January 30, 1981



UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

THE ATOMIC SAFETY AND LICENSING BOARD

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| In the Matter of ) | |
| ) | Docket Nos. 50-237-SP |
| COMMONWEALTH EDISON COMPANY ) | 50-249-SP |
| ) | (Spent Fuel Pool |
| (Dresden Station, Units 2 & 3)) | Modification) |

APPLICANT'S SUPPLEMENTAL TESTIMONY
ON FUEL CHANNEL BOWING

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AFFIDAVIT OF DENNIS O'BOYLE

STATE OF ILLINOIS )
) SS.
COUNTY OF C O O K )

I, Dennis O'Boyle, being first duly sworn, state that the attached testimony is true and correct to the best of my knowledge and belief.

Dennis O'Boyle
Dennis O'Boyle

SUBSCRIBED AND SWORN TO
before me this 30th day
of January, 1981

Katherine F. Brenna
Notary Public

# TESTIMONY ON DIMENSIONAL CHANGES OF BWR FUEL CHANNELS AS A RESULT OF IRRADIATION AND ON NON-GE FUEL BUNDLES AND CHANNELS

DENNIS O'BOYLE

## BACKGROUND

My name is Dennis O'Boyle and I am employed by Commonwealth Edison Company in the Nuclear Fuel Services Department. I graduated from Marquette University with a B.S. in Mechanical Engineering and from the University of Wisconsin with an M.S. and a Ph.D. in Metallurgical Engineering and have worked with nuclear fuel materials continuously during the past 15 years. Prior to joining Commonwealth Edison in 1977, I was an Associate Professor of Engineering at the University of Illinois at Urbana. While at the University of Illinois I taught graduate-level courses in nuclear metallurgy and nuclear ceramics. A brief resume of my professional experience is attached to this testimony.

Commonwealth Edison's Nuclear Fuel Services Department, NFS, is responsible for engineering and neutronic analysis for the nuclear fuel in the cores of the Edison reactors. The primary responsibility for the design of the fuel storage racks lies with the Station Nuclear Engineering Department, SNED.

## INTRODUCTION

When a channeled, boiling water reactor fuel assembly is irradiated in the reactor core, normal operational pressure gradients and neutron flux gradients cause the dimensions of the channel to change slightly from the original as-fabricated dimensions. The most significant dimensional changes are a slight bulging of the four channel side walls, and longitudinal channel bowing. The first purpose of this testimony is to review the nature of these dimensional changes and to summarize the results of Commonwealth Edison's recent measurements of irradiated channels at Quad Cities Nuclear Station.

A second purpose of my testimony is to confirm that the fuel channels and fuel bundles provided by manufacturers other than General Electric are similar in design to GE fuel channels and GE fuel bundles and therefore the results given in Mr. Mefford's testimony are applicable to all fuel channels and fuel bundles used at Dresden Units 2 and 3.

BOILING WATER REACTOR FUEL ASSEMBLIES

An overview of boiling water reactor fuel assemblies and their relationship to the reactor control blades and other components in the reactor core is shown in Figure 1.[1/] Fuel assemblies for boiling water reactors consist of two major components, a fuel bundle and a fuel channel. Figure 2 is a sketch of a typical fuel rod and a typical fuel assembly.

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1/ Figure 1 depicts BWR/6 fuel assemblies. Dresden Units 2 and 3 and Quad Cities Units 1 and 2 are BWR/3 reactors. The differences between BWR/3-type and BWR/6-type G.E. reactors are not significant for purposes of this testimony. PWR fuel bundles such as those used at Commonwealth Edison's Zion Station do not have channels.

The fuel bundle shown in Figure 2 contains 64 rods in an 8x8 array, which are held in position by an upper tie plate, a lower tie plate, and seven grid spacers. This 8x8-type fuel bundle is fabricated and delivered to Edison as a single structural unit and is normally handled in the fuel storage pool as a single unit. That is, the individual nuclear fuel rods are not handled separately.

The fuel channel, also illustrated in Figures 1, 2, and 4 is placed over the fuel bundle and completely surrounds the 8x8 array of fuel rods. The fuel channel slides over both the upper tie plate and the lower tie plate and is attached to the upper tie plate by a channel fastener assembly (shown in Figure 3). The fuel channel is about 13-1/2 feet long. It has a square cross section of 5.278-inches (inside diameter) and 0.080-inch wall thickness. The weight of a channeled fuel assembly is approximately 680 lbs., to which the channel contributes approximately 64 lbs. The channel material is a zirconium-base alloy called Zircaloy-4.

In the reactor core the fuel channel performs the following major functions:

a. It forms the outer periphery of the flow path for coolant through the fuel bundle;

b. It provides surfaces to guide insertion and withdrawal of control rod blades between the fuel assemblies;

c. It provides structural stiffness to the fuel bundle;

d. It provides a coolant stagnation envelope for in-core fuel sipping.

Channel-to-channel spacing in the reactor core is maintained by means of two spacer buttons located on the upper portion of the fuel channel, as shown in Figures 1 and 4.

Fuel assemblies are normally stored in the Dresden fuel storage pools with the channels in place. However, channels can be removed in the fuel storage pool and the fuel bundles can be transported and stored in the fuel storage racks without channels.

A BWR fuel channel is much stiffer than the array of fuel rods which it encloses. The "bow," "bulge," and "twist" deformations discussed in this testimony refer to dimensional changes in the channel and are independent of whether or not the channel contains a fuel bundle. Dimensional measurements made on irradiated fuel assemblies have established that the external dimensions of the channel are independent of the specific fuel bundle that is placed in the fuel channel.

FUEL CHANNEL DIMENSIONAL CHANGES DURING IRRADIATION

When a fuel assembly is irradiated in the reactor core, certain physical stresses are placed on the channel and neutron flux gradients occur across the channel walls. Both of these result in small deformations of the channel. The three modes of channel deformation are twist, side-wall bulging, and longitudinal bowing. Measurements and analysis have established that the amount of channel twist is small and does not significantly affect the clearance between the channel and the fuel storage rack.

Channel side-wall bulging occurs as a result of the coolant pressure differential across the channel wall, which produces a slight outward displacement of the four sides of the channel. Because the outward displacement (bulging) of the walls, less than 0.060 inches, is small compared to the overall cross sectional dimension (5.438 inches outer diameter), the cross section of the channel remains essentially square. Side-wall bulge is largest about 4 to 6 feet from the bottom of the channel where the combined effect of in-core pressure differential and fast neutron flux is the greatest. The magnitude of the bulge decreases toward the top of the channel.

The second major deformation process is channel bowing which results in displacement of the mid-elevation of the channel with respect to the upper and lower ends of the channel. In contrast to bulging, the cross-sectional area of the channel at any one elevation is unaffected by bowing. Bowing is a result of fast neutron flux gradients that exist across the walls of a channel when the fuel assembly is placed in specific core locations. Significant channel bowing generally occurs when the channels reside for several cycles of irradiation in locations near the periphery of the core where flux gradients are highest.

When the Dresden high density racks were designed in 1977, channel side-wall bulge was widely considered to be the most important deformation mechanism. As a result of early channel deformation measurements made at other utilities, it became apparent that channel bow could also be an important deformation mechanism, depending on the in-core location and exposure history of the channel. Channel bulge and bowing were recognized and measured because these deformations, if great enough, might interfere with insertion of control blades into the reactor.

## CHANNEL DEFORMATION MEASUREMENTS AT COMMONWEALTH EDISON

In 1977 GE issued certain recommendations limiting the exposure of BWR fuel channels to 33,000 Megawatt

Days per Standard Ton. In 1979 GE made further recommendations relating to the location history of fuel channels in the reactor core. The purpose of these recommendations was to eliminate the potential of interference between the channels and the reactor control blades. After reviewing the early channel deformation data obtained by other utilities, I concluded that the G.E. recommendations limiting channel exposure were unnecessarily conservative. To extend the useful lifetime of channels, upon my recommendation, Edison decided to purchase a channel measuring system and to measure the dimensions of several hundred irradiated channels. Thus, the motivation for performing channel deformation measurements was related to in-core channel performance and was unrelated to fuel storage rack requirements.

In October, 1979, a specification was written for a channel measuring system, which was then submitted for outside bids. A measuring system was purchased from General Electric Company in April, 1980. This system, which was the first commercial system built by GE, was delivered to Quad Cities Nuclear Station in May, 1980. Set up and initial testing of the channel measuring system was completed in June, 1980, and the first measurements of irradiated channels were made at Quad Cities in late June.

Between July and November of 1980, three separate groups of irradiated channels were measured in the Quad Cities fuel storage pool.

1. Prior to the Quad Cities 1 end-of-cycle 5 outage, 272 channels were measured.
2. During the Quad Cities 1 end-of-cycle 5 outage, an additional 377 channels were measured.
3. During November, 1980, 226 channels, which were on fuel that was removed from the core at the end-of-cycle 5, were measured.

Thus, a total of 875 irradiated channels were measured. This program to document the deformation of irradiated channels was the most extensive channel measuring program ever conducted by a U.S. utility. Since the design of the channels in use at Quad Cities and at Dresden is identical, and the reactors are both BWR-3 types, the Quad Cities measurement results apply directly to Dresden fuel channels.

When the results of these measurements started to become available, my associate in NFS, Ed Armstrong, and I recognized that large channel bow could result in some interference with the storage locations in the high density fuel storage racks, especially if the storage racks were fabricated to the minimum dimensions allowed by the engineering drawings. For this reason, this matter was disclosed to the other parties in the Dresden spent fuel rack proceeding and brought to the attention of the Board.

RESULTS OF THE CHANNEL DEFORMATION MEASUREMENTS

For the purpose of evaluating the fit of the irradiated channels in the high density fuel storage racks, a computer program was written to reanalyze the channel data. This reanalysis, which was done during the first week of December, 1980, was necessary because the criteria for possible channel interference with the fuel storage racks was different than the criteria for continued in-core use of the fuel channels.

A total of 1736 channel sides were measured and the data recorded with the channel measuring system. Approximately 86% of the channel sides had a total deformation (bow plus bulge) of less than 0.150 inches over the 162.2 inch length of the channel. 94.5% of the sides had a bow plus bulge deformation of less than 0.200 inches. Less than 1% (15) of the surfaces measured had a total bow plus bulge deformation of greater than 0.300 inches. Of these, one channel side showed bow plus bulge of 0.420 inches and one other side showed bow plus bulge of 0.390 inches. The remaining 13 channel surfaces had total bow plus bulge of less than 0.350 inches.

A review of the irradiation history and in-core locations was made of the 15 channels having the largest in-core deformation (greater than 0.300-inches). Most of these channels were loaded into the peripheral core region where the fast neutron flux gradient was the largest. In view of these observations, an effective method to mitigate large in-core channel deformation is to control the number of cycles that a channel is irradiated in a peripheral core location.

## FUTURE TRENDS IN CHANNEL BOW

Since the existing fuel channels were purchased, several major changes have occurred in channel design and in operations that are expected to decrease the probability of channels developing large deformation during irradiation. Some of these changes are:

1. Heat treatment and fabrication processes for BWR fuel channels have been changed by the manufacturers to produce channels that are expected to be more dimensionally stable under irradiation. Starting in 1980, these new fuel channels were delivered to Quad Cities and Dresden for use in future cycles.
2. The fuel channel measurements that were made at Quad Cities during 1980 resulted in the removal

of channels having large deformations from the reactor core. The channel measuring system has been shipped to Dresden Nuclear Station and during the Dresden Unit 2 outage which ends in May, 1981, we plan to measure all of the Dresden-2 irradiated channels that will be returned to the reactor for additional service. Channels having deformations over 0.125-inches (bow plus bulge) will not be returned for additional use. We plan to do similar measurements on Dresden Unit 3 fuel channels during the refueling outage in 1982, although in view of the rapidly increasing data base it may not be necessary to measure every channel. This culling process will reduce the possibility of propagation of large channel deformations in future cycles.

3. In the future the effect of in-core location on channel bowing will be one consideration used by nuclear core designers in selecting in-core locations so that bowing is not compounded by multi-cycle irradiation on the core periphery.

Thus, I believe that the results of Commonwealth Edison's channel deformation measurement program described above are a reasonable data base to use in addressing the possible extent of such channel deformations at Dresden in the future. Furthermore, for the reasons stated above, I believe that the magnitude of in-core channel deformation will decrease in future cycles.

Non-G.E. Fuel Bundles and Channels

The above discussion of fuel assembly design and channel dimensional measurements applies to fuel bundles and channels supplied by General Electric Company. Recently Commonwealth Edison has purchased fuel bundles from Exxon Nuclear Company (Exxon) and fuel channels from Carpenter Technology Corporation (CarTech). These CarTech fuel channels will be inserted in Dresden-2 starting this year. The final design package for the Exxon fuel bundles was received by Edison in late November, 1980 and the first Exxon bundles are scheduled to be irradiated in D-3 starting in May, 1982. Details of the Exxon fuel bundle design and the CarTech channel design are proprietary and therefore have not been provided to Mr. Mefford of General Electric for his review.

I have reviewed the design of both the Exxon fuel bundles and the CarTech channels and have compared the critical component dimensions and component materials to those used in General Electric fuel assemblies. The materials used in the upper tie plates of the G.E. and Exxon fuel bundles are nearly identical and the designs are similar. The materials and dimensions of the G.E. and CarTech channels are nearly identical. Based on my design review of the CarTech channels and the Exxon fuel bundles, I conclude that the loads that these components can withstand are not significantly different than similar components supplied by General Electric Company.

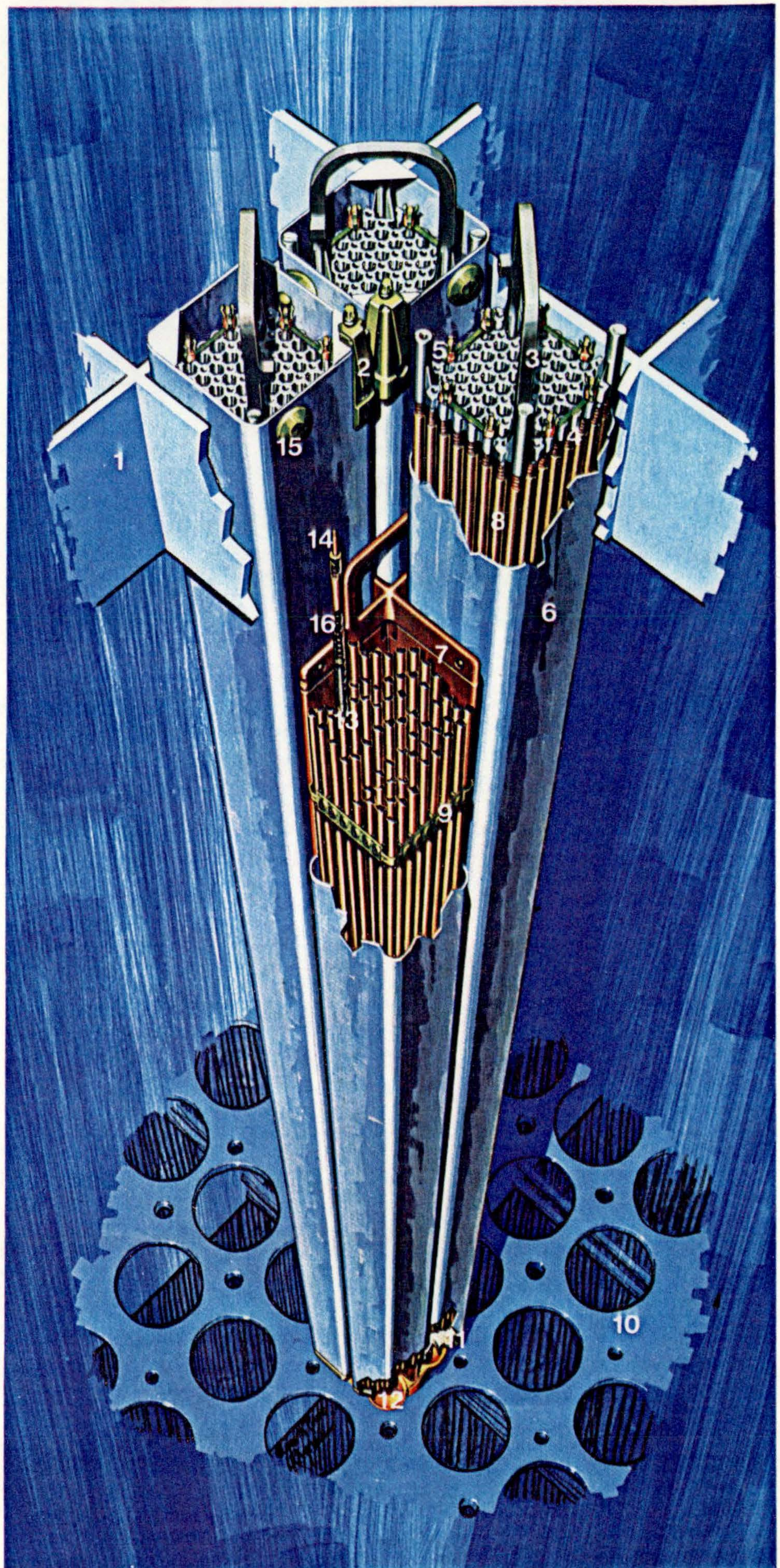
The GE-designed channel fastener assembly will be used with the non-GE fuel bundles and channels, so Mr. Mefford's testimony with respect to the safety of this component applies.

Based on this comparative design review and materials evaluation, I am confident that Mr. Mefford's conclusions also apply to the non-GE Fuel assemblies and fuel channels. Therefore, I believe that the worst possible interferences between any bowed fuel channel and the high density racks will not present any safety problem with respect to any fuel assemblies or fuel channels used by Edison at Dresden Units 2 and 3.

# BWR/6 FUEL ASSEMBLIES & CONTROL ROD MODULE

1. TOP FUEL GUIDE
2. CHANNEL FASTENER
3. UPPER TIE PLATE
4. EXPANSION SPRING
5. LOCKING TAB
6. CHANNEL
7. CONTROL ROD
8. FUEL ROD
9. SPACER
10. CORE PLATE ASSEMBLY
11. LOWER TIE PLATE
12. FUEL SUPPORT PIECE
13. FUEL PELLETS
14. END PLUG
15. CHANNEL SPACER
16. PLENUM SPRING

GENERAL ELECTRIC



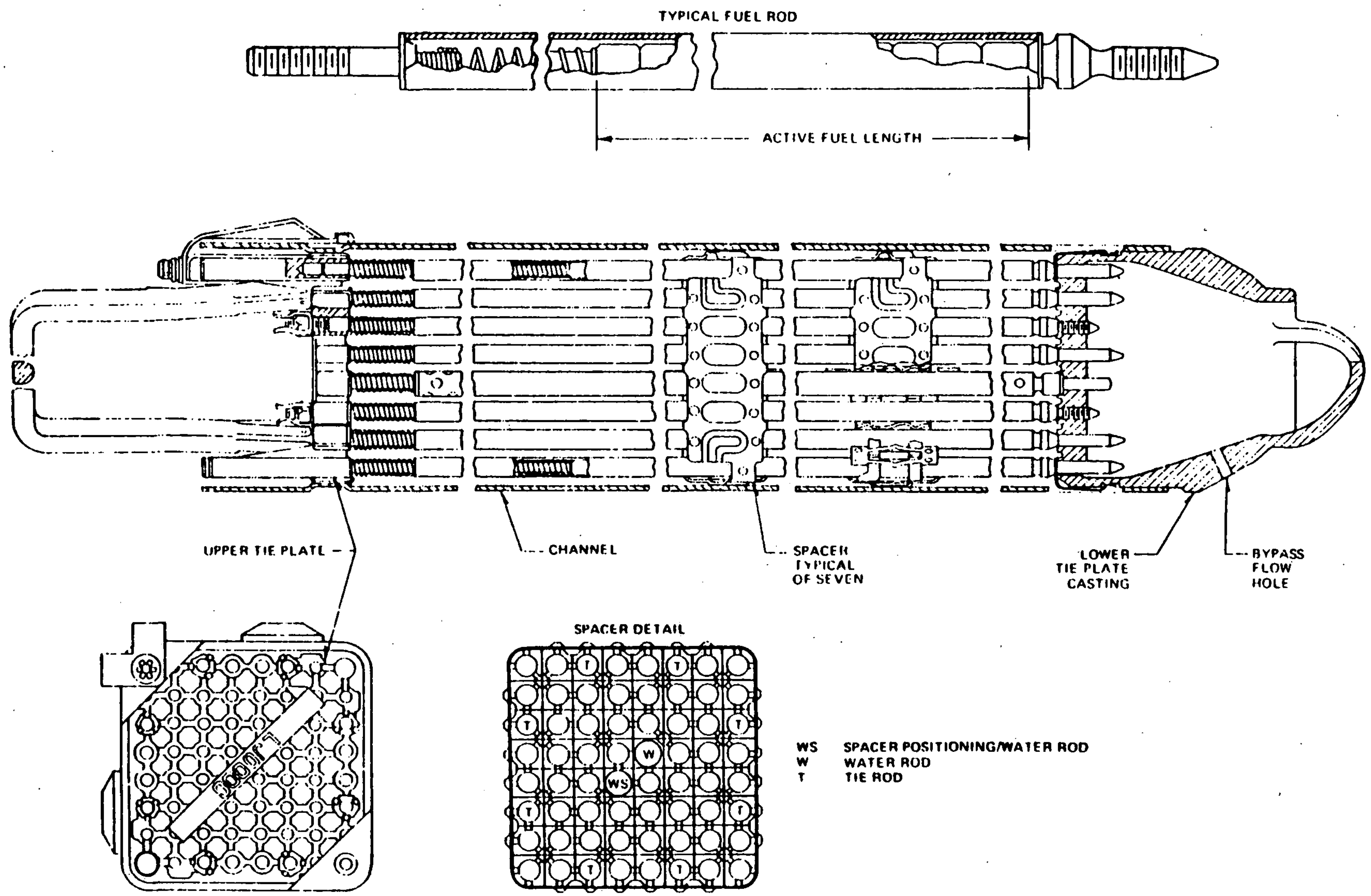



Fig. 2 8x8R and P8x8R Fuel Assemblies

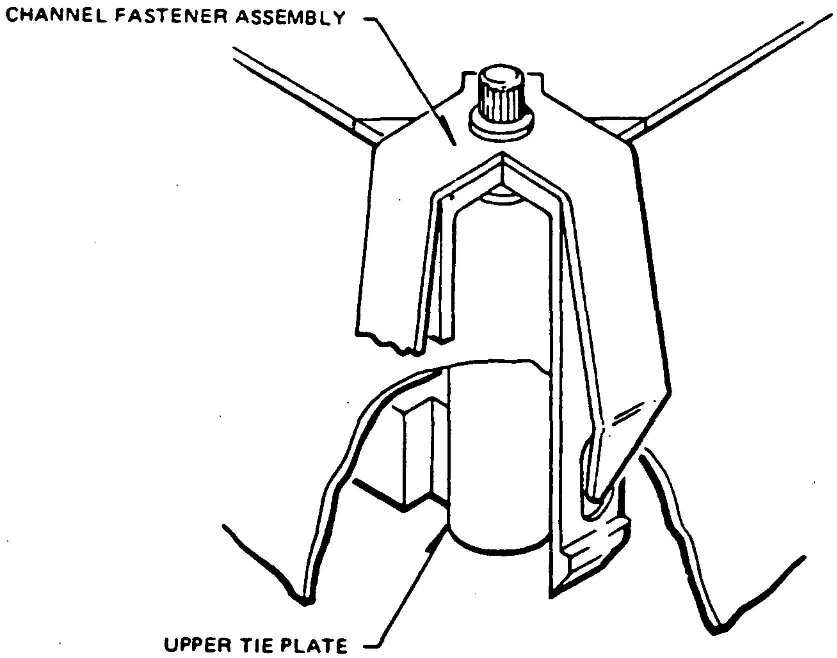



Fig. 3 Channel Fastener Assembly

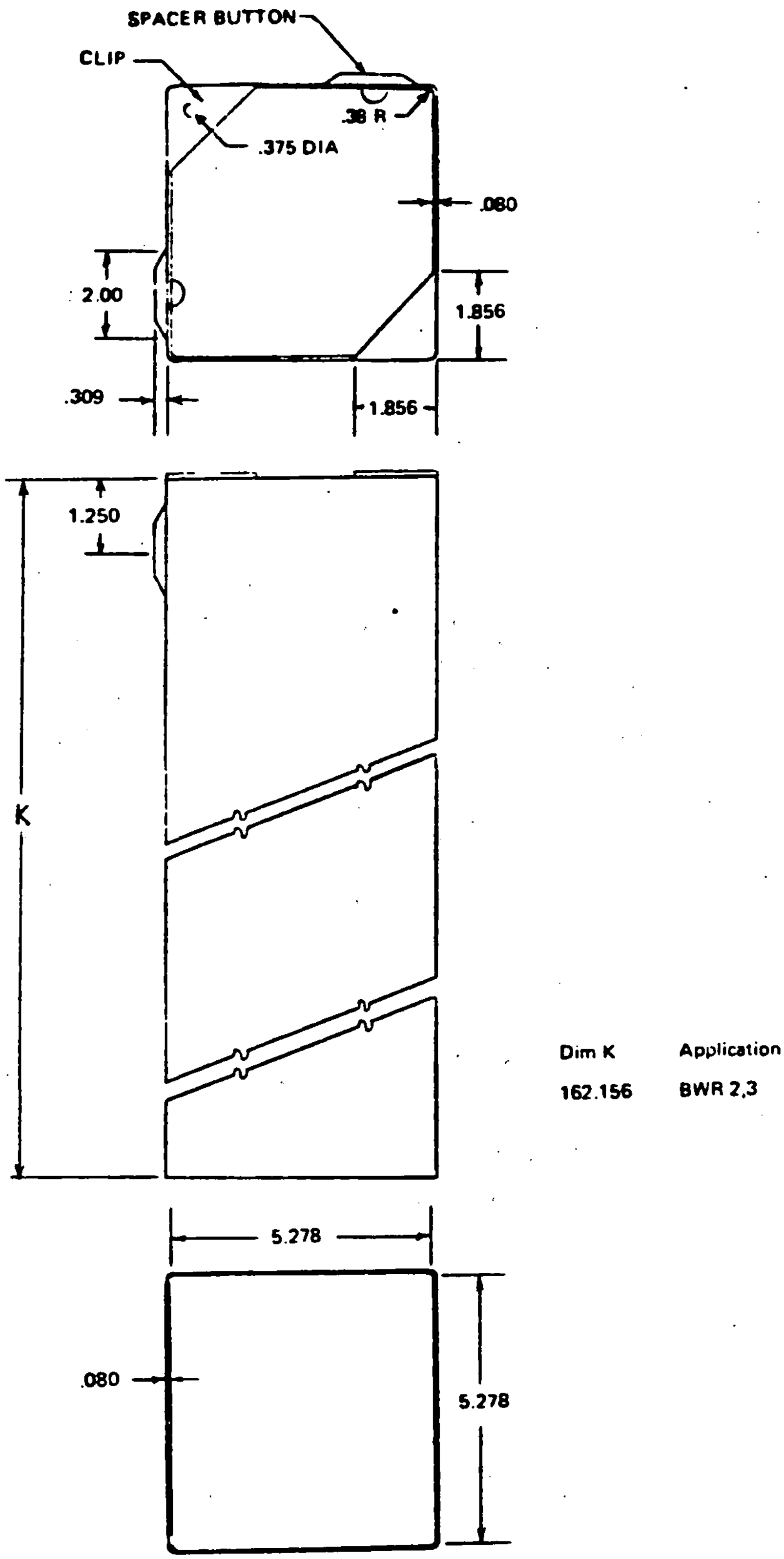



Fig. 4 Nominal Dimensions of a Typical 80 mil Fuel Channel

DENNIS O'BOYLE

Present Position:

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Responsible for nuclear fuel performance evaluation, fuel development programs, special nuclear fuel tests, and core materials performance.

Previous Experience:

June 73 to May 77 — Associate Professor
Departments of Ceramic Engineering and Nuclear Engineering
University of Illinois
Urbana, Illinois

Directed graduate research and taught advanced undergraduate and graduate courses in Nuclear Ceramics and Nuclear Metallurgy.

August 72 to June 73 — Visiting Associate Professor
Departments of Nuclear Engineering and Metallurgical Engineering
University of Wisconsin
Madison, Wisconsin

Taught courses in nuclear materials.

June 65 to August 72 — Group Leader
Argonne National Laboratory
Argonne, Illinois

Research Interests: Properties of ceramic nuclear fuels, fission-product behavior, electron probe analysis.

Education:

| | | |
|---|---|---|
| B.S. ME | Marquette University | June 1960 |
| M.S. Met.E. | University of Wisconsin | Aug. 1962 |
| Ph.D. | University of Wisconsin | June 1965 |

Publications

Over fourty technical publications dealing mainly with the properties and performance of nuclear fuel materials.

Registered Professional Engineer in Wisconsin and Illinois.

Professional Societies:

American Institute of Mining, Metallurgical, and Petroleum Engineers
American Nuclear Society
American Society for Metals
Electron Probe Analysis Society of America
The Scientific Research Society of America
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Consulting Activities:

Institute of Atomic Energy, Sao Paulo, Brazil
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Swiss Institute for Reactor Research, Würenlingen, Switzerland