water from 50°-90°C, J. Electrochemical Society, 114, pp. 353-354 (1967).

4. BNL-NUREG-25582, J. R. Weeks, Corrosion Considerations in the Use of Boral in Spent Fuel Storage Pool Racks, January 1979 (Brookhaven National Laboratory report).

5. XN-NS-TP-009; Fuel Storage Racks Corroson Program, Boral-Stainless Steel, November 9, 1978 (Exxon Nuclear Company non-proprietary version).

6. Commonwealth Edison Co., "Neutron Absorber Sampling Plan - In Pool," November 4, 1980.

PROFESSIONAL RESUME FOR JOSEPH E. DRALEY

Education

Attended the Catholic University of America, 1935-9, awarded Bachelor of Applied Chemistry degree, 1939.

Attended Catholic University, 1939-42 and 1945-46, awarded Ph.D. degree in Chemistry, 1947.

Professional Career

Metallurgical Laboratory, University of Chicago, 1942-1945.
Group Leader in Technical Division, then in Metallurgy Division, in charge of laboratory investigations in corrosion related to design and development of nuclear reactors. Aqueous corrosion of aluminum, uranium, thorium and their alloys; hydriding of uranium and thorium; formation and deposition of hydrous oxide films.

Kellex Corp., New York City, 1945-46.
Project engineer. Established plan for examination and evaluation of corrosion in gaseous diffusion plant; assisted in making company plans for the future.

Kellex Corp., Applied Physics Lab., Silver Spring, Maryland, 1946-47.
Project Engineer. Assisted in ram-jet development; research on heat transfer in supersonic airflow.

Oak Ridge National Laboratory, Oak Ridge, Tenn., 1947-48.
Metallurgy Division Section Chief in charge of corrosion research activities. Studied aqueous corrosion of beryllium and aluminum.

Argonne National Laboratory, Argonne, Ill., Associate Chemist, 1948; promoted to Senior Chemist, 1955.
Group Leader in Metallurgy Division, in charge of basic corrosion research, 1948-1968 (for applied research also during a part of this period). Corrosion of a number of metals and alloys in water, steam, and oxygen; application of materials to nuclear reactors. Coordinator for the Laboratory's program in sodium technology (Liquid Metal Fast Breeder Reactor Program), 1967-1969. Assistant Manager of the sodium technology program (Chemical Engineering Division), 1970-1971. Member Environmental Statement Project, preparing National Environmental Policy Act impact statements for nuclear power plants, 1971-1974. Ass't. Laboratory Director for Program Planning 1974-1978. Manager, OTEC Biofouling, Corrosion and Materials Project, Materials Science Division, 1978-present. Member, Argonne Senate Committee on Scientific programs, 1968-1972, Chairman 1970-1971. Member, Argonne's CTR (Controlled Thermonuclear Research) Study Group, 1970-1973, Chairman 1972-1973.

Awards:

W. R. Whitney Award (National Association of Corrosion Engineers), 1961, for outstanding contributions to the science of corrosion.

Merit Award of the Chicago Technical Societies Council, 1970, for outstanding technical and social achievements.

PROFESSIONAL RESUME FOR
JOSEPH E. DRALEY (Contd)

Technical Societies:

Member of
American Chemical Society
Electrochemical Society
American Nuclear Society (1969-1978)
Amer. Inst. Min. Met. Pet. Engrs., The Metallurgical Society
Amer. Assn. for the Advancement of Science
Sigma Xi

Chairman, Corrosion Division, Electrochemical Society, 1956-7
Editor, Corrosion Division, Electrochemical Society Journal, 1957-8
Member, Corrosion Resistant Metals Comm., TMS AIME, 1959- , Chairman, 1967-9
Member, Corrosion Research Council, 1963-5
Chairman, Symposium on Corrosion by Liquid Metals, The Met. Soc., 1969

Other Professional Activities:

Originator of periodic AEC Contractor Corrosion Symposia, 1951
Member, Shippingport Fuel Panel, 1953-6
Contributor to International Conferences on the Peaceful Uses of Atomic Energy, Geneva, 1955, 1958, 1964; participated in first and third
Chairman, Gordon Research Conference on Corrosion, 1958
Member, Fluid Fuel Reactors Task Force, 1959
Organizer, International Symposium on Aqueous Corrosion of Reactor Materials, Brussels, 1959
Chief U. S. Delegate to International Atomic Energy Agency meeting on Corrosion of Reactor Materials, Salzburg, 1962
Exchange visitor to Russian Corrosion Chemistry Institutes, 1962
Advisor to Advances in Corrosion Science and Technology since 1965
Consultant to the Atomic Energy Commission on Minimization of River Pollution by Radioactive Effluents, 1966-8
Member, ANL Study Group on Environmental Pollution, 1967
Participant, U. S. - U. K. Libby-Crocroft Exchanges on Corrosion, Harwell, 1967 and Columbus, Ohio, 1968
Chairman, International Conference on Sodium Technology, Argonne, 1968
Invited lecturer at the Workshop on Biofouling at Thermal Power Plants, June 16-17, 1975, Johns Hopkins University
Invited lecturer at the American Chemical Society, the Electrochemical Society, and the National Association of Corrosion Engineers series of lectures on Chemistry in Corrosion, Chicago, IL, March 30, 1976

TECHNICAL PUBLICATIONS OF JOSEPH E. DRALEY

and of Those under His Supervision

(Publications are listed in the order: journal articles--contributions to books and symposia--Manhattan Project and A.E.C. reports)

I. Dissertation for the Ph.D. degree:

Joseph E. Draley, Complex of Cupric Ion with Acetate and Glycinate Ions in Aqueous Solution, the Catholic University of America, 1946.

II. Publications in the Area of the Corrosion of Aluminum and its Alloys by Water:

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S. Mori, R. E. Loess and J. E. Draley: An Eddy Current Gauge for Measuring Al Corrosion; Corrosion, 19, 269t-271t, Aug. 1963.

J. E. Draley, W. E. Ruther, and S. Greenberg: Corrosion Experience with Al Powder Products; J. of Powder Met., 1, 28-41, April 1965.

S. Mori and J. E. Draley: Oxide Dissolution and Its Effect on the Corrosion of 1100 Aluminum in Water at 70°C; J. Electrochem. Soc., 114, 352-353, April 1967.

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R. A. Legault and J. E. Draley: An Electrochemical Study of Aluminum Corrosion in Boiling High Purity Water; Corrosion, 23, 365-370, December 1967.

J. E. Draley and W. E. Ruther: Corrosion of Aluminum and Its Alloys at Elevated Temperatures; Proc. Met. Info. Meeting, Oak Ridge April 11-13, 1955; TID-6502, pp. 669-680 (1960).

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Also in Progress in Nuclear Energy Series, IV, Vol. 2, 1960, Pergamon Press pp. 284-300.

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W. E. Ruther and J. E. Draley: Aluminum Alloy Corrosion; Research Reactor Fuel Element Conf., Gatlinburg, Sept. 17-19, 1962; TID-7642, pp. 601-611.

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CT-3045 R. P. Straetz and J. E. Draley: A Study of the Reaction Rate between Thorium and Purified Hydrogen; June 11, 1945.

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CT-3036 J. W. Arendt, W. W. Binger, J. Hopkins and F. Nelson: Aqueous Corrosion of Thorium and Thorium Alloys; June 23, 1945.

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ANL-5672 W. E. Ruther and W. B. Seefeldt: Aqueous Corrosion of Uranium and Uranium-6w/o Zirconium Alloy; Jan. 1957.

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Professional Qualifications of

Joseph E. Draley

At Argonne National Laboratory I manage the OTEC (Ocean Thermal Energy Conversion) Biofouling, Corrosion, and Materials Project, carrying out a national program for the Department of Energy. In the present instance, testifying before the NRC Licensing Board, I speak on my own behalf and do not represent Argonne National Laboratory. At the Metallurgical Laboratory of the University of Chicago (3 years), Oak Ridge National Laboratory (1-1/2 years), and Argonne National Laboratory (20 years) I studied the corrosion and oxidation of metals, serving as group leader or Section Chief before going into management. A considerable amount of the corrosion work done has been of direct interest for nuclear power plants. I have also studied the environmental impact of nuclear power plants in connection with construction permit or operating license applications. A professional resume is attached, giving these and other details.

Over 150 technical publications have been authored by me or people working in groups I headed. Of these, I was author or coauthor of nearly 100 publications. The preponderant majority of all these publications were on the topic of corrosion or oxidation; many dealt with the aqueous corrosion of aluminum and a smaller number with the aqueous corrosion of stainless steel and zirconium alloys. In a number of instances, publications dealt with nuclear systems. A list of technical publications is attached.

I have been active in corrosion affairs in the Electrochemical Society and the Metallurgical Society of the AIME, serving as Corrosion Division Chairman and corrosion editor of the official journal for the former, and chairman of the Corrosion Resistant Metals Committee of the latter. I helped to originate American Corrosion symposia related to nuclear energy and an international meeting (Brussels, 1959) on the same topic. I participated in the Geneva Conferences on the Peaceful Uses of Atomic Energy.

I hold a bachelor's degree in chemical engineering (1939) and a PhD degree in chemistry (1947).