50-269

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Babcock & Wilcox Company

Working Together to Economically Provide Reliable and Safe Electrical Power

September 16, 1985

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Mr. C. O. Thomas, Chief
Standardization and Special Projects Branch
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Attachment: Letter, J. H. Taylor to David Moran dated September 6, 1985

Dear Mr. Thomas:

The attached letter requesting NRC review of BAW-1875 "The B&W Owners Group Cavity Dosimetry Program" was inadvertently addressed to the incorrect individual at the NRC.

Please take the necessary actions to assure that BAW-1875 receives a timely review.

Should you have any questions, please contact Mr. C. J. Hudson at (804) 385-2550.

Very truly yours,

CJHudson for

J. H. Taylor
Manager
Licensing Services

JHT/fw

cc: w/o attachment

B. J. Elliot - NRC
L. Lois - NRC
P. N. Randall - NRC
G. Vissing - NRC

G006
1/1

BAW-1875

August 1985

THE B&W OWNERS GROUP

MATERIALS COMMITTEE

The B&W Owners Group Cavity Dosimetry Program

Babcock & Wilcox
a McDermott company

BAW-1875

August 1985

The B&W Owners Group Cavity Dosimetry Program

by
S. Q. King

Prepared for

B&W Owners Group Materials Committee
Arkansas Power & Light Company
Duke Power Company
Florida Power Company
GPU Nuclear
Sacramento Municipal Utility District
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INTRODUCTION

The Cavity Dosimetry Program[1] to be performed by the B&W Owners Group responds to NRC requirements that commerical nuclear plants monitor reactor vessel neutron fluence throughout the vessel lifetimes. The Cavity Dosimetry Program will include two experiments-the Flux Perturbation Study and the Cavity Dosimetry Benchmark[1]-to demonstrate the effectiveness of ex-vessel dosimetry and to provide data upon which to develop and benchmark a method by which cavity dosimetry can be used to predict reactor vessel fluence. The program will produce a demonstrated technology for application to plant-specific cavity dosimetry installation to allow continuous monitoring of actual fluence and updating of the predicted fluence for each reactor vessel.

2. Background

The Reactor Vessel Surveillance Program (RVSP)[1] became a requirement in the early 1970's when it was determined that significant differences occurred in the neutron embrittlement sensitivity of various steels and weldments used in reactor vessel fabrications. The applicable regulations are published in Appendix H of 10.CFR.50. In addition, American Society for Testing and Materials (ASTM) Standard E-185 supports the requirements of 10.CFR.50, Appendix H, "Reactor Vessel Material Surveillance Program Requirements" through a cooperative effort between the standards development committee and the NRC.

(1) see page 21

Today, the regulatory requirements of Appendix H in conjunction with 10 CFR 50 Appendix G, "Fracture Toughness Requirements" are recognized throughout the nuclear industry as the standards and procedures for ensuring the integrity of reactor pressure vessels subjected to neutron irradiation during service. The B&WOG, through the Integrated Reactor Vessel Surveillance Program (IRVSP), has followed these procedures and regulations and consequently has obtained an increasingly accurate knowledge of the condition of each reactor vessel in the IRVSP.

The condition of a pressure vessel can be ascertained at any point in plant life by knowing the accumulated fluence and the relationship between fluence and material toughness degradation. During the time that the RVSP is in effect, both of these factors are known; the fluence is measured by in-vessel dosimetry and the effect of the fluence on pressure vessel steel is obtained before the actual steel receives that level of fluence. With completion of the RVSP, the damage function will have been established but monitoring of the vessel fluence will cease unless it is provided by some other method.

It is anticipated that all of the empirical data needed to determine the relationship between accumulated neutron fluence and relevant material properties for the B&W 177 FA plants will have been collected by the early 1990's. Determining this relationship is, of course, the primary objective of the RVSP; once it has

been established, the RVSP may be considered to be complete. The RVSP has a secondary objective which is the indirect measurement of the fast neutron fluence on and through the pressure vessel. Since this fluence monitoring will stop with the completion of the RVSP, and there are reasons to continue to monitor neutron fluence over the life of the vessel, the B&WOG has developed the Cavity Dosimetry Program, designed for that purpose.

The B&WOG Cavity Dosimetry Program will develop the technology necessary for the installation of neutron dosimetry for placement in the cavity of the B&W-designed 177FA reactors to monitor fluence indefinitely. At present, it is planned that this dosimetry will consist of Solid State Track Recorders (SSTR's), installed in special holders in the reactor cavity. This cavity-installed SSTR dosimetry has a number of advantages over capsule-contained Radiometric Material (RM) dosimetry:

(a) The relative ease of installation and removal of the dosimeters allows for frequent fluence measurements.

(b) Effect on refueling outage time is minimized; the dosimetry installation and removal operations are not carried out over the fuel, i.e. the Reactor Vessel head is in place.

(c) Irradiated dosimeters (SSTRs) do not become significantly activated and thus are not radioactive. Handling and shipping is routine and thus less expensive.

(d) SSTR Dosimeter data do not decay; thus prompt counting is not mandatory.

Before cavity dosimetry can be used to monitor vessel fluence, however, it needs to be demonstrated in a B&W plant configuration. Experience to date, by HEDL and others, has generally been positive. Thus, the primary intent of this paper is to explain the Cavity Dosimetry Benchmark Experiment, and how the results will be used to establish an accurate method to determine vessel fluence from a knowledge of cavity fluence.

The important points of the preceeding discussion are restated below. The Reactor Vessel Surveillance Program has two purposes: determination of the relationship between fluence and material damage and the monitoring of the accumulation of vessel fluence. Between the time the RVSP ends and plant EOL, another method is needed to monitor vessel fluence. The method proposed by the B&W Owners Group for the surveillance of long-term vessel fluence is the Cavity Dosimetry Program. The Cavity Dosimetry Program provides the technology necessary for long term surveillance of reactor vessel fluence.

3. The B&WOG CAVITY DOSIMETRY PROGRAM

The determination of vessel fluence from measurements is a semi-empirical process. This is because there is no known way to measure vessel fluence directly. It can be measured indirectly, however, by first measuring a quantity that has a determinable

or known relationship to vessel fluence and then calculating the vessel fluence through this known relationship. The measureable quantity that is most often used in vessel fluence determination (at the present time) is the activity of a foil or wire dosimeter. The dosimeter, with precisely known constituents and mass, is irradiated for a known length of time in a surveillance capsule. The capsule is located inside the Reactor Vessel (downcomer). The neutron-sensitive elements in the dosimeter become activated through various neutron absorption events occurring at a rate that is proportional to the incident neutron flux. The activity of the dosimeter after irradiation is related to the time-integrated neutron flux, or fluence, to which it has been exposed. The relationship between the fluence and the activity can be complicated depending on the dosimeter material, but methods have been developed that allow the determination of capsule fluence from dosimeter activity. The capsule fluence is not the vessel fluence, however, and the relationship between the two is complex. The 2-D transport code, DOT-IV, is used to simultaneously calculate the vessel flux, the capsule flux, and the saturated dosimeter activity. Using the DOT-IV results with the evaluated dosimeter data and the power history of the reactor, the vessel fluence is calculated. This process is used to determine vessel fluence using in-vessel dosimetry measurements.

A very similar procedure can be used to determine vessel fluence using ex-vessel dosimetry measurements, i.e. cavity-installed

dosimetry. The Cavity Dosimetry Program provides the methodology to determine the vessel fluence based on measured fluence in the cavity; this methodology, called the "Semiempirical Method", is described in detail on pages 13 and 14 and in Figure 4. For either in-vessel dosimetry or ex-vessel dosimetry, actual measurements are taken at only one location, yet knowledge of the fluence is required at numerous locations (such as to calculate the flux gradient through the vessel wall at the maximum azimuthal location). The accuracy of the prediction of the vessel flux depends on the accuracy of the DOT-IV analysis that relates the flux in the vessel to the flux at the dosimeter location. Accurate predictions of cavity flux are more difficult than in-vessel flux predictions because the problem is geometrically more complex compounded by the effects of cavity streaming. Accurate predictions are possible however, and they will be ensured by the use of an iterative refinement of the analytical model using the results of the Cavity Dosimetry Benchmark Experiment (In-Out Experiment).

The important points of the preceeding discussion are restated below. Monitoring vessel fluence is a process involving the indirect measurement of fluence at a single point and the application of benchmarked analytical procedures to result in energy and space dependent neutron fluence at numerous locations of interest.

The use of cavity dosimetry in the process requires that the analytical model be developed and refined using the results of the ex-vessel benchmark.

3.1 **Structure of the Cavity Dosimetry Program**

The Cavity Dosimetry Program consists of the development of a method to determine the vessel fluence using the results of cavity dosimetry measurements as outlined in Figure (1). The results of the program (semiempirical method-block 22 of Figure 1) will be the subject of a topical report that will be submitted for NRC review (block 23). Dosimetry and mounting hardware will be designed and installed in the cavity of the Davis Besse Reactor as shown in blocks (1-6) of Figure (1). After irradiation through cycle (6) (block 7) the dosimetry will be counted by various organizations followed by an initial B&W analysis of the results (blocks 8-11). All organizations concerned will be involved in refining the data and resolving discrepancies to result in the final "measured" set of dosimeter activities, (blocks 12-14). In parallel, B&W will develop a set of "calculated" dosimeter activities using the analytical methods shown in blocks (15-18) (and in more detail in Figure (3)). The calculated results will be compared to the measured results followed by iterations on the calculations as necessary as shown in blocks (19-22), resulting in the final form of the semiempirical method, described in section 3.2.

3.2 CAVITY DOSIMETRY BENCHMARK EXPERIMENT

The Cavity Dosimetry Benchmark Experiment (In-Out Experiment) features a full scale test in a B&W-designed reactor using ex-vessel and in-vessel measurements. Dosimetry will be supplied by four contributors to the program as shown in Table (1).

The objectives of the program are to: (1) obtain measured fluence spectra at numerous locations at full scale to develop an optimum analytical model for the prediction of vessel fluence, and (2) assess the calculational and dosimetric uncertainties in the determination of vessel fluence. The experiment also allows estimation of the accuracy of SSTR's by comparison to other types of dosimeters (particularly RM's), and measurement of the axial neutron flux profile in the cavity. Data will also be taken on cavity gamma flux for assessment of effects of photofission events on experimental results.

Fifteen dosimetry holders will be installed in the cavity of the host reactor as shown in Figure (2). Each holder has provision for five dosimeters (or sets of dosimeters) for a total capacity of 75 dosimeters (sets). At least two types of passive neutron detectors are planned to be used: RM's, and SSTR's. In addition, the installation of Paired Uranium Detectors is planned. The threshold energies for the RM's cover the range from .5 eV to 2.5 MeV. Additionally, about twelve passive gamma detectors will be installed (LiF chips).

TABLE (1)

CAVITY DOSIMETRY

DOSIMETRY CONTRIBUTOR OR OWNER	LOCATION OF DOSIMETER PACKAGE	TYPE OF DOSIMETER[(a)]	COMMENTS[(b)]
Babcock & Wilcox Owners Group (B&WOG)	6°-mid pl	RM,SSTR,LiF	Azimuthal n+γ fluence Distribution
	11°-mid pl	" " "	Azimuthal dist
	11.5°-mid pl	" " PUD	Fluence using alt. method
	-up. act. fuel	" " LiF	Axial n + γ fluence Dist.
	-nozzle	" " PUD	Axial n + γ fluence Dist. alt. method
	-seal plate	" " LiF	Axial n +γ fluence Dist.
	26.5°-mid pl	RM, LIF	Azimuthal n + γ fluence dist.
	42.5°-mid pl	RM,SSTR,LiF	Azimuthal n + γ fluence dist.
Hanford Engineering Dev. Lab. (HEDL)	6°-mid pl 11.5°-mid pl -up act fuel -nozzle 42.5°-mid pl	RM,SSTR,LiF " " " " " " " " " " " "	Independent measurements at same locations as most of the B&WOG dosimetry
University of Arkansas (U of A)	11°-mid pl -over cavity height	RM Stainless Steel Chain	Independent measurement at 11° axial dist. at 11°
National Bureau of Standards (NBS)	All locations 11.5°-mid pl -nozzle	LiF PUD PUD	measure gamma fluence alt. meas. method for neutron fluence

Notes

(a) RM: Radiometric Monitor
SSTR: Solid State Track Recorder
LiF: Lithium Flouride Detector
PUD: Paired Uranium Detector

(b) Overall purposes are to develop a 3-D distribution of cavity fluence, determine accuracy of SSTR's, and measure neutron and gamma spectra.

In-vessel dosimetry will include a normal, unirradiated surveillance capsule, installed in the spare surveillance capsule holder tube at 11.5 degrees. The capsule will contain six neutron-sensitive elements (RM's) covering incident neutron threshold energies from 0.5 eV to 2.5 MeV.

The azimuthal locations of the dosimeter strings were chosen to avoid areas of possibly large flux gradients where it is difficult to predict the neutron flux analytically. Three strings have been located in the region of maximum flux (6^{o}, 11^{o}, and 11.5^{o}) and one is in the region of minimum flux (42.5^{o}). The 11^{o} string will include a beaded stainless steel chain for measurement of the axial flux gradient. Additionally, a string at 26.5^{o} is being installed.

The 75 sets of ex-vessel dosimetry and the in-vessel surveillance capsule will be irradiated for the duration of a single cycle. Following shutdown, the dosimetry will be removed and analyzed using gamma spectroscopy or fission track counting (as appropriate). The resulting data will provide measured fluence near the inside and outside vessel surfaces which will be used to benchmark an analytically-determined fluence distribution in the vessel. Data comparisons will be made to establish that the results are appropriately consistent. The comparisons will be made in such a way that the experimental uncertainty due to counting and analysis will be minimized, i.e. some of the dosimetry will

be independently counted by each of the contributors in a round-robin approach. Each of the four contributing organizations, Babcock & Wilcox, Hanford Engineering Development Laboratory, University of Arkansas, and National Bureau of Standards, has the capability to analyze Radioactive Monitors and Paired Uranium Detectors. Each supplier will be involved in the analysis of not only his own dosimetry but also the dosimetry of some (or all) of the other contributors. The B&W Owners Group will plan, coordinate, and supervise the round-robin effort. The internal comparisons that will be made include: (1) RM's to RM's, (2) activation RMs to fission RMs, (3) SSTRs to RMs, (4) PUDs to RMs, (5) PUDs to SSTRs, (6) SS chain to nearby RMs, and (7) cycle 5 capsule RM results to In-Vessel RMs.

The effects of axial neutron streaming on the prediction of cavity fluence at the mid plane will be investigated by comparing benchmarked DOT-IV results for the axial plane (r,z) with benchmarked DOT-IV results for the azimuthal plane (r,) at the mid plane.

The evaluated results of the IN-OUT Experiment will be used to iteratively develop a final analytical procedure to be used in prediction of vessel fluence from cavity dosimetry measurements (the Semiempirical Method), as shown in Figure (3).

The effect of various DOT-IV input parameters on the flux will be investigated and optimized in the model development process,

including energy group structure, angular quadrature, cross-sections, and interval size. This process will help to determine which of these parameters are important in calculation of fast flux in the cavity. The final form of the Semiempirical Method will depend on the results of the iterative procedure. It will include a calculational procedure similar to the flow chart in Figure (4), but may also contain a set of instructions or recommendations for the user as well as correction factors or analytical procedures for application to input or output or both. It is recognized that cavity configurations differ, but the effect of these differences will be accounted for by continued refinement of the Semiempirical Method on a case by case basis in the Plant Specific Program. Results and methodology will be be submitted as a Topical Report for NRC approval.

The Semiempirical Method is the process by which the vessel fluence can be determined using the results of analytical procedures that have been normalized to measured data. The method will provide the space-and energy-dependent neutron fluence in the pressure vessel using the two-dimensional transport code DOT-IV. The Semiempirical Method shown in Figure (4) will now be described in detail. The reader should refer to Figure (4) in reading the following. The time span over which the final vessel fluence (Block 18) is integrated must be the same time span covered by the Power History (Block 6) and the series of power distributions (Block 1). The time weighted average neutron source as a function

of energy and position (Block 3) is calculated as follows. First the time-weighted average power distribution is determined and then applied to the normalized fission spectrum. This quantity is then multiplied by the power density and other factors to yield the distributed source in neutrons per cubic centimeter per second, which is input directly to DOT-IV.

The cross sections (Block 5) are macroscopic energy dependent material cross sections produced from microscopic data using standard techniques. The DOT-IV analysis will incorporate cylindrical geometry, an accurate scattering algorithm, and 48 scattering angles*.

The final DOT run will calculate the energy-dependent neutron flux as a function of position in the vessel and at the dosimetry location. Using the power history and the flux, the fast fluence is calculated at all locations of interest. The fluence (or reaction rate) at the dosimeter location is compared to the calculated fluence (Block 16) and a normalization factor is computed. This normalization factor along with any correction factors from the experiments will be applied to the vessel fluence (Block 19) to obtain the final normalized vessel fluence.

The Semiempirical Method, that has just been described, is applicable for all B&W 177 reactors. Some of the constants or correction

*Present plan is to use P_3S8 for initial runs.

factors (Block 14 Figure 4) will be different for different reactors, due primarily to differing cavity configurations, but the basic process is the same in each case.

3.3 **Plant Specific Program**

A knowledge of the accumulated vessel fluence as a function of time is required in order to predict the vessel material degradation from some given time. The accuracy of the prediction is influenced by the number of points on the fluence vs. time curve. It therefore is desirable to maximize the number of "measured" (fluence, time) pairs.

Additionally, it is prudent to reserve a few specially prepared dosimeters for recording integrated vessel fluence over the 40 year life and preferably beyond that. These dedicated dosimeters would be important to plant life extension and because they would provide the only actual measurement of fluence for long irradiation times.

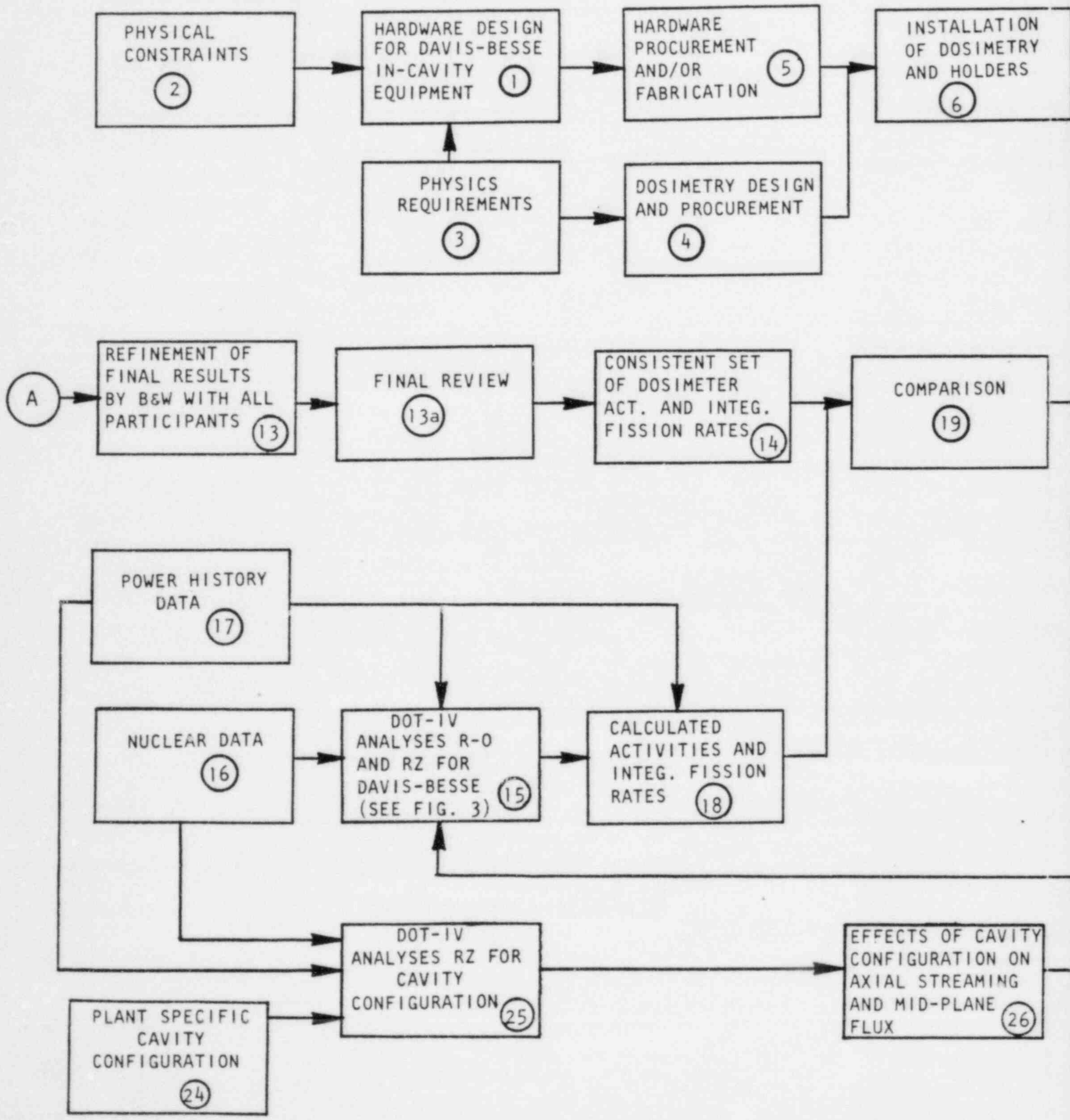
Both of these objectives, frequent short term (1-2 years) fluence determinations and a few long term (4 years or more) fluence recordings could be accomplished with the employment of a plant specific Cavity Dosimetry Program. The detailed plan for installation and removal of dosimeters would be addressed individually by the licensee at a time consistent with the results of the IN-OUT experiment.

4. CONCLUSIONS

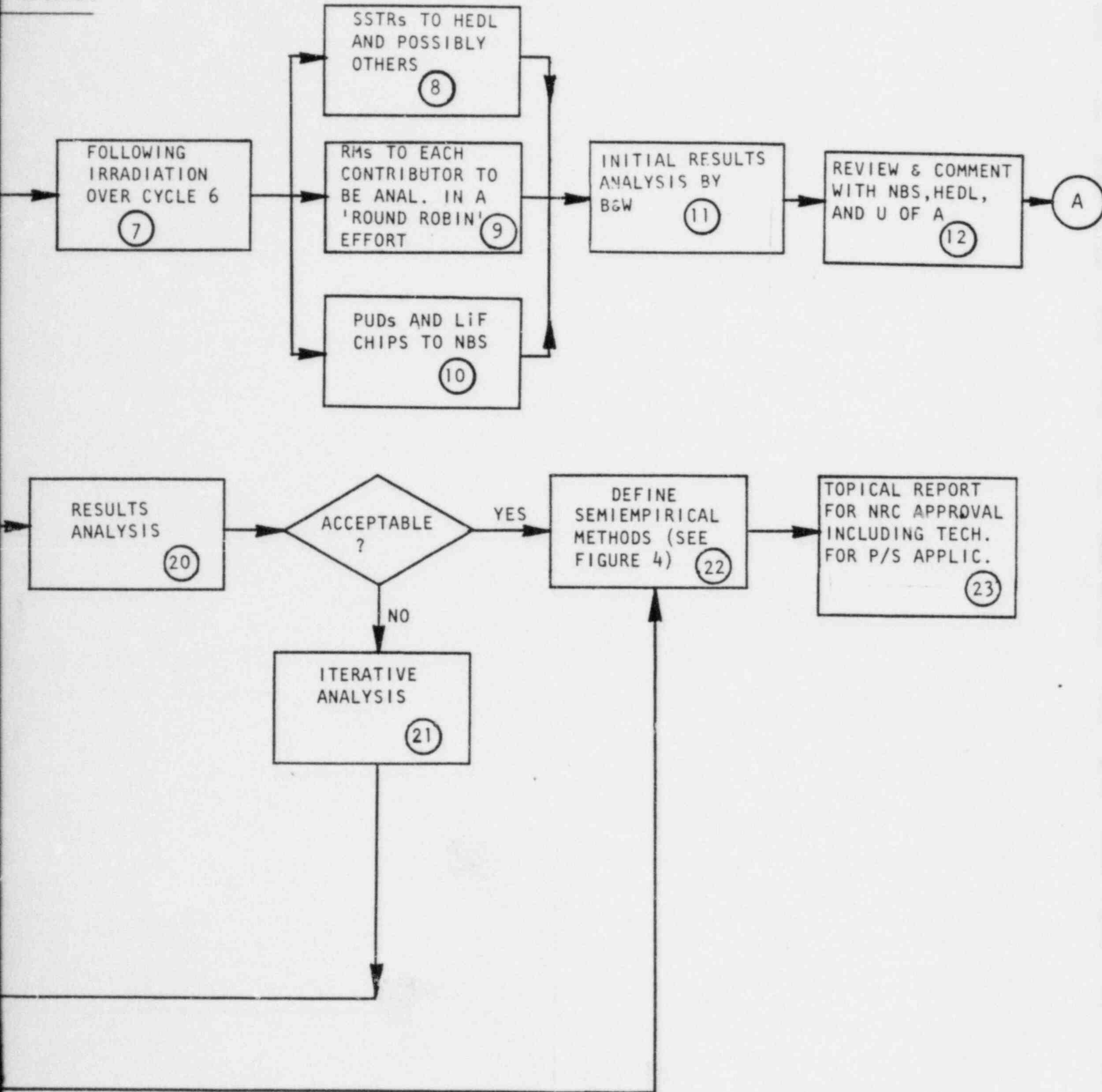
The Cavity Dosimetry Program will provide the means to determine the accumulated vessel fluence based on measured data for the operating life of each plant. In combination with the results of the Integrated RVSP, the Cavity Dosimetry Program will provide the means to (1) determine the condition of each reactor vessel at any time and (2) project remaining vessel life. In short, the program makes it possible to continuously monitor the vessel fluence.

FIGURE 1

CAVITY DOSIMETRY



PROGRAM



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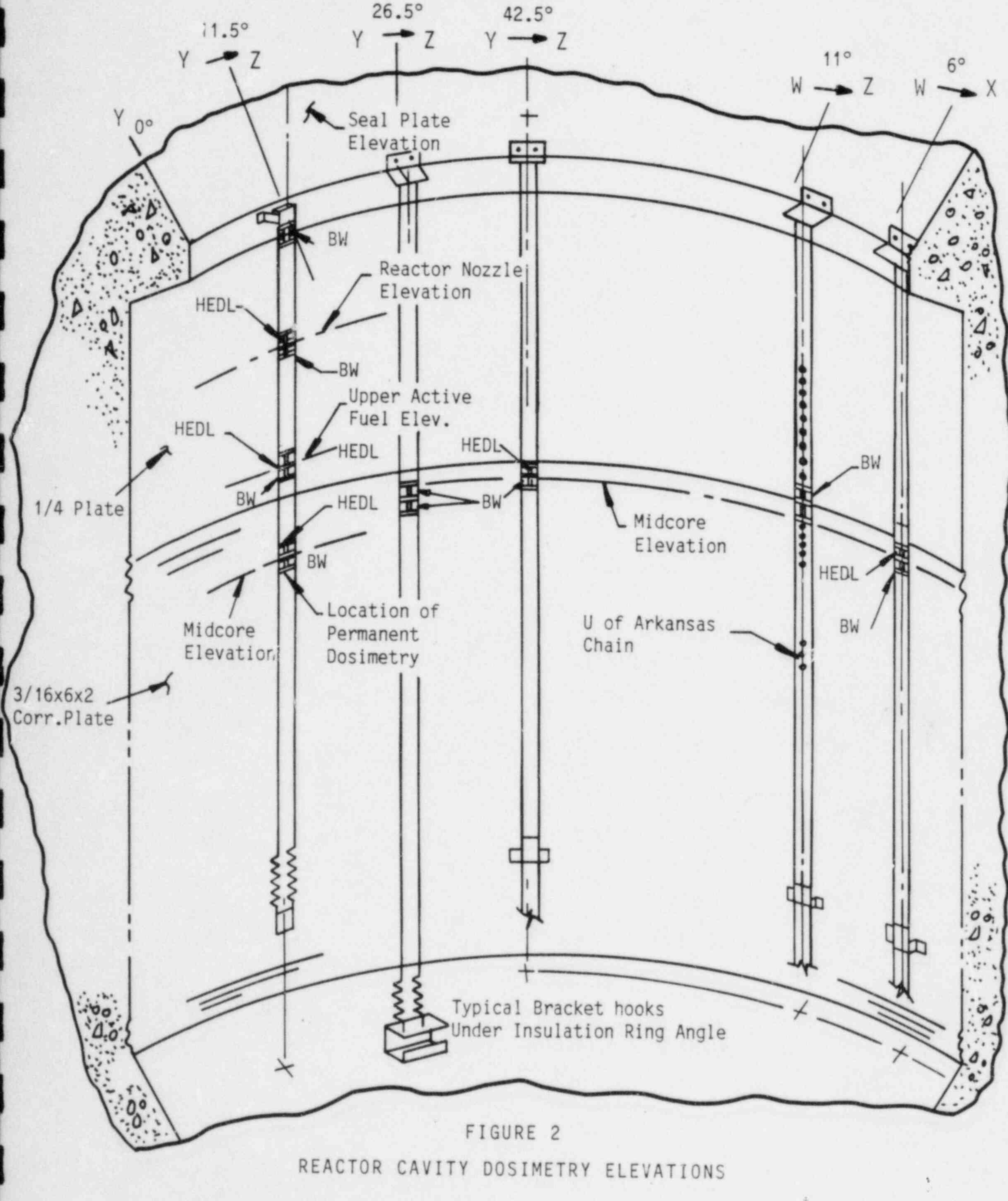
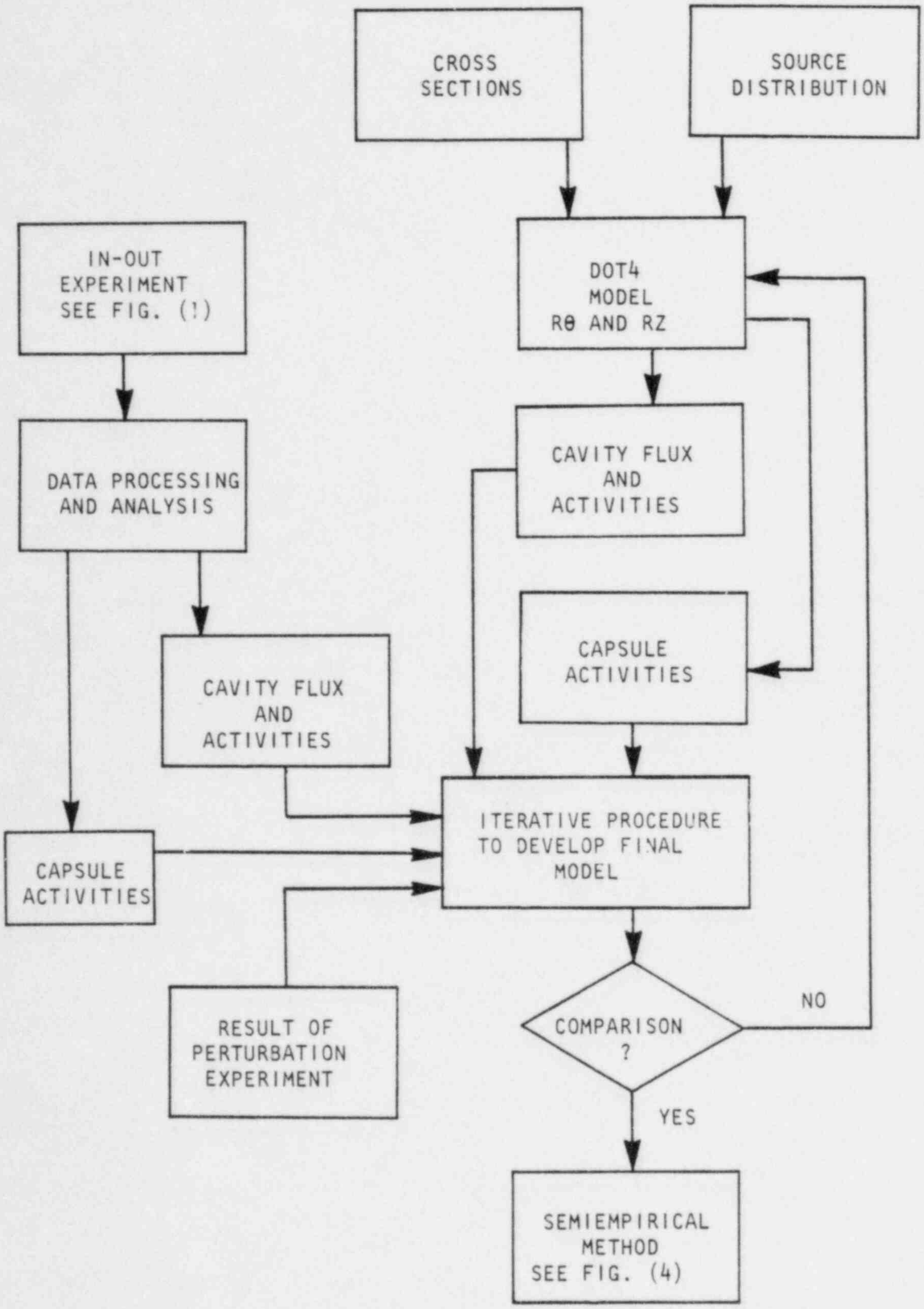


FIGURE 2

REACTOR CAVITY DOSIMETRY ELEVATIONS

FIGURE 3

DEVELOPMENT OF SEMIEMPIRICAL METHOD
USING RESULTS OF THE IN-OUT EXPERIMENT



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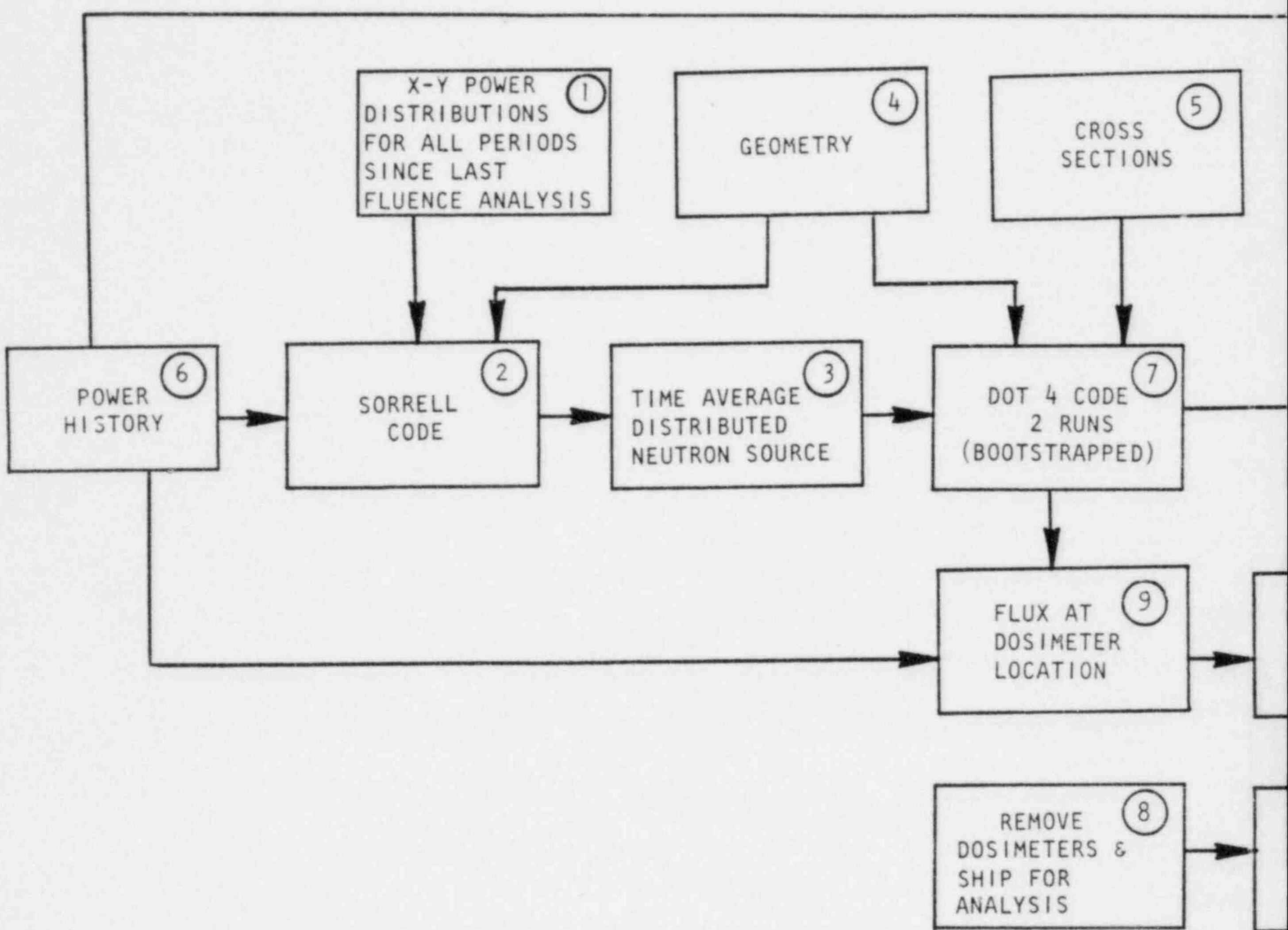

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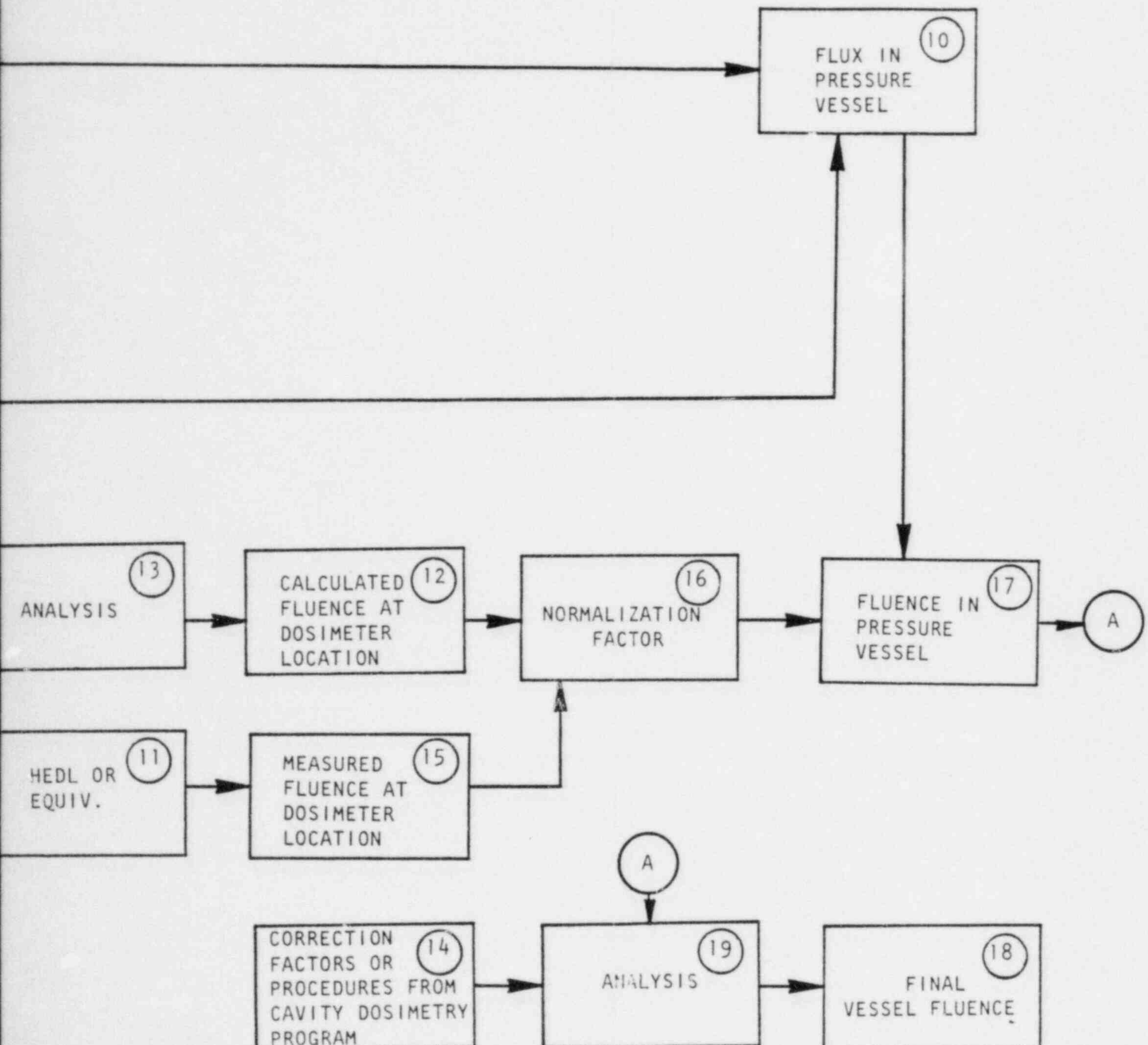

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Definition of Terms

The following definitions are provided for clarity:

Cavity Dosimetry Benchmark Experiment -- the experiment currently being set up to measure accumulated neutrons and gamma fluence at numerous locations outside the Davis Besse reactor vessel and at one location inside the vessel.

Cavity Dosimetry Program -- the program shown in detail in Figure (1).

GIP code -- computer program which calculates macroscopic material cross sections from microscopic cross sections and number densities.

In-out Experiment -- another term for Cavity Dosimetry Benchmark experiment.

IRVSP -- Integrated Reactor Vessel Surveillance Program

LiF -- Lithium Flouride gamma detector

Perturbation Experiment -- experiment currently underway to demonstrate accuracy of analytical techniques.

Plant Specific Cavity Dosimetry -- the dosimetry which will be installed in the cavity of each reactor.

PUD -- Paired Uranium Detector

RM -- Radiometric Material (activation or fission type neutron dosimeter).

RVSP -- Reactor Vessel Surveillance Program

SORREL code -- calculates time weighted average power distribution, models core liner, writes 8 and distributed source on tape for use by DOT-IV.

SSTR -- Solid State Track Recorder-neutron dosimeter