NEXUS/ANC 9

The next-generation Westinghouse core design system

Westinghouse

Introduction

NEXUS/ANC 9 is the next generation Westinghouse core design system. It accurately and efficiently models and predicts core performance for all square-lattice pressurized water reactors (PWR), including the **AP1000**® PWR. The solution techniques are state of the art, fast and accurate. New usability features, which were developed using Human Performance tools, allow rapid setup of core models and analysis of core conditions.

The NEXUS code system is used to generate cross-section data files for the core simulator, ANC 9. These data files are generated only once for each unique region of fuel, and include a full range of fuel and moderator temperatures, burnups, and other core conditions for modeling the fuel throughout its lifetime in the reactor. The NEXUS "once-through" cross-section methodology was licensed with the U.S. Nuclear Regulatory Commission (NRC) in 2007.

ANC 9 is the latest version of the ANC multidimensional PWR core neutronics simulator. ANC was originally licensed with the NRC in 1986 and has been used as the analysis code of record for core design safety analysis and plant operational data calculations for well over 500 PWR plant cycles. These designs span virtually all PWR plant and fuel lattice types (14x14 to 18x18) with fuel enrichments up to 5.0 w/o, removable (Pyrex, WABA) and integral (IFBA, gadolinia, and erbia) fuel burnable absorbers including combinations of both, and cycle lengths from 12 to 24 months. Compared to other current 3D simulations, ANC 9 introduces a markedly improved pin-power reconstruction methodology that was licensed with the NRC in 2010.

ANC is in use by more than 30 utilities, fuel vendors, government institutes and universities in nine countries.

The NEXUS/ANC 9 system is the solution engine powering Version 7 of the BEACON™ Core Monitoring System, the only online PWR core monitoring system approved by the NRC. BEACON 7 can interface with both moveable and fixed incore detector flux mapping systems.

NEXUS Code System Overview

NEXRun

The running of the NEXUS code system (Figure 1) is fully automated via NEXRun, the only code with which the user has direct interaction.

NEXPre/ALPHA 9

NEXPRe and ALPHA 9 work together to automate the matrix of calculations for the PARAGON lattice code, covering all the conditions needed for the once-through cross-section data files used in ANC 9.

PARAGON

PARAGON is the state-of-the-art lattice physics code that calculates the required cross-section data for ANC. PARAGON was licensed with the NRC in 2004 and has been used for core designs since 2005. The complete generalized geometry capability allows for accurate, explicit modeling of current and future heterogeneous fuel designs.

NEXLink

NEXLink processes the nuclear data from the PARAGON lattice code and generates fitted cross-section data needed by the ANC 9 core simulator in HDF5 file format.

Repository Data System

The repository data system is a controlled and verified library of plant- and fuel-component data.

The NEXUS code system is designed to be user friendly. With very few lines of NEXUS inputs, the user can generate all the data needed by the core simulator and core monitoring systems.

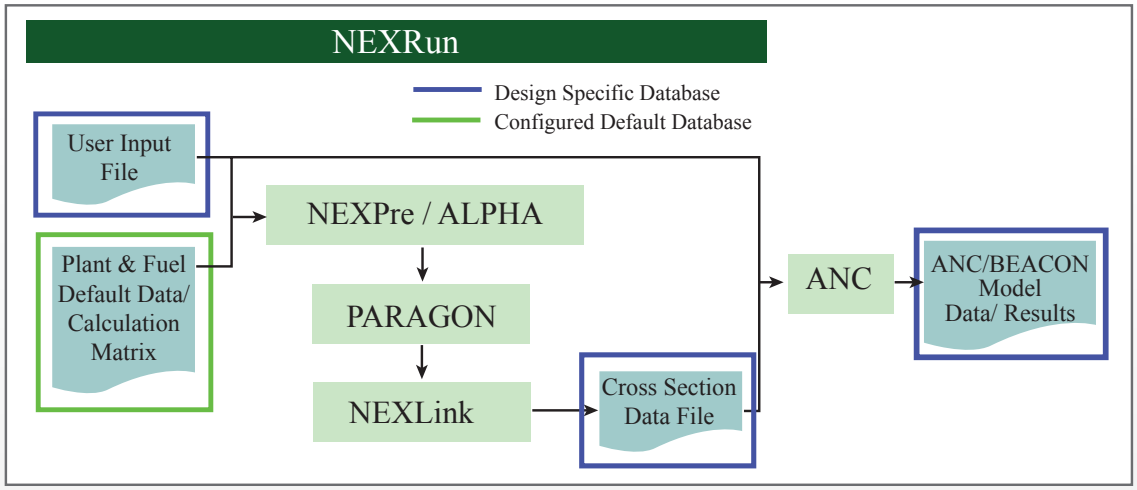


Figure 1 - NEXUS Code System

ANC 9 Overview

ANC 9 is a highly accurate and efficient three-dimensional core neutronics simulator built on years of experience in nodal simulation. ANC 9 incorporates many enhanced core physics methodologies. It is designed to support a wide range of PWRs currently under operation, as well as the evolutionary core operational features of the **AP1000** plant design. ANC 9 employs the once-through cross-section methodology, implemented through the NEXUS code system and the nodal expansion method, providing accurate predictions for a wide range of operating conditions.

ANC 9 capabilities include:

- Once-through, full-temperature-range, cross-section methodology
- Detailed, node-wise tracking of core depletion parameters and isotopics
- Advanced modeling of control rod cusping effects for accurate differential rod worth predictions
- Improved thermal-hydraulic modeling by integrating the VIPRE-W[1] thermal-hydraulic code
- Axial homogenization model
- Explicit modeling of spacer grids
- Flexible axial meshing
- B-10 depletion during cycle burnup
- Modeling of incore detectors – both fixed-incore and movable detectors
- Automated sequences for most reload design applications
- Seamless integration with the BEACON core monitoring system
- Automation of core predictive and monitor calculations to power the BEACON system
- Features for **AP1000** plant analysis, including Mechanical Shim (MSHIM) Rod Control
- User-friendly interface
- Fuel shuffling checks
- Searches on key core parameters such as boron concentration, control rod position, power level and axial offset
- Wide variety of user-selectable edits for the display of desired results

– [1]VIPRE-W incorporates technology developed for the United States Electric Power Industry under the sponsorship of EPRI, the Electric Power Research Institute.

Description of Technical Features

ANC 9 decouples the exposure and neutronic mesh structures by using a 1-D axial homogenization method for each channel (Figure 2). This method does not require assembly axial meshes to coincide and allows for explicit modeling of control rod positions, burnable absorbers and spacer grids. Another advantage of the axial homogenization model is that it allows for advanced treatment of the control rod cusping effect, which results in improved differential rod worth predictions.

Exposure, solution and "physical" axial mesh structures are combined in a detailed sub-node mesh. The cross sections are evaluated on the sub-node mesh and homogenized to the nodal mesh using the axial homogenization model. Multiple axial mesh configurations are possible in ANC 9 (Figure 2).

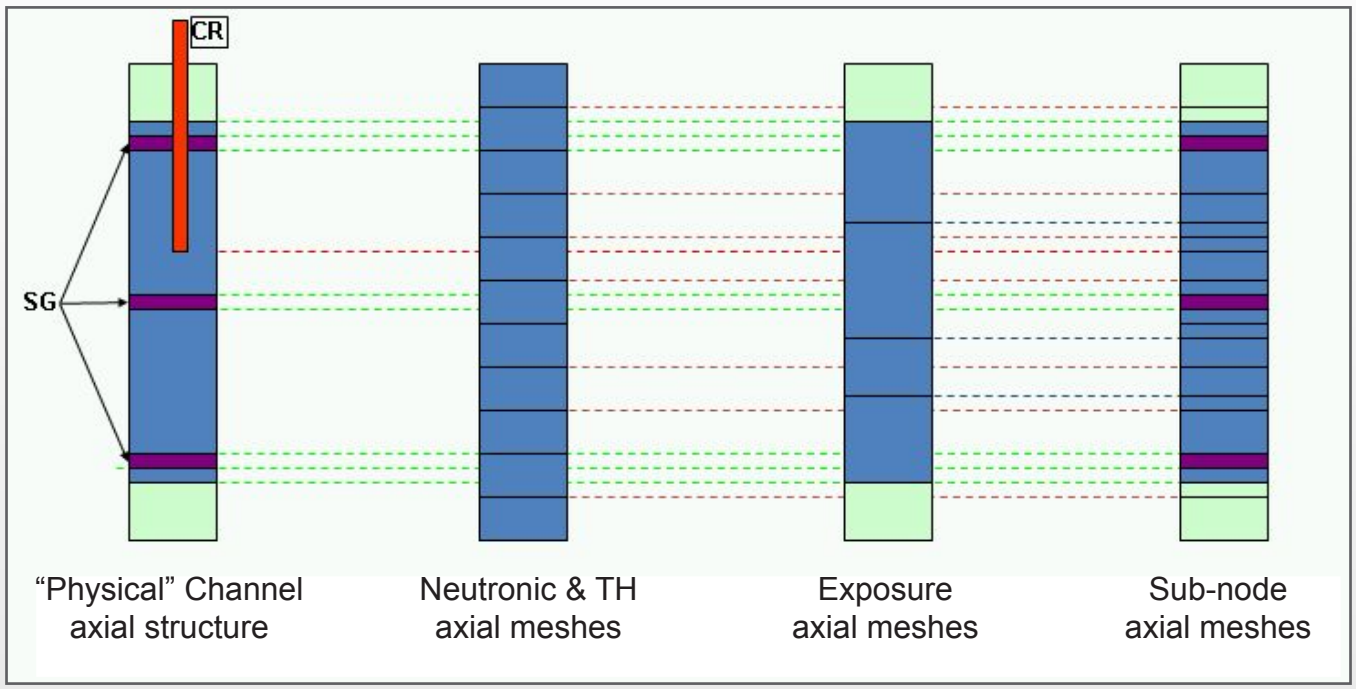


Figure 2 - ANC 9 Axial Mesh Configurations

Support for Transient Nodal Analysis

The NEXUS/ANC 9 code system includes neutron kinetics capabilities approved by the NRC. The time-dependent solution is based on the stiffness confinement method, which is designed to efficiently and accurately solve the time-dependent equations during core reactivity transients. This capability can also be used as the nodal kinetics solver in the NRC approved Westinghouse methodology for severe rod ejection and non-LOCA transient analysis.

Support for Nuclear Design Calculations

ANC 9 automates many of the standard nuclear design calculations for both safety assessment and operational data in the Westinghouse reload methodology and avoids tedious, error-prone user input. These include the automated calculations of reactivity coefficients and rodded scenarios, such as rod worth, stuck rod and rod ejection.

Support for Startup Physics Testing

The NEXUS/ANC 9 system includes full functionality to support Westinghouse's NRC-approved startup physics testing techniques, including dynamic rod worth measurement (DRWM™). In its third decade of use, DRWM-based low-power physics testing (LPPT) has been applied in over 200 plant startups at 40 units.

Support for Core Monitoring

The NEXUS/ANC 9 system is the calculational engine powering the BEACON 7 (Figure 3) system; the 3D core monitoring model is identical to the 3D core design model used to license the core. The NEXUS/ANC 9 code system can model in-core instrumentation for online core monitoring, including movable and fixed-incore detectors and thermocouples.

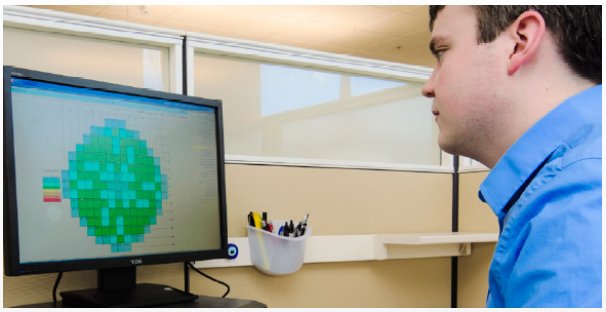
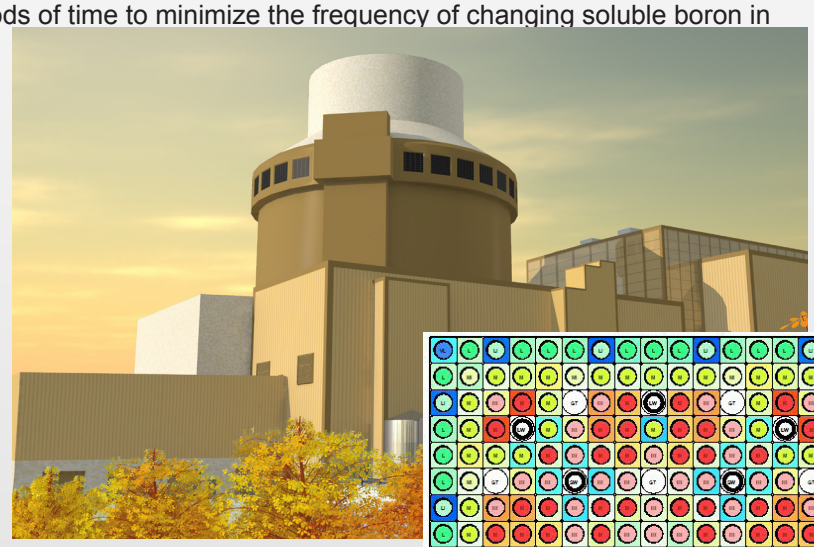


Figure 3 - The BEACON™ Core Monitoring System

Support for AP1000 Nuclear Reactor Modeling

The design of the Westinghouse **AP1000** nuclear reactor presents additional requirements beyond conventional PWRs for nuclear design code systems. The **AP1000** nuclear reactor is designed to operate with the mechanical shim (MSHIM) operational strategy that has control rods inserted into the fuel for significant periods of time to minimize the frequency of changing soluble boron in the primary reactor coolant and associated water processing.



The MSHIM logic has been integrated into the NEXUS/ANC 9 code system. Users can simulate the base load and load following operational scenarios using the MSHIM Search and MSHIM base-load automated functions.

The MSHIM strategy requires robust cross-section representation and pin-power reconstruction methodology that are able to capture the effect of control rod presence on the fuel during depletion. NEXUS/ANC 9 includes an innovative, efficient and recently NRC-approved methodology to automatically calculate these effects without any special user intervention or input.
Additionally, NEXUS/ANC 9 tracks the effects of control rod depletion by depleting the actual control rod materials, including tungsten.

NEXUS/ANC 9 can model highly heterogeneous enrichment and burnable absorber assembly designs (Figure 4) used in the **AP1000** nuclear reactor, particularly in the Advanced First Core Design.

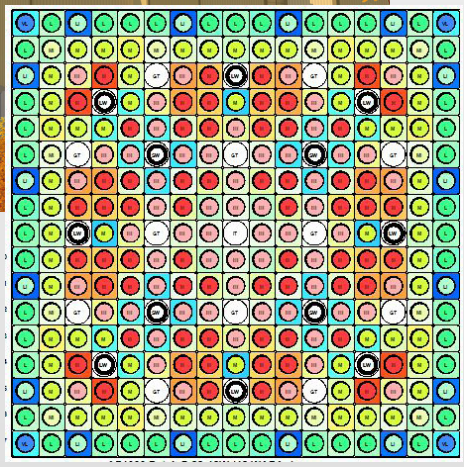


*Figure 4 – **AP1000** Example Lattice Design*

Integration with Westinghouse Technology Products

The NEXUS/ANC 9 code system, with its ancillary codes, provides seamless interfacing with several Westinghouse technology products to streamline and reduce unnecessary conservatism in reload design and plant support activities:

- Fuel rod power distribution information for the PAD fuel performance code via the ALFRED interface code
- VIPRE-W code system linkage via the ANCKVIPRE application for steam line break analysis analysis and 3-dimensional reactivity insertion accident (RIA) analysis
- VIPRE-W and BOB/BOA code linkage with modeling flexibility from whole core to subsections of a fuel rod for CIPS/CILC loading pattern risk assessment

System Qualification

The NEXUS/ANC 9 code system has been extensively qualified and is fully licensed by the NRC. PARAGON has been qualified against a variety of industry-standard critical experiments and MCNP benchmarks, and was licensed in 2004. ANC was initially licensed in 1986, then as part of the PHOENIX-P/ANC code system in 1988, and later as part of the PARAGON/ANC code system in 2004. The NEXUS/ANC 9 code system was fully qualified for all core design applications and approved by the NRC in 2007 for uranium-fueled PWRs.

These qualifications involved comparisons of ANC predictions against measurements for many operated PWR cycles, including comprehensive reactivity, temperature coefficient and power distribution comparisons. These benchmarks were performed for numerous plants with varying lattice and fuel types, power ratings and cycle lengths, and included the full range of safety and plant operational data calculations for both first and reload cores.

Of course the most important qualification of any nuclear code system is the successful design of operating plant cycles; ANC has been used as the core design code of record for hundreds of operated cycles and continues to be used for designing PWR cores worldwide. NEXUS/ANC 9 continues this tradition by integrating improved methodology, ease of use and extensibility with the proven track record of ANC.

Software Process

The NEXUS/ANC 9 code system has been developed under a rigorous software quality assurance process. Software developed at Westinghouse follows the ISO Tick/IT standards. It has been developed in close collaboration with technical experts from across the worldwide Westinghouse organization. The code system has been tested in real-world situations by end users, at Westinghouse, at other fuel vendors and at utilities.

Operational Platform

The NEXUS/ANC 9 code system is designed to run on Westinghouse-qualified computer systems running the 64-bit SuSE Linux Enterprise Server operating system on Intel processors. The Westinghouse Network Management Service provides customers with Westinghouse-qualified computing hardware that is tailored to their computing needs and is backed by round-the-clock support from Westinghouse engineers. Customers may also choose to have Westinghouse host their computing needs with the Customer Collaboration Center (C3) product.

Training

Westinghouse has extensive experience in partnering with domestic and international customers in implementing technology products to perform independent core design activities. Westinghouse can also work in a collaborative mode providing technical support.

Future Research and Development

Westinghouse is committed to continually improving the NEXUS/ANC 9 code system through its near-term and long-term research and development activities. The NEXUS/ANC 9 code system has been selected as the reference benchmark core simulator used in the U.S. Department of Energy sponsored Energy Innovation hub project led by the Consortium for Advanced Simulation of Light Water Reactors (CASL). The NEXUS/ANC 9 code system is supported by a dedicated group of physics methods and software engineers devoted to improving the capabilities of the system.

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