Report

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WIMS - A GENERAL PURPOSE CODE FOR REACTOR CORE ANALYSIS

This is the Introduction to the WIMS User Guide made available through the ANSWERS Software Service

December 1995

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1 Overview

WIMS[1] is the most extensive and versatile software package currently available for neutronics calculations. WIMS has an open structure which comprises a set of methods linked together to form a calculational scheme that can be used to solve most problems associated with Thermal Reactor Physics. The user can tailor his or her choice of methods to get the optimal assessment to meet his or her needs. WIMS can be used to analyse problems ranging from simple homogeneous cells to complex whole core calculations. In addition WIMS links to the whole core code PANTHER[2] to act as a lattice code generating a library of cell constants.

Due to its open structure WIMS can be used on many classes of problem on all reactor types. These range from lattice cell calculations as part of the WIMS / PANTHER package to whole analysis of small reactors. The code also has features to calculate damage and heating of core components.

WIMS has a long pedigree stretching back over thirty years. Early versions of WIMS established a software tool to analyse a range of thermal reactor types including light water moderated, heavy water moderated and graphite moderated designs. The result was WIMSD[2] which was supplied by the WIMS development team to the NEA and RSIC databanks in the mid 1960's. Since then it has been a standard tool for reactor physicists world-wide and is still amongst the most often requested software from the databanks.

WIMS has been continually developed since then to become the modern software tool that is WIMS7. With the success of WIMSD, new versions evolved to permit more demanding and rigorous analyses. WIMSE, which was developed in the context of UK work in support of high temperature reactors, introduced a more modular structure, advanced resonance shielding capabilities, and a capability for 3D calculations. A special purpose version, LWRWIMS has been used extensively in the UK and Europe on light water reactor problems.

As application of these methods becomes more diverse, their range of applicability requires close scrutiny. WIMS is the first Reactor Physics code to provide an integrated Monte Carlo method, MONK5W, for the purpose of internal validation. WIMS users now have the capability of carrying out benchmark calculations on all thermal reactor types to evaluate any modelling approximation. This facility is particularly useful in new situations that have limited experimental data to validate a calculational route.

WIMS7 has remained faithful to the original concept of generating an open software package to deal with all reactor types, whilst at the same time, considerably extending and improving its flexibility and accuracy.

WIMS7 is supplied with the latest JEF2.2 validated nuclear data libraries, and a range of graphics utilities are available.

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[1] WIMS - Winfrith Improved Multigroup Scheme.
[2] For further information see Reference Section of this User Guide under Introduction

2 The Capabilities of WIMS

The WIMS7 code has an open structure which means that the user can interact with the code to tailor a calculation to his needs. This means that the code has an almost limitless range of application. In particular, the WIMS7 code has been used to calculate lattice cell data for all the major Thermal Reactor types. It can be used on the following applications :

Reactor Type	Geometry	Fuel	Moderator
PWR	Cluster of pins on square pitch	UO_2	H_2O
BWR	Cluster of pins on square pitch	UO_2	H_2O
VVER	Cluster of pins on triangular Hexagonal cluster of pins	UO_2	H_2O
AGR	Cluster of three rings of pins	UO_2	Graphite
RBMK	Cluster of two rings of pins	UO_2	Graphite
CANDU/SGHWR	Cluster of three or four rings of pins	UO_2	D_2O
MAGNOX	Single pin	U metal	Graphite
HTGCR	Particulate fuel in graphite	UO_2	Graphite
MTR	Plate fuel	U in metal	H_2O
Storage ponds	Various	Various	H_2O
Flasks	Various	Various	H_2O , Gas
Experiments	Various including Spheres	Various	H_2O, D_2O, Graphite
Reprocessing	Particles in Liquor	Various	Liquor

The code can calculate the following parameters :-

1) Reactivity.
2) Reactivity Coefficients.
3) Flux and Power distributions including pin power estimates on all reactor geometry.
4) Variations of inventory with irradiation.
5) Poison burnout.
6) Actinide and fission product inventory.
7) Heating of core components.
9) Xenon and other fission product transients.
10) Reaction rates and reaction rate ratios.

This comprehensive list of parameters covers all the major parameters required for core simulation and criticality calculations.

3 The Structure of WIMS

Users must be able to visualise their calculation broken down into a series of well defined operations, each being performed by a different module of the software. A single operation could be, for example, the production of few group nuclear data from fine group data by condensation of the group structure. The subsequent operation could then use this few group data in a lattice calculation or any other type of appropriate calculation. These separate operations communicate within WIMS by using a standard set of data files called 'interfaces'. With this concept it is straightforward to add further facilities to the code to enhance its functionality, as shown by the recent incorporation of MONK5W. The operations in WIMS7 can be subdivided into seven categories

(i) Data Preparation - Library reading
(ii) Service Modules - Data manipulation
(iii) Flux Solution
(iv) Resonance Shielding
(v) Depletion
(vi) Edit
(vii) Links to other codes

Normally a number of alternative modules are available in each category. The user can, for example, specify a flux solution by any of the following methods:

(i) Collision Probability in 1D or 2D
(ii) Characteristics Method
(iii) Sn method in 1D or 2D
(iv) Monte Carlo
(v) Diffusion Theory
(vi) Hybrid Methods

Details of the functionality and input requirements for all the modules that currently comprise WIMS are given in subsequent sections of this manual.

4 The WIMS Modules

The WIMS modules are described in Section 2 of this manual. A short outline of their capabilities is included here.

4.1 Service Modules

The linking of operations performed in individual modules into a calculational scheme is enhanced by the use of Service Modules to transform the model described by the interface before it is passed to the next calculational stage. For example, a fine 172 group model can be transformed into a quicker regrouped 8 group model by using the module WCONDENSE. The module WSMEAR can be used to simplify a complicated geometry into one suitable for a spectrum calculation. Other service modules carry out simple operations such as copying or merging interfaces, generating macroscopic cross sections, and reversing the procedure of WCONDENSE and WSMEAR.

4.2 Flux Solution and Associated Modules

There are three main categories of problem that can be solved using WIMS. These are:

(i) Flux solution - the solution of the Neutron Boltzmann Transport equation or a simplification of that equation. This includes 3D solutions or the solution of 2D problems with imposed bucklings to represent leakage.

(ii) Gamma and Neutron Heating - The estimation of gamma and neutron source strengths, their migration and subsequent energy deposition.

(iii) Depletion - the calculation of the change in nuclide inventory due to irradiation of materials.

All these solution methods are available in WIMS7. A wide range of flux solution options is available as summarised below.

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Module	Method
THESEUS	1D Collision Probability method
FLURIG	1D Collision Probability method
PIJ	2D Collision Probability method with special options for clusters of pins
PRIZE	2D Collision Probability method - R,Z geometry
PROCOL	Collision Probability method for Granular Fuels
SPECTROX	Simple Collision Probability method for Spectrum Calculation
PERSEUS	Multicell Collision Probability method for Spectrum Calculation
PIP	Flux Solution for Collision Probability method
DSN	1D Sn method
TWOTRAN	2D Sn method
CHART	1D Characteristics method
CACTUS	General 2D Characteristics method
SNAP	3D Diffusion theory method
MAX	3D Hybrid Monte Carlo method
MONK	3D Monte Carlo method

The structure of the scheme is such that geometric information (apart from volumes and material allocations to them) is confined to the particular solution in use. This allows considerable flexibility. The main extensions compared to earlier versions of WIMS lie in the linkage to a three dimensional diffusion program WSNAP, more extensive transport options, including WCACTUS and WTWOTRAN and the incorporation of Monte Carlo options including MONK5W with all its general geometry capabilities.

WIMS has a general depletion module WBRNUP which can treat all burnup problems. There are a variety of options in WBRNUP to allow the user to choose from two basic methods of solving the depletion equations and there are special methods to deal with burnable poisons.

The neutron and gamma heating methods utilise the WPHODAT and WGAM modules. The WPHODAT module accesses a special library to generate the photon sources resulting from a given irradiation in a problem. The WGAM module then carries out a photon or neutron transport calculation to estimate the distribution functions. This calculation is carried out using a Monte Carlo technique. The neutron or photon distributions are then transformed into heat deposition distributions.

4.3 Edit Capabilities

A general print control scheme has been devised to provide the user with very wide control over the level of output printed. A range of edit modules are provided to allow the user to print the contents of an interface, or information such as reaction rates. A new, more comprehensive, edit module called WEDIT is now available with WIMS. This module allows users to interrogate one or more interfaces and

print in a concise form the main quantities being analysed such as reaction rates, reactions, power distributions and reactivity. This comprehensive edit capability will become the basic module for future development of output features in the current and future versions of the code.

4.4 Links to Other Reactor Physics Software

WIMS also interfaces with other Reactor Physics software. The special purpose module called WLED links a database of reactor specific few group cross-sections, as generated by WIMS, to the PANTHER whole core code to produce an integrated neutronics and thermal hydraulics calculational scheme for a power reactor. In a similar way the TRAIL facility continues burn-up dependent cross sections, as generated by WIMS, with an extension database of other cross sections and the latest fission yield and decay data , to provide input to the FISPIN[3] inventory activity code.

5 Input Facilities

The basic input to WIMS is via sequential codeword and parameter strings. To improve the WIMS user image a series of graphical support programs have been developed.

(i) CACTUSEdit[4] , a GUI based tool for interactively setting up and displaying any 2D CACTUS model.

(ii) MONK5WView[4], provides 2 & 3D representations of a MONK5W geometry model. These representations can be viewed in any level of detail via a simple-to-use GUI interface. Ray tracing through a geometry model to display the geometry as seen by the particle tracking routines of MONK5W is provided by a complementary tool, VISAGE,.

(iii) MENTOR, a fully customisable graphics based utility that simplifies data input for standard applications. The user has only to choose between a series of parameters to set up the input. MENTOR thus helps the user to become familiar with WIMS input and simplifies execution of production work requiring many repetitive type calculations. MENTOR is supplied with a set of input templates for standard calculational routes for PWR, AGR, BWR, VVER and other systems on request.

These facilities for input preparation and visualisation have improved the process of building and checking data for complicated problems using WIMS7. Further details of these facilities are given in the graphics section of this manual.

[3] For further information see Reference Section of this User Guide under Introduction.
[4] Developed by ECN Petten and available through ANSWERS.

6 Nuclear Data Library

Vital to any neutronics calculation is the nuclear data library. The WIMS data library has been progressively improved since the first version of the WIMS code. Originally the data was predominantly obtained from the UK Nuclear Data Library (UKNDL) using UK based library preparation codes. This led to widely used 69 group WIMS 1986 library. With the widespread use of the code and the greater international co-operation over basic nuclear data, a new library has been generated from the internationally validated JEF2.2 evaluation.

The JEF2.2 library has both a 69 group form, where the group structure is the same as the older libraries, and a new 172 group form. This new group structure was designed to improve the accuracy of the code when dealing with higher actinides and also to make cross comparisons with other reactor physics software, such as the French APOLLO scheme, more straightforward. In addition, the new data library has extra nuclides and extra reactions included to satisfy two needs. First, the treatment of actinides and their depletion requires both extra reactions (e.g. n,2n) and extra nuclides to accurately model the burnup of these nuclides. It is necessary to allow branching to model the depletion of some of the higher actinides. Secondly, the accuracy of the fission product treatment has been improved by increasing the number of fission products to more accurately cover the production of nuclides from fission. With the new library, 99% of the total reactivity effect of the fission products is now modelled explicitly. The use of pseudo fission products has now been eliminated for modelling absorption. One pseudo fission product remains on the library to model the effect of fission product scatter. This effect was not treated in previous libraries.

The JEF 2.2 library has been benchmarked against a wide range of applications The total validation evidence now runs to some hundreds of comparisons ranging from simple lattices to operating reactors, and the uncertainty bounds due to nuclear data are well determined for most applications.

For the old libraries largely based on UKNDL, the validation procedure led to adjustments of data when they could be clearly shown to be justified. In the early days the most important of these was a change in the Uranium-238 resonance integral which was subsequently confirmed to be due to inaccurate measurement of capture widths in the low lying resonance. With the recent JEF2.2 tabulation this adjustment process has not yet been necessary; however this is an ongoing process and there is continuing work aimed at improving the performance and accuracy of the data library.

The new data library with its enhanced 172 group structure and an extended list of nuclides and reactions has extended the range of application of WIMS and now permits more accurate calculations of alternative and new fuel cycles such as MOX.

7. Resonance Modelling

An accurate, rapid, deterministic method of treating resonance capture is central to the success of any reactor physics code scheme. In common with all previous WIMS versions, WIMS7 can treat resonance capture by an equivalence model procedure. With the inclusion of the LWRWIMS facilities in WIMS7, the range of this equivalence method covers all the major thermal reactor geometries. The method

provides average cross sections for any fuel pin for energy groups in the resonance region, ie from energies of 4eV to 9 keV .
For many purposes this is adequate, but there are some for which it is not. Examples of these are granular fuel elements, dissolved fuel, Duplex fuel (a two zone fuel pellet with low enrichment in the centre)

WIMS7 also has a well tested sub-group model which permits accurate calculations to be made for such cases - indeed for any of the wide range of geometries that the code is capable of modelling. The methodology used in WIMS7 is the one developed and applied in WIMSE and as such has been well validated. The data are directly obtained from the resonance integrals used in the equivalence model and the two are essentially identical for simple problems.

Use of these resonance shielding methods has been extensively validated against both reactivity and reaction rate (conversion ratio) measurements.

8 New Features and Improvements in WIMS7

WIMS7 includes several significant enhancements of its predecessor WIMS6. The major changes are:-

(i) Inclusion of the full LWRWIMS capability.
(ii) Improvements to WCACTUS.
(iii) Improvements to the poison burnup option in WBRNUP.
(iv) Inclusion of WTWOTRAN and a Reflector edit.
(v) Streamlining of Input/Output.
(vi) Inclusion of WEDIT.

8.1 Inclusion of LWRWIMS Features

The features in LWRWIMS that allowed LWR reactors to be modelled accurately have been included in this release. An option has been added to the WHEAD module to allow the use of LWRWIMS style input for a LWR assembly on an (x,y) pitch. This then leads to the same resonance calculation as in LWRWIMS with its ability to deal with any variant on the design of LWR fuel elements with a rectangular outer boundary. Allied to this change a new module called WPERSEUS has been included. This model takes the LWR geometry and performs a spectrum calculation to be used to generate few group nuclear data. The method uses the same multi-cell method used so successfully in LWRWIMS.

8.2 Improvements to WCACTUS

WCACTUS, the general 2D characteristics method, has been the subject of intense modification for WIMS7 to promote WCACTUS as the prime flux solution for production use. Improvements include:
(i) Execution has been speeded up by a factor of three. This has been achieved mainly by a simple change to the strategy for dealing with the exponential function.
(ii) The earlier versions of the code would not converge for cases with a fine group structure. This was due to the so called ‘negative self scatter ‘effect. The mode of convergence has been changed and this problem has been removed.

(iii) Input of data for standard LWR lattices has been improved. The amount of data required for a standard LWR lattice cell calculation has been greatly reduced by using this option.
(iv) The restart option has been improved so that in a depletion calculation a previous sub-group or main transport flux solution can be used efficiently in subsequent cycles. This has reduced the convergence time and thus speeded up the calculation.
(v) Input of data for a standard VVER calculation has been improved.

These changes have resulted in improvements in the speed and range of WCACTUS as well as improving the user image of the module. WCACTUS is now regarded as the major flux solution module in WIMS7.

8.3 Improvements to the Poison Burnup Option

Improvements have been implemented in the WBRNUP module, which can be use to carry out depletion calculations. In earlier versions of WIMS the poison option only treated poison pins that had no fissile content. In a standard LWR calculation where the poison is incorporated in a fuel pin this was a major deficiency resulting in an inaccurate calculation of the burnout of poison pins . This deficiency has now been removed by the addition of a method similar to the FINE option in LWRWIMS. This method is general and can be used on any reactor type that is now available in WIMS7.

8.4 Inclusion of WTWOTRAN and a Reflector Edit

The transport method TWOTRAN which was available in LWRWIMS has been added as a flux solution module. The geometry of this module is at present restricted to (x,y) but that will shortly be updated to include other 2D geometries at the next release. In addition to this change the WMIX module has been extended so that a route can be set up in WIMS7 to calculate reflector data for PANTHER. This route is similar to that already operational in LWRWIMS, but due to the structure of WIMS7, has the potential to be more flexible.

8.5 Streamlining Input / Output

A series of minor changes to the input and output have been carried out. In particular these allow the user to input nuclide names (e.g. U235) instead of nuclide identifiers in all modules in WIMS7. The changes also removed the necessity of inputting some default parameters. Better output controls for standard production runs have reduced the output to more manageable quantities.

8.6 Inclusion of WEDIT

The WEDIT editing facility has now been included in WIMS7 so that the code can be used within cyclic calculations.

8.7 Improvements to WLED

The WLED module, used for writing a database for PANTHER, has been modified so that pin power reconstruction data is readily input for all reactor geometries.

9 Quality Assured Code Management

Quality Assurance (QA) is essential in all areas of design, manufacture and operation of nuclear facilities. Computer software used to analyse these facilities is no exception, especially in the area of safety assessment. QA principles embrace all aspects of a software package including development, maintenance and in-service use within the industry. In the United Kingdom, these requirements have led to the establishment of the ANSWERS Software Service to act as a centrally controlled repository and distribution centre for all major computing codes and data libraries used in areas of reactor physics, criticality and shielding. In addition ANSWERS provides a code user support and training service.

The ANSWERS Software Service uses a comprehensive set of software management procedures to ensure the entire software life-cycle including specification, design, coding, testing and in-use support and maintenance is conducted within an established Quality Management System. These standards are employed in the development and validation of WIMS and in the commissioning and user support of the software and data. The Quality Management System provided by these procedures is certified against the International Standard ISO 9001.

When the development of a version of WIMS has been completed the source code is then passed to ANSWERS for testing, commissioning and finally distribution as a recognised updated version of the WIMS code. The version of WIMS is formally identified (e.g. WIMS7A) and the changes made since the previous version and the documentation that supports those changes are recorded and archived. ANSWERS then commissions the version of WIMS onto a range of industry standard computer platforms and distributes the code to the user community in the form of uniquely identified load modules.

The load module for each computer type is fully tested at the completion of the commissioning phase and again on installation at the user site. Note that this latter installation phase is simply a process of copying an executable program - no source code implementation is required by the user and the code can be up and running within a couple of hours.

Each issue of a version of WIMS is distributed in ready-to-run form for maximum user confidence and convenience, with each step in the development and distribution sequence being performed under an effective Quality Management System. The route from source code to in-use load module is maintained in a fully traceable form by ANSWERS for current and archived versions of the code. The adoption of these QA procedures has added to the confidence in the use of WIMS for reactor physics calculations and is aimed at meeting the requirements of all code users both today and in the years to come.

10 Code Distribution and User Support

The current version of WIMS is WIMS7A and is available through the ANSWERS Service of AEA Technology. WIMS7A has been commissioned on a wide range of computer hardware including mainframe, workstations and personal computers (PCs).

The standard package issued by ANSWERS comprises:

Executable load modules for WIMS7, MENTOR
Standard nuclear data libraries (172 and 69 groups)
Sample problem inputs and outputs for implementation
Hardware-specific installation guide
User Guide and Reference Manual
Validation Manual

Options include the MONK5W module, CACTUSedit, MONKVIEW and VISAGE.

The ANSWERS Service offers a comprehensive user support package which includes maintenance, trouble-shooting and expert advice, as well as providing access to new code versions as they become available. In addition, regular seminars and training courses are held, including well-established hands-on workshops for those new to the code.