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1 INTRODUCTION

The PREP-PWR-1.0 computer code is a substantially modified version of the PREWIM code which formed part of the original MARIA System [1]. PREP-PWR-1.0 is a comprehensive pre-processor code which generates input data for the WIMS-D/4.1 code [2] for PWR fuel assemblies, with or without control and burnable poison rods. This data is generated at various base and off-base conditions. The code also generates input data for the WEDRO1.1 code [3] which processes the WIMS-E file produced by WIMS-D/4.1. The geometrical model used in PREP-PWR-1.0 is based on the model used by the PREWIM code.

It should be highlighted at the outset that this report should be read in conjunction with Section 1 of the MARIA System report. The details of the modelling of a PWR fuel assembly are not given in this report except where they differ from the original model used in the MARIA System.

PREP-PWR-1.0 forms part of an overall PWR assembly cross section library generation package which includes the WIMS-D/4.1 and WEDRO1.1 codes. WIMS-D/4.1 generates cross sections at various conditions and writes this data on a WIMS-E file. WEDRO1.1 then processes this WIMS-E file and produces a set of condensed, homogenised cross sections which are then input to POLX1.0 [4] which generates a polynomial assembly cross section library for each assembly.

The amount of data generation and manipulation involved is phenomenal and virtually impossible (certainly impractical) to perform manually. PREP-PWR-1.0 automates the whole data generation procedure, thus minimising user errors.

The overall cross section generation methodology is described in the next sect followed by a brief overview of the model in Section 3. Aspects of the base/off-base calculational scheme are outlined in Section 4. In Section 5 additional features of the code are described while the input data format of PREP-PWR-1.0 is listed in

Section 6. Sections 7 and 8 contain a description of the sample problems and suggestions for further improvements to the code respectively.

2 CROSS SECTION GENERATION METHODOLOGY

The choice of cross section generation methodology is governed by a number of aspects such as the current and future needs, abilities and resources of a particular research group. The methodology which has been implemented in the PREP-PWR-1.0 code is presented here.

A fundamental aspect of this methodology is the geometrical model used. In PREP-PWR-1.0 a simplified one-dimensional cylindrical model is used to represent the two-dimensional fuel assembly. The geometrical model is based on that used in PREWIM.

PREP-PWR-1.0 also generates input data for the WEDRO1.1 code which processes the cross section and other data received from WIMSD4.1. At this stage, PREP-PWR-1.0 generates WEDRO1.1 input data defining the particular microscopic burnup treatment mentioned below. If a macroscopic or some other burnup treatment is required the user may either modify the WEDRO subroutine in PREP-PWR-1.0 or simply modify the WEDRO1.1 input data generated by the PREP-PWR-1.0 code.

Isotopes Treated Microscopically

WIMS ID	Name	WIMS ID	Name
235	Uranium-235	135	Xenon-135
2238	Uranium-238	61149	Promethium-14
3239	Plutonium-239	149	Samarium-149
1240	Plutonium-240	10	Boron-10 (Burnable)
241	Plutonium-241	1010	Boron-10 (Soluble)
242	Plutonium-242	-	Microscopic Water
53135	Iodine-135	-	Macroscopic Structural Material

Another important aspect is the choice of state parameters, defining the state of the assembly. Here one has to decide on which state parameters to treat as independent variables in the cross section representation. The state parameters which have been chosen are exposure, water temperature/density, soluble boron concentration, and fuel temperature. The fact that the water pressure is kept constant allows the water temperature and density to be treated as a single state parameter.

A base/off-base calculational strategy has been implemented to generate data for the assembly calculations at various state parameter conditions. This strategy comprises two aspects. The first involves the assembly depletion calculations. These are performed at average operation conditions and are known as the base calculations. The second involves perturbing these conditions at selected depletion points of the depletion calculation. These, in turn, are known as the off-base calculations. For the base (depletion) calculations the power level is kept constant at its average operating value. This necessitates that the fuel temperature be changed as a function of exposure.

Please note that in this report the term perturbation does not necessarily imply small variations from base values but, in fact, implies any variation from base values.

3 OVERVIEW OF MODEL

In this section a brief overview of the fuel assembly model used is given and the important aspects highlighted. The two-dimensional fuel assembly is modelled by a simplified one-dimensional cylindrical system using the WIMS-D/4.1 cluster option [5]. An attempt has been made to take into account all important physical effects. A fraction of the assembly is modelled by placing a heterogeneous guide tube, burnable absorber rod or control rod at the centre surrounded by annuli containing fuel rods, structural material, instrumentational thimbles and the inter-assembly water gap.

The fuel rods consist of UO_2 fuel of any enrichment. Any number of boro-silicate glass (Pyrex) burnable poison rods in almost any loading configuration can be modelled. It is assumed that the number of control rods per assembly is equal to the number of guide tubes. Macroscopic Ag-In-Cd cross sections, specially prepared for this type of calculation, have been generated [6] and placed in the WIMS-D/4.1 basic cross section library. This Ag-In-Cd material is then used for the control rod instead of the individual silver, indium and cadmium cross sections in the WIMS-D/4.1 library.

The spacer grids and sleeves (consisting of Inconel-718) along the active fuel length are averaged over the active fuel length.

4 BASE/OFF-BASE CALCULATIONAL SCHEME

4.1 Calculational Path

One of the main factors which influenced the structure of the calculational path in PREP-PWR-1.0 was the desire to maintain as many sections as possible of the original source code of PREWIM to prevent repeating development work already performed and thus saving time and effort. Figure 1 outlines the various phases in the calculational strategy.

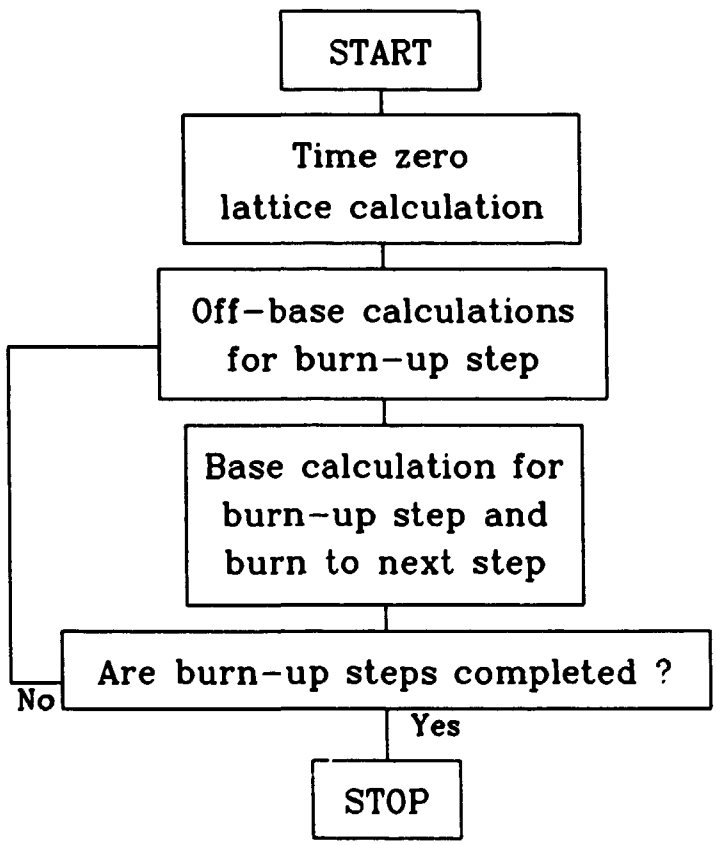

Figure 1: Base/Off-Base Calculational Strategy

The base and off-base calculations are performed in the specific order shown in Figure 2 for each burnup step. Before examining the figure it is important to take note of the definitions below.

Base Assembly Geometry — The geometry of a fuel assembly as the assembly is entered into the core with zero exposure (i.e. new).

Off-Base Assembly Geometry — The assembly geometry which is perturbed from its base state. For example, a fuel assembly in which control rods have been inserted or burnable poison rods extracted.

Base State Parameters — The set of state parameters at their normal operating conditions.

Off-Base State Parameters — The set of state parameters in which one or more have been perturbed from their base values.

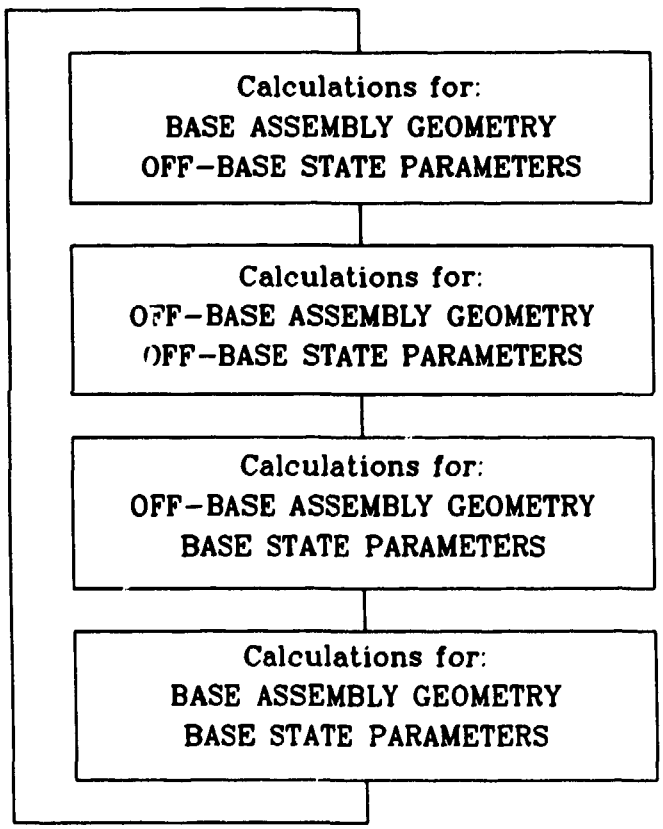

Figure 2: Order of Base/Off-Base Calculations

4.2 Perturbing of State Parameters

The state parameters can be perturbed individually or collectively. There are, however, certain aspects which need to be understood concerning the perturbation of the state parameters and these are discussed below.

4.2.1 Moderator (Water) Temperature/Density

The moderator (water) temperature/density relation for a given pressure is obtained by using the STATUS subroutine in the TABASCO thermal hydraulics module [7]. It is assumed that the moderator pressure remains fixed. This assumption allows the moderator temperature and density to be treated as one state parameter. This assumption will obviously not apply to BWR fuel assemblies.

When the moderator (water) temperature is changed, the perturbed water density is calculated, assuming the pressure remains constant. This perturbed water density is then used to calculate the new number densities for hydrogen and oxygen. The perturbed soluble boron number densities are also determined owing to the change in water density while conserving the boron/water ppm ratio. The number densities of the structural material isotopes in the moderator are left unchanged.

The modified moderator (water) density is specified on the COOLANT card which enacts the writing of the "historic coolant density" on file 6 of the WIMS-E file. If the water density were not specified on the COOLANT card, WIMS-D/4.1 would determine a density for the coolant from the specifications of the material defined as coolant on the COOLANT card. This density is not the true water density since various structural materials are weighted into the coolant.

Whenever a moderator (water) temperature/density off-base calculation is

performed, the correct water density is placed in the "historic coolant density" position of file 6 of the WIMSE file.

4.2.2 Soluble Boron Concentration

The perturbation of the soluble boron concentration involves both the ppm value and the water density. When the soluble boron concentration is perturbed, the new boron number densities are determined due to the change in the ppm value and for the current water density thus ensuring the correct boron/water ppm ratio.

4.2.3 Fuel Temperature

A perturbation in the fuel temperature results in a perturbation in the reactor power level since the coolant temperature and other parameters remain fixed. The fuel temperature perturbations are based on the effective Doppler fuel temperature. The TABASCO module converts the Doppler temperature to the actual fuel temperature and determines the corresponding power level.

Directly connected to a change in reactor power is a change in the equilibrium xenon concentration. This physical phenomenon is accounted for within the WIMS-D/4.1 code. WIMS-D/4.1 has the feature that, when a POWERC card is specified with a zero step length, it corrects the xenon number density to the equilibrium xenon number density at the perturbed power level.

Owing to the operational characteristics of WIMS-D/4.1 the power has to be changed to its perturbed level in the off-base calculation immediately prior to the current off-base calculation in which the fuel temperature is perturbed. The fuel temperature, on the other hand, is changed in the current step by the TEMPERATURE card. Thus the fuel temperature cannot be perturbed in the first off-base calculation of a burnup step.

4.3 Burnable Poison Extraction

In the burnable poison extraction off-base calculations, all the boro-silicate glass burnable absorbers are extracted and replaced with water. The calculations with the burnable poison rods extracted, by definition, form part of the off-base assembly geometry calculations since the base assembly geometry is perturbed by the physical extraction of the burnable poison rods. The regions in the lattice cell model containing the burnable poison rod are replaced by coolant, thereby "extracting" the burnable poison rod. One of the WIMS-D/4.1 requirements is that the number of edit regions must remain constant for each of the lattice calculations in a set, whether the burnable poison rods are present or not. Two consecutive annuli containing the same material are lumped together as one edit region in WIMS-D/4.1. The same material can be used in a number of different annuli without having the edit regions lumped together as long as they are not in direct contact with each other. For this region, two additional but identical water materials are defined and placed alternatively in the 4 regions (annuli) which previously comprised the burnable poison rod. The burnable poison rod is thus extracted and can be reinserted by respecifying the materials in the regions making up the burnable poison rod. The number densities of the isotopes making up the materials of the burnable poison rod are conserved by this approach of defining additional materials.

Perturbing the fuel temperature results in the specification of the POWERC card with a zero step length as discussed in the previous section. The POWERC card directs WIMS-D/4.1 to enter its burnup calculation (chain). When burnable poison rods are present, however, the POISON option is also specified, which causes a collision probability to be performed for the burnup treatment of the burnable absorbers (see Section 5.3).

Once the burnable poison rods have been removed and the burnup chain is entered owing to a fuel temperature perturbation, WIMS-D/4.1 aborts on the activation of the POISON option since no burnable poison rods reside in the system at that time.

For this reason the POISON option is deactivated at the start of the off-base calculations to prevent the latter situation from developing.

Once the rods have been removed, the off-base state parameter calculations are performed with the assembly in its off-base geometry state.

4.4 Control Rod Insertion

In the control rod insertion off-base calculation, Ag-In-Cd control rods are inserted into all the guide tube and burnable poison positions. This is done by the definition of additional materials in a similar manner to that described in Section 4.3.

Firstly, the central cell in the model is replaced by a heterogeneous control rod while conserving the WIMS-D/4.1 edit regions (as described earlier). Secondly, if there is a guide tube annulus at any other location in the geometrical model (this happens only for assemblies initially loaded with burnable poison rods) the material in that annulus is replaced by a volume-weighted control rod cell.

4.5 Treatment of Different Assembly Types

There are four types of fuel assemblies which PREP-PWR-1.0 treats. Each of these is characterised by the rod in the centre of the geometric model. The fuel assembly types are defined below.

CASE K = 1 Fuel assemblies without control rods or burnable absorber rods. Off-base state parameter calculations can be performed with this type of assembly but control rod insertion off-base calculations are NOT supported.

CASE K = 2 Fuel assemblies with control rods. State parameter off-base

calculations can be performed with this type of assembly. If no control rod insertion off-base calculations are requested the fuel assembly is burned with the control rods present. This is the case, under certain circumstances, where the control rods are partially inserted.

If, on the other hand, control rod insertion off-base calculations are requested for this type of assembly, it is then treated as a case 1 assembly. In this case the assembly is burned without the control rods present and the control rods inserted as an off-base calculation when requested.

CASE K = 3 Fuel assemblies with the number of burnable absorber rods equal to the number of guide tubes. This type of fuel assembly is more the exception than the rule. This case has not been tested for the off-base calculations.

CASE K = 4 Fuel assemblies with the number of burnable absorber rods fewer than the number of guide tubes. State parameter off-base calculations as well as burnable poison extraction and control rod insertion off-base calculations can be performed.

In all these cases, the central cell is modelled heterogeneously. This central cell is surrounded by the annuli containing the other constituents in the fuel assembly such as fuel pins, instrumentation thimbles, structural material etc. The central cell for case K=1 is a guide tube cell whereas for case K=2 it is a control rod (if no control rod insertion calculations are requested, otherwise it is a guide tube). For cases K=3 & 4 the central cell is a burnable absorber rod.

When performing off-base calculations involving control rod insertion and burnable poison extraction, the central cell is removed and replaced by another rod cell, depending on the required off-base calculation.

5 FURTHER MODIFICATIONS TO PREWIM

5.1 Compatibility with WIMS-D/4.1

The original version of PREWIM was developed to prepare input data for the WIMS-TRACA code [1]. There are a few features (activated by keyword input data) available in WIMS-TRACA, which are not available in WIMS-D/4.1 and vice versa. PREP-PWR-1.0 generates input data for the WIMS-D/4.1 code and can thus not be used with WIMS-TRACA.

5.2 TABASCO Module

All the thermal hydraulic calculations in PREP-PWR-1.0 are done by the TABASCO module. TABASCO is a correlative thermal hydraulics module which calculates coolant, cladding and fuel temperatures, as well as expanded radii for PWR type fuel rods under specified conditions of power and exposure. TABASCO also has the ability to perform the "reverse" of this calculation in that the module can determine the power associated with a specified fuel temperature. Full details of the TABASCO module are found in Reference 7.

5.3 Use of the POISON Option

A shortcoming in the WIMS-D/4.1 calculation of the burnup of fuel assemblies containing burnable poison rods is the inability of the homogeneous flux solution to predict the rapid change in the radial flux profile within the poison rods. The reaction rate within the rod is thus in error, causing subsequent errors in the depletion calculation. This error is particularly noticeable with highly absorbing rods and can be remedied by using the POISON option in the WIMS-D/4.1 code.

This option forces a pin cell collision probability calculation to be performed at each criticality calculation in the burnup step thus effectively modelling the radial flux profile.

The POISON option is activated in the lattice calculation in which the system is burned (i.e. the base calculation) and deactivated for all off-base calculations. This option is used only for fuel assemblies containing burnable poison rods.

5.4 Dancoff Factor Treatment

A number of modifications have been made to the calculation of the Dancoff and Bell factors in PREP-PWR-1.0. Full details of these modifications can be found in Reference 8 although a brief summary is given below.

The original method used to calculate Dancoff Factors in the PREWIM code has been modified to give more rigorous Dancoff Factors even though the difference between the Dancoff Factors generated by the two methods is small.

A) The expression for defining the effective group removal cross section of the non-fuel regions as used in WIMS has been adopted

$$\bar{\Sigma}_t = \sum_{\text{isotopes}} N_D^i \left(\lambda_t \sigma_p^i + \sigma_a^i\right)$$

B) Group-dependent Σ_t values are used for all the resonance groups. The group dependent microscopic cross sections for the isotopes used in PREP-PWR-1.0 are given in the table in Appendix A.

C) The calculation of the Dancoff Factors are performed using the Carlvik method [9] with a modification to account for the gap and clad used in WIMS [10].

5.5 Material Compositions

PREP-PWR-1.0 contains a library of materials which are used for the modelling of the fuel assemblies. These are listed in Table 2 below and replace Table 1 in Reference 1. These changes have been effected to ensure compatibility with the material specifications of the Koeberg Nuclear Power Station. The latter material specifications can be modified by redefining them in the PREP-PWR-1.0 source code.

Table 2: Material Specifications at Cold Conditions (20 °C)

Material Number	Region	Material	Density (g/cm^3)
1	Fuel	UO2	10.412 (95 % of theoretical)
2	Cladding	Zr-4	6.55
3	Coolant	H_2O + Boron	1.00
4	Grid	Inconel-718	8.20
5	Guide tube	Zr-4	6.55
6	Instrumentation thimble	Zr-4	6.55
7	Control	Ag-In-Cd	10.16
8	Control clad	SS-304	7.90
9	Burnable absorber inner gas	Helium	10^{-4}
10	Burnable absorber	BS_i (Pyrex)	2.237
11	Burnable absorber inner clad	SS-304	7.90
12	Burnable absorber outer clad	SS-304	7.90
13	Shroud + barrel	SS-304	7.90

14	Reflector	H_2O + Boron	1.00
15	Moderator in fuel cell	3 + 4	--
16	Guide tube cell	3 + 5 + 15	--
17	Instrumentation thimble	3 + 6 + 15	--
18	Reflector mixed	14 + 13	--
19	Control cell	3 + 5 + 7 + 8 + 15	

5.6 Generation of WEDRO1.1 Keyword Input Data

Details of the keyword input data required by the WEDRO1.1 code can be found in Reference 3. This data defines the manner in which the WIMS-E files, generated by the WIMS-D/4.1 code, are processed. The information required by WEDRO1.1 includes the specification of the sub-files to be processed; upscatter correction option; homogenisation; group condensation and microscopic treatment specifications.

Owing to the large volumes of data which could be contained in the WIMS-E file and their correct processing, it is of great benefit to the user that PREP-PWR-1.0 generates this data for WEDRO1.1. It certainly minimises possible user error.

5.7 Logical Files Required

The logical file units required by PREP-PWR-1.0 are outlined below. One must bear in mind that PREP-PWR-1.0 operates as part of an overall cross section generation system and as such has certain restrictions placed on the use of logical units. It is for this reason that the conventional logical unit used for reading (File 5) is used by PREP-PWR-1.0 as an output file.

Unit 1 WEDRO1.1 keyword input data. (Fixed Blocked, record length 80)

Unit 5 WIMS-D/4.1 input data generated by PREP-PWR-1.0. (Fixed Block record length 80)

Unit 6 Printed output from PREP-PWR-1.0 code. (Fixed Blocked, record length 133)

Unit 10 General Data (See Section 6). (Variable Block Size)

Unit 11 Input data for PREP-PWR-1.0. (Fixed Blocked, record length 80)

6 PREP-PWR-1.0 INPUT DATA SPECIFICATIONS

The PREP-PWR-1.0 input data are split into four sections. The data in Sections 0 & 2 are always required whereas the data in Sections 1 & 3 are only required in certain circumstances.

SECTION 0 These are the *general options* for the code and are always required.

SECTION 1 In this section the *general data* for the fuel assemblies are given. This data is optional and is necessary only the first time a set of assembly types is specified, that is, the general case. This data is stored on logical unit 10 and is used by the particular cases which are defined by the data in Section 2.

SECTION 2 This section defines the *specific data* of the problem and is always required.

SECTION 3 In this section, *off-base data* is defined for the off-base calculations. The first card in this section must always be specified and if off-base calculations are required, the rest of the cards are also expected.

6.1 Section 0: General Options

CARD 0.1 (I3,3X,12A6) *General Options*

IDAT < 0 Data for a particular case. The suppress card (Card 0.3) needs to be specified.

= 0 Data for a particular case. The suppress card (Card 0.3) is not required.

> 0 Data for a general case with the initiation of all data in Section 1.

The cards in Section 1 are not required if IDAT ≤ 0.

TIT(1), TIT(2) Catalog file for general data

(TIT(I), I = 3, 12) Identification title of the general case

CARD 0.2 (A20) Run-Identifier

RUNID 20 character (alpha-numeric) run identifier for the WIMS-D/4.1 calculation.
If the RUNID is 20 blanks, it will be generated according to the assembly type, otherwise it must have no blanks at all.

CARD 0.3 (16I3) Suppress Data
(If IDAT < 0 or IDAT > 1)

(NSUPRE(I) I = 1, 16)
List of the data to be placed in the SUPPRESS card of the WIMS-D/4.1 input data. If IDAT > 1 the SUPPRESS card is defaulted to: 1 1 1 1

1 1 1 1 1 1 1 1 1 1 1 1

CARD 0.4 (4I6) Store Data
(If IDAT > 2)

((NSTORE(I,K), I = 1, 4), K = 1, 5)

List of the data to be placed in the STORE card. One card for each calculation type K (K = 1, 5). If IDAT ≤ 2, the NSTORE card is defaulted to:
160000, 100000, 100000, 5000
The STORE information for K=5 is not used.

6.2 Section 1: General Data

Cards 1 are only required if IDAT > 0.

CARD 1.1 (7I6)

NR Number of rows and columns of fuel pins in the fuel assembly

NTG Number of guide tube or control rod positions in the fuel assembly

NTI Number of instrumentation thimbles in the fuel assembly

NEN Number of different enrichments of the fuel assemblies without control rods or burnable poison rods (K=1). NEN ≤ 5

NEC Number of different enrichments of fuel assemblies with control rods (K=2). NEC ≤ 5

NVC Number of fuel assemblies with a different number of burnable poison rods (K=3 or 4). NVC ≤ 5

NIN Number of fuel pins in the assembly without any edge or corner close to a guide tube, instrumentation thimble or in the periphery of the fuel assembly.

CARD 1.2 (6E12.6) Fuel pin dimensions at cold conditions (cm).

RF Outer radius of the fuel

RIV Inner radius of the cladding

REV Outer radius of the cladding

PR Fuel pin pitch

PA Fuel assembly pitch

HF Active length of fuel

CARD 1.3 (6E12.6) Guide-tube dimensions at cold conditions (cm). (If NTG > 0)

RIS Inner radius of the guide tube in the top zone

RES Outer radius of the guide tube in the top zone

HS Length of the top zone

RII Inner radius of the guide tube in the bottom zone

REI Outer radius of the guide tube in the bottom zone

HI Length of bottom zone

CARD 1.4 (6E12.6) Instrumentation thimble dimensions at cold conditions (cm)
(If NTI > 0)

RISI Inner radius of instrumentation thimble in the top zone

RESI Outer radius of instrumentation thimble in the top zone

HSI Length of the top zone

RIII Inner radius of instrumentation thimble in the bottom zone (if different from RISI)

REII Outer radius of instrumentation thimble in the bottom zone (if different from RESI)

HII Length of bottom zone (if different from HSI)

CARD 1.5 (6E12.6) Control-rod dimensions at cold conditions (cm)

RAC Outer radius of the absorber

RIVAC Inner radius of the cladding of the control rods

REVAC Outer radius of the cladding of the control rods

CARD 1.6 (6E12.6) Burnable absorber rod dimensions at cold conditions (cm)

RIAVC Inner radius of the inner cladding of the burnable absorber

REAVC Outer radius of the inner cladding of the burnable absorber

RIVC Inner radius of the burnable absorber

REVC Outer radius of the burnable absorber

RIVVC Inner radius of the outer cladding of the burnable absorber

REVVC Outer radius of the outer cladding of the burnable absorber

CARD 1.7 (2I6,2E12.6/(6E12.6)) Basic Materials

Only for the materials J whose properties should be changed from the standard values (Section 5.5, Table 2). If $J \leq 0$ or $J > 14$ this set of cards is terminated.

J Basic material number

NUC(J) Number of isotopes which are included in the material J. $NUC \leq 10$

D(J) Density ($g.cm^{-3}$) of material J at cold conditions

ALF(J) Linear expansion coefficient ($^{o}C^{-1}$)

(AID(I,J), FID(I,J), J = 1, NUC(J))

Isotope identification on the WIMS-D/4.1 library and isotopic concentration $(cm.b)^{-1}$ for the NUC(J) isotopes

The fuel (J=1) should be UO_2 with any enrichment. The order of the isotopes should be: U-235, U-238, O, Pu-239 and Xe-135. The last isotopes may have zero concentrations.

The water (J=3 or J=14) should be specified with 1 000 ppm of natural boron in weight since 1 000 ppm is the reference soluble boron concentration used by PREP-PWR-1.0. The order of the isotopes should be: B-10 (not burnable), H and O. The reference density should be 1.0 $g.cm^{-3}$.

If NUC(J) = 0 input only D(J) and ALF(J) in order to change the standard values.

If NUC(J) < 0 the AID and FID values for material J are set equal to those of the material ABS(NUC(J)) and also the D and ALF values if they are ≤ 0 in this card.

Cards 1.7 may be repeated for the same material J in order to make successive changes to the standard or previous properties.

CARD 1.8 (4E12.6) Mass and Pressure

WUO2	>	12	UO_2 mass per fuel pin (g)
	=	1 to 12	UO_2 absolute density at cold conditions in the active volume of RF radius and HF length $(g.cm^{-3})$
	<	1	UO_2 relative density in the active volume with reference to the standard value

WGRID — Mass of all the grids in the active volume (g)

WSLEV — Mass of all the sleeves in the grids within the active length (g)

PRES > 0 — Coolant pressure of the core (psia)

< 0 — Coolant pressure of the core (bar)

CARD 1.9 (5E12.6) — Enrichments for the fuel assemblies (K=1)

(ENR(I), I = 1, NEN) — Enrichments (w/o)

CARD 1.10 (5E12.6) — Enrichments for fuel assemblies with control rods (K=2)

(ENC(I), I = 1, NEC) — Enrichments (w/o)

CARD 1.11 (4I6/5E12.6) — Fuel assemblies with burnable absorber rods

These cards are entered NVC times for IVC = 1, NVC.

NRVC(IVC) — Number of burnable absorber rods in the fuel assembly. Assemblies for which NRVC(IVC) = NTG, should be specified first in these cards (i.e. IVC=1)

NR2VC(IVC) — Number of fuel pins on the corners of burnable absorber rods

NR3VC(IVC) — Number of fuel pins between burnable absorber rods and guide tubes or instrumentation thimbles

NEVC(IVC) Number of enrichments in the IVC class of assemblies (NEVC(IVC) ≤ 5)

ENVC(I,IVC), I = 1, NEVC(IVC)
Enrichments of the class IVC

CARDS 1.12 which were required in PREWIM are no longer required in PREP-PWR-1.0.

CARD 1.13 Options for WIMS-D/4.1

PREP-PWR-1.0 sets certain default values for the input options for WIMS-D/4.1. Any of the default values can be overwritten by using this card. Only the options not equal to zero are changed. The default values are in parenthesis.

CARD 1.13.1 (12I6/12I6/9I6)

IOP(1)	LOC(1)	Data memory for K=1	(142 000)
IOP(2)	LOC(2)	Data memory for K=2	(142 000)
IOP(3)	LOC(3)	Data memory for K=3	(142 000)
IOP(4)	LOC(4)	Data memory for K=4	(152 000)
IOP(5)		Not required	
IOP(6)	ICELL	i in the CELL card	(7)
IOP(7)	ISEQ	i in the sequence card	(1)
IOP(8)	IG(1)	i in the NGROUP card for K=1	(15)
IOP(9)	IG(2)	i in the NGROUP card for K=2	(15)
IOP(10)	IG(3)	i in the NGROUP card for K=3	(15)
IOP(11)	IG(4)	i in the NGROUP card for K=4	(15)

IOP(12)		Not required	
		{ IG(N) ≤ 28 }	
IOP(13)	IGP	IGP in the NGROUP card (IGP ≤ 7)	(2)
IOP(14)	NTX	NTAPXS in the NGROUP card	(8)
IOP(15)	NMESH(1)	i in the NMESH card for K=1	(31)
IOP(16)	NMESH(2)	i in the NMESH card for K=2	(35)
IOP(17)	NMESH(3)	i in the NMESH card for K=3	(35)
IOP(18)	NMESH(4)	i in the NMESH card for K=4	(48)
IOP(19)		Not required	
IOP(20)	NSN	n in the S_n card	(6)
IOP(21)	NTH	n in the THERMAL card	(6)
IOP(22)	LEAK	m in the LEAKAGE card	(7)
IOP(23)	NBEE	i in the BEEONE card	(1)
IOP(24)		Not required	

IOP(25) m_r for the radial buckling

IOP(26) l_r for the radial buckling

$B^2_r = m_r.10^{lr}$

IOP(27) m_z for the axial buckling

IOP(28) l_z for the axial buckling

$B^2_z = m_z.10^{lz}$

IOP(29) Change to default MARIA Model for K=1

IOP(30) Change to default MARIA Model for K=2

IOP(31) Change to default MARIA Model for K=3

IOP(32) Change to default MARIA Model for K=4

IOP(33) Not required

CARD 1.13.2 (24I3) Group Structure

(If IOP(K+7) > 0)

NIG(I,K), I = 1, IG(K) The list of the group numbers in decreasing energy that make the partition of the 69 group WIMS-D/4.1

structure. The last number must be 69.
If IOP(K+7) = 0, the standard PREP-PWR-1.0 group structure is used; namely 5, 10, 15, 20, 25, 30, 35, 40, 45, 49, 53, 57, 61, 65, 69.
If IOP(K+7) < 0, the group structure of the K-1 type is taken.

CARD 1.13.3 (8I3) Collapsed and thermal groups
(If IOP(K+7) > 0)

NIGP(I,K), I = 1, IGP+1 Group numbers making the partition of the transport group structure in the collapsed group structure.
Should be NIGP(IGP,K) = IG(K).
NIGP(IGP+1,K) = n in the THERMAL card.
If IOP(K+7) = 0 the standard collapsed group structure of PREP-PWR-1.0 is taken, namely 9; 15; 6.
If IOP(K+7) < 0 the collapsed group structure of the type K-1 is taken.

CARD 1.13.4 (7I3) Geometry Data
(If IOP(K+28) ≠ 0)

IOPG(1) NANN(K) Changes the number of annuli. NANN(K) ≤ 16

IOPG(2) NANR(K) Changes the number of annuli with rods. NANR(K) ≤ 8

IOPG(3) NREG(K) Changes the number of edit regions.

IOPG(4) NCOL(K) Changes the number of collapsed regions. NCOL(K) ≤ 9

IOPG(5) NMAT(K) Changes the number of materials. NMAT(K) ≤ 30

IOPG(6) NMAB(K) Changes the number of materials which undergo burnup.

IOPG(7) NSUB(K) Changes the number of rod zones. NSUB(K) ≤ 3

CARD 1.13.5 (6E12.6) Annuli Radii
(If IOPG(1) ≠ 0)

RA(I,L), I = 1, NANN(K) Outer radius for each annulus at cold conditions (cm)

CARD 1.13.6 (6E12.6) Radii for the Arrays of Rods
(If IOPG(2) ≠ 0)

RR(I,L), I = 1, NANR(K) Array radii at cold conditions (cm)

CARD 1.13.7 (6E12.6) Number of Rods per Array
(If IOPG(2) ≠ 0)

ZR(I,L), I = 1, ANR(K) Number of rods per array

The cards 1.13.5 to 1.13.7 should be supplied for L=K if K ≠ 4. If K=4 these cards should be supplied for each class of assemblies with a different number of burnable absorber rods. (Note: L = 5 + J; J = 1 + NVC.)

CARD 1.13.8 (16I3) Materials
(If IOPG(1) ≠ 0)

MA(I,K), I = 1, NANN(K) Material number per annulus

CARD 1.13.9 (16I3) Expansion Material
(If IOPG(1) ≠ 0)

IEXP(I,K), I = 1, NANN(K) Expansion material class per annulus

CARD 1.13.10 (16I3) Spatial Intervals
(If IOPG(1) ≠ 0 or IOPG(K+14) ≠ 0)

IMESH(I,K), I = 1, NANN(K) OR IMESH(I,K), I = 1, NMESH(K)
Number of spatial intervals per annulus

CARD 1.13.11 (9I3) Collapsed Regions
(If IOPG(4) ≠ 0)

MOMOD(I,K),I=1,NCOL(K) Collapsed regions partition on the transport regions structure. The data in this card are not used.

CARD 1.13.12 (24I3) Material Class
(If IOPG(5) ≠ 0)

MAT(I,K), I = 1, NMAT(K) Material class (1 - 18) in PREP-PWR-1.0 for each material.

CARD 1.13.13 (24I3) Spectrum
(If IOPG(5) ≠ 0)

IESP(I,K), I = 1, NMAT(K) WIMS-D/4.1 Spectrum type per material number

CARD 1.13.14 (24I3) Material Allocation per Rod
(If IOPG(7) ≠ 0 or IOPG(2) ≠ 0)

((MS(I,J,K), I=1, NSUB(K)), J=1, NANR(K))
Material number per rod zone in each rod annulus

The order of specifying cards 1.13 is as follows:

1. Cards 1.13.2 to 1.13.14 for K=1 if IOP(29) ≠ 0
2. Cards 1.13.2 to 1.13.14 for K=2 if IOP(30) ≠ 0
3. Cards 1.13.2 to 1.13.14 for K=3 if IOP(31) ≠ 0
4. Cards 1.13.2 to 1.13.4 for K=4 if IOP(32) ≠ 0 or IOP(11) ≠ 0
5. Cards 1.13.5 to 1.13.7 for each J=1, NVC

CARD 1.14.1 (2I6,2E12.4/3E12.4) Cross Sections for the control materials
(If IOP(24)=IHPS=1001)

IHS ν position in the SIGMA(I) table of cross sections

IHL Length of SIGMA(I) table

SACT Activation cross section

SFNU $\nu\Sigma_f$

SIGMA(I), I = 1, IHL

SIGMA(1) = Σa

SIGMA(IHS) = Σgg

SIGMA(IHS-J) = $\Sigma g \rightarrow g\text{-}J$

SIGMA(IHS+J) = $\Sigma g \rightarrow g+J$

The number of cards to be specified is IG(2)*2.

CARD 1.14.2 which were required in PREWIM are no longer required in PREP-PWR-1.0

CARD 1.15.1 (I3) Option for Additional Input

IOPT = 0 No additional input to be read

= 1 Parameters for PRIME, SAVE and COOLANT cards of the WIMS-D/4.1 input are to be read on card 1.15.2. These parameters are defaulted if not specified.

CARD 1.15.2 (5I3) PRIME, SAVE and COOLANT parameters

IPRIME	i in the PRIME card	(0)
ISAVEI	i in the SAVE card	(1)
ISAVEJ	j in the SAVE card	(1)
ISAVEK	k in the SAVE card	(64)
ICOOL	n in the COOLANT card	(8)

6.3 Section 2: Specific Data

CARD 2.1 (4I3,6E12.6) Specific Conditions

JOUT ≤ 0 The generated data for all the classes of assemblies are written in the same unit NOUT.

> 0 The generated data for each class of assemblies are written in successive units NOUT + JOUT. Normally JOUT = 1.

KOUT Class (type) of assembly to be treated (K = 1, 2, 3 or 4)

NBORO Number of soluble boron concentrations for cases without burnup. NBORO ≤ 50

NBURN ≤ 0 No burnup required

> 0 Number of burnup steps. NBORO should be equal to NBURN. NBURN ≤ 50

TEFF = 0 Resonance effective temperature of the fuel will be calculated by the TABASCO module.

< 0 Resonance effective temperature of the fuel in degrees F

> 0 Resonance effective temperature of the fuel in degrees C

TF = 0 Average fuel temperature for the radial expansion will be calculated by the TABASCO module.

< 0 Average fuel temperature for the radial expansion in degrees F

> 0 Average fuel temperature for the radial expansion in degrees C

TV = 0 Average clad temperature will be calculated by the TABASCO module.

< 0 Average clad temperature in degrees F

> 0 Average clad temperature in degrees C

TM = 0 Average coolant and moderator temperature will be calculated by the TABASCO module.

< 0 Average coolant and moderator temperature in degrees F

> 0 Average coolant and moderator temperature in degrees C

TR = 0 Average reflector temperature will be set by the TABASCO module.

< 0 Average reflector temperature in degrees F

> 0 Average reflector temperature in degrees C

PD Percentage of power density relative to the nominal value (%), for use only in the title of the WIMS-D/4.1 input data

CARD 2.2 (2E12.6) Inlet Temperature and Flow Rate

TINLET = 0 Inlet temperature will be set by the TABASCO module.

> 0 Inlet temperature to be used by TABASCO module in degrees Celsius

MDOT = 0 Total mass flow rate will be set by TABASCO module.

> 0 Total mass flow rate per rod to be used by TABASCO module ($kg.s^{-1}$)

CARD 2.3 (4I3,6E12.6) Boron Concentration
(If NBURN ≤ 0)

BORO(I), I = 1, NBORO Natural boron concentration in the coolant and moderator (ppm in weight)

CARD 2.4 (5E12.6) Burnup Steps
(If NBURN > 0)
One card per step, NBURN cards in total.

BORO(IB) Boron concentration (ppm of natural boron in weight)

RQ(IB) > 0 Specific power density (MW/T of heavy isotopes)
= 0 A linear power density of 183 W/cm will be used
< 0 Linear power density in W/cm

RTAU(IB) < 0 Length of the burnup step in MWd/T
= 0 Zero burnup in this step
> 0 Length of burnup step in days

INDB(IB) Number of spectrum calculation steps in the burnup step defined above. If RTAU(IB) ≠ 0 and INDB(IB) = 0, INDB(IB) is set to 5.

XENON(IB) Modification factor of the xenon-135 concentration with respect to the previous step. If XENON(IB) = 0 it is not used.

CARD 2.5 (1E12.6) Power Density
(If NBURN = 0 and any of TEFF, TF, TV, TM = 0)

RQ(1) > 0 Specific power density in MW/T of heavy isotopes
= 0 A linear power density of 183 W/cm will be used.
> 0 Linear power density in W/cm

6.4 Section 3: Off-Base Data

CARD 3.1 (3I3) Off-Base Calculation Flag

IBASE = 0 No off-base calculations to be performed

> 0 IBASE off-base calculations will be performed at each exposure point with fixed perturbations over the burnup range IBASE≤11.

< 0 ABS(IBASE) off-base calculations will be performed at each exposure point with variable perturbations over the burnup range ABS(IBASE) ≤ 11.

NOTE: IBASE must be incremented by 1 if burnable poison extraction and/or control rod insertion calculations are required.

IBP = 0 No burnable poison rod extraction off-base calculations will be performed.

= 1 Burnable poison rods extraction off-base calculations will be performed.

ICR = 0 No control rod insertion off-base calculations will be performed.

= 1 Control rod insertion off-base calculations will be performed.

CARD 3.2 (1E12.6) Final Boron Concentration

BORO Soluble boron concentration for the final burnup step NBURN+1

CARD 3.3 (3E12.6) Deltas by which the State Parameters are Perturbed.

DFTEMP Value by which the resonance effective fuel temperature must be changed for the off-base calculation.

DWTEMP Value by which the moderator (water) temperature must be changed for the off-base calculation.

DBCONC Value by which the soluble boron concentration must be changed for the off-base calculation.

Cards 3.3 must be given for each of the off-base calculations.

CARD 3.4 (2I3) Type of Control Rod Insertion/Burnable Poison Extraction Off-Base Calculation
(If IBP > 0 or ICR > 0)

IBPEXT = 0 No burnable poison extraction off-base calculation to be performed

= 1 A single burnable poison rod extraction off-base calculation will be performed at base state parameter conditions.

= 2 Burnable poison extraction off-base calculations will be performed for each of the state parameter off-base conditions and at base state parameter values.

ICRINS = 0 No control rod insertion off-base calculation to be performed

= 1 A single control rod insertion off-base calculation will be performed at base state parameter conditions.

= 2 Control rod insertion off-base calculations will be performed for each of the state parameter off-base conditions and at base state parameter values.

If IBASE < 0 (i.e. variable perturbations) the above set of 3.3 & 3.4 cards must be given for each burnup step and the time zero step (NBURN+1 sets).

7 SAMPLE PROBLEMS

It is not a straightforward task to define sample problems for PREP-PWR-1.0 since the code is a data pre-processor and generates data for other codes. Checking the correct operation of the code entails, on the one hand, verifying the correct calculation of certain parameters while, on the other hand, visual inspection of sizable volumes of data generated for the WIMS-D/4.1 and WEDRO1.1 codes. With some effort this can be done but the overall performance of the resulting assembly cross section library, generated by the cross section generation package, as used in global core calculations is considered the ultimate test of the code.

PREP-PWR-1.0 has already been used in an overall assembly cross section generation package to generate cross section libraries for the two nuclear power stations mentioned below. Core cycle calculations, which have been performed using these libraries, have produced acceptable results. The first library which was generated was for unit 2 of the Almaraz nuclear power station in Spain. This was done as part of the IAEA Co-ordinated Research Project on In-core Fuel Management code validation and is documented in Reference 11. The second library was generated for the two units at the KOEBERG nuclear power station and is documented in Reference 12.

A set of 5 sample problems does, however, accompany the code. These illustrate the type of systems which PREP-PWR-1.0 can treat.

Sample Problem 1 This represents a 17*17 PWR fuel assembly with no burnable poison loading. No control rod insertion calculations are performed and obviously no burnable poison rod extractions can

be done. A set of off-base state parameter calculations are performed at each burnup step. The assembly is burned for 3 burnup steps.

Sample Problem 2 This represents the same fuel assembly in Sample Problem 1 except that control rods are inserted into the assembly and the assembly is burned for 4 burnup steps.

Sample Problem 3 This represents a 17*17 PWR fuel assembly with 8 burnable poison rods. No control rod insertion or burnable poison extraction calculations are performed. A set of off-base state parameter calculations are performed at each burnup step. The assembly is burned for 3 burnup steps.

Sample Problem 4 This represents the same fuel assembly in Sample Problem 3 except that both burnable poison extraction and control rod insertion calculations are performed in addition to the set of off-base state parameter calculations. The assembly is burned for 2 burnup steps.

Sample Problem 5 This represents a 17*17 PWR fuel assembly with no burnable poison loading. No control rod insertion or off-base state parameter calculations have been performed. The fuel assembly is burned for 3 burnup steps.

8 SUGGESTIONS FOR FURTHER IMPROVEMENTS

It would be advantageous if PREP-PWR-1.0 could prepare data for the generation of cross sections for three-dimensional applications. One of the main changes envisaged in this approach is the treatment of the grids and sleeves. At this stage, the grids and sleeves are averaged over the active length of the fuel assembly. For three-

dimensional applications it would be necessary to generate two sets of cross sections; those in the vicinity of the grids and those between the grids.

It is also envisaged that an additional type of off-base calculation be introduced, namely a xenon off-base to enable xenon transients to be modelled. At this stage PREP-PWR-1.0 keeps the xenon at equilibrium conditions and thus xenon transient effects cannot be modelled. This feature is required particularly for start-up and possible accident conditions.

The logic structure in PREP-PWR-1.0 is extremely complex and can be bewildering to any programmer wishing to make changes to the code. This complex logic structure has resulted due to the large number of possible states each fuel assembly could be in. It would be much easier to make modifications to the code if the complicated "spaghetti" of IF statements were rewritten in a more ordered form.

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APPENDIX A

Group-dependent Microscopic Cross Sections used for Dancoff Factor Calculations

WIMS E-GROUP	H_1	B_{10}	C_{12}	O_{16}	Cr_{52}	Mn_{55}	Fe_{56}	Ni_{58}	Zr_{91}	U_{235}	U_{238}	Pu_{239}
15	19,19	11,10	4,38	3,48	11,82	0,05	8,10	7,51	1,53	7,53	2,71	6,82
16	19,47	13,31	4,39	3,48	13,20	0,01	3,00	16,17	1,64	8,65	2,74	8,26
17	19,74	15,75	4,39	3,48	4,94	0,24	2,77	10,75	1,68	10,15	2,85	10,31
18	19,97	18,82	4,40	3,48	3,07	0,16	3,55	9,50	1,65	11,83	3,48	9,48
19	20,00	22,66	4,40	3,48	2,94	1,91	4,35	9,31	1,52	14,60	4,41	15,21
20	20,00	30,41	4,40	3,48	2,94	0,59	5,11	10,05	1,64	18,81	5,04	17,67
21	20,00	45,50	4,40	3,48	2,95	6,82	5,61	10,70	2,05	25,55	11,36	34,31
22	20,00	65,39	4,40	3,48	2,95	0,34	5,74	10,84	1,52	39,66	16,24	49,56
23	20,00	85,30	4,40	3,48	2,96	0,33	5,76	10,90	1,52	45,36	21,38	102,17
24	20,00	108,69	4,40	3,48	2,98	0,38	5,78	10,94	1,52	77,59	68,47	33,62
25	20,04	142,06	4,40	3,48	3,00	0,48	5,79	10,99	1,52	92,78	80,13	74,04
26	20,11	182,71	4,40	3,48	3,02	0,62	5,81	11,04	1,52	89,88	2,41	242,81
27	20,20	256,00	4,40	3,48	3,06	0,88	5,86	11,13	1,52	81,57	136,03	56,84

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