JOSHUA—A Nuclear Reactor Design and Analysis Computational System

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Abstract

JOSHUA is a computational system developed to perform the extensive engineering and physics calculations needed in the design and analysis of Savannah River Plant (SRP) nuclear reactors. Application of this system significantly enhanced the efficiency, effectiveness, accuracy, and safety of nuclear reactor design and analysis. The unique features of SRP reactors, which necessitated the Site's development of its own, unique design and analysis capability, are described. Short histories of computer science and reactor physics and engineering, and the state of those sciences when JOSHUA development began in 1968, are presented. The first transistor-based computers, with random-access disk storage and computer terminals, had just become commercially available. SRP had used the technical developments from the Manhattan Project and had developed extensive experimental data describing SRP reactor phenomena. The JOSHUA system, including both the operating system and the applications system, is described. The importance of such a modular, data-based computational system for the multi-step, iterative reactor calculations is explained. The significance of this development is discussed in terms of its impact on SRP reactor design and analysis, its impact on the development of integrated computational system for reactor design and analysis, and its impact on computer science.

Introduction

JOSHUA[1] is a computational system developed to perform the extensive engineering and physics calculations needed in the design and analysis of Savannah River Site (SRS) nuclear reactors (Honek 1975). Development of the system began in 1968 and continued for about a decade. JOSHUA is a modular, data-based scientific computing system. It comprised an operating system to facilitate data management, program execution, computer terminal use, and an applications system to perform the numerical calculations representing the science and engineering models. JOSHUA applications represent an improved organization and enhancement of science and engineering models based upon the powerful theoretical, mathematical, and experimental methods that were developed during the Manhattan Project and improved in subsequent years. The JOSHUA Operating System was revolutionary in that it used new computing technologies that were just beginning to become commercially available. These technologies included solid-state electronics for both memory and digital computation, random access data storage disks, and computer terminals to display alphanumeric characters and graphics. At Savannah River, safety considerations were always paramount in the design and operation of the nuclear reactors, and JOSHUA applications reflect this priority. The use of the JOSHUA system significantly enhanced the efficiency, effectiveness, accuracy, and safety of nuclear reactor design and analysis.

Development of JOSHUA in Historical Context

The Savannah River Plant Reactors

The Savannah River Plant, now Savannah River Site, was built to produce the nuclear materials, principally tritium and Pu-239, required by the United States nuclear weapons program. When the United States government announced its decision to build the Site in 1950, there were very few reactors in the world, almost all in the United States, and each of these reactors was unique. By the late 1950s, a number of companies in the U.S. and other countries were developing the reactors that would form the basis of the nuclear power industry for commercial electrical generation. These commercial ventures focused on relatively few reactor types and sought the economic benefits of reactor standardization. Because the Savannah River Plant reactors were intended for materials production, they were of a very different design than the nuclear reactors that were built later to produce electricity and for marine propulsion. The SRP design was strongly influenced by experience in design and operation of the production reactors built at Hanford, Washington, during the Manhattan Project. Some of the characteristics that distinguished Savannah River reactors from other reactors, especially power reactors, are the following:

- Low pressure and low temperature operation
- High specific power (i.e., heat generation rate per unit volume produced in fuel materials)
- Very high heat fluxes (i.e., heat transfer from fuel materials to coolant)
- Heavy water (i.e., D_2O) moderator and coolant
- Downflow of coolant through fuel assemblies
- Metal fuel materials, generally aluminum alloys clad in aluminum, rather than ceramic fuel materials
- Calandria reactor vessel construction with an upper plenum. Coolant flows from the upper plenum, down through multiple channels in each of about 600 fuel assemblies, exiting the assembly through a bottom end fitting and into the bulk moderator space. The coolant exits the reactor through six nozzles in the bottom of the vessel and is pumped through light-water-cooled heat exchangers and back into the upper plenum.
- Each of the fuel assemblies is composed of nested, concentric fuel (or target) tubes or annular slugs. The tubes are thin-walled, and the coolant channels between the tubes are thin.

The materials production purpose of these reactors led to unique design criteria and operating characteristics. The basic scientific principles governing the neutron physics, heat transfer, and fluid flow phenomena that occur in Savannah River Plant reactors are those that also apply to all other reactor types. However, the physical conditions and characteristics of the SRP reactors are different from those in power reactors. Thus, Savannah River design, operations, and safety analysis necessitated that unique experimental, theoretical, and computational capabilities be developed, maintained, and applied at the Site. No other sites had similar reactors. Full-scale experimental mockups existed to test the hydraulic characteristics that occurred in fuel assemblies. A full-scale experimental facility representing a one-sixth sector of the reactor was used to model heavy water flow in the moderator space. A full-scale, zero-power experimental reactor (the Process Development Pile, or PDP) was used to measure the nuclear characteristics of full reactor charges. Columbia University performed important thermal-hydraulic experiments for Savannah River, using electrically heated tubes to simulate the nuclear heating that occurs in fuel tubes.[2]

Some History and the State of Nuclear Science and Engineering in 1968

Nuclear science and engineering has a rich personal and technical history including the stories of Marie Curie, Roentgen, Hahn, Strassmann, Einstein, Bohr, Fermi, Bethe, Oppenheimer, and many others. The early history of this science encompassed only a century. With the discovery of nuclear fission just at the advent of World War II, the pace of discovery and development quickened. In his famous letter to President Roosevelt, Albert Einstein advocated pursuit of nuclear research aimed at potential military applications. During the wartime Manhattan Project, some of the world's most talented scientists worked together in theoretical, mathematical, and experimental efforts that led to developing nuclear reactors to manufacture materials that could be separated, purified, and fabricated into nuclear weapons. A number of experimental nuclear reactors were built, and, ultimately, the production reactors were built at the Hanford Works. These reactors produced the fissionable Pu-239 that was used in the "Trinity" test and subsequently used against Nagasaki on August 9, 1945, following by only three days the attack on Hiroshima. Following World War II, nuclear reactor science continued to develop at a rapid pace, with emphasis changing from the startling, dramatic discoveries of the war years to sustained improvement in theories, methods, and nuclear properties of materials. The understanding of nuclear science and engineering that resulted from this work was available and applied in the initial design and development of the SRP reactors. Through the 1950s and 1960s, nuclear reactor scientists and engineers continued to refine this science, and its application, as Savannah River operations evolved and became more effective and more efficient. Important experimental work was performed at Savannah River Plant, but the use of computational and numerical methods was severely limited because "computing machines" included only graphs, hand calculations, slide rules, electromechanical calculators, and large, lethargic vacuum tube-based computers.[3]

Some History and the State of Computer Science in 1968

After the emergence of the abacus in Asia Minor about 5,000 years ago, it was several centuries until the next significant advance emerged in computing devices. In 1642, Blaise Pascal invented a numerical wheel calculator to add sums up to eight figures long. In 1694, Gottfried Wilhem von Leibniz improved on Pascal's machine with a device of wheels and gears that could multiply. In 1812, Charles Babbage built a machine powered by steam and as large as a locomotive, which would have a stored program and could perform calculations and print the results automatically. In 1889, Herman Hollerith, in search of a faster way to compute the U. S. census, invented a computer using punched cards to store data, which were fed into the machine that compiled the results mechanically. In 1931, Vannevar Bush developed a calculator for solving differential equations that had long left scientists and mathematicians baffled. John Atanasoff and Clifford Berry envisioned and by 1940 developed an all-electronic computer that applied Boolean algebra to computer circuitry.

As with nuclear science and engineering, computer science sustained a dramatic acceleration in World War II. The German engineer Konrad Zuse developed a computer to design airplanes and missiles. The British applied computers to breaking secret codes. In 1944, Howard Aiken led a Harvard-IBM team to produce an all-electronic calculator,[4] the Mark I, to create ballistic charts for the U.S. Navy. The ENIAC,[5] also spurred by the war effort, was a vacuum-tube-based computer that was more than 1000 times faster than the Mark I. In 1945, John von Neumann led the development of the EDVAC computer that represented a profoundly important, new computer architecture with a memory to hold both data and a stored program and a central processing unit, which allowed all computer functions to be coordinated through a single source. UNIVAC I, built by Remington Rand in 1951, was the first commercially available computer to take advantage of von Neumann's new architecture. In 1948, the invention of the transistor[6] radically changed computer developments. By the early 1960s, almost all new computers used transistors rather than vacuum tubes and contained printers, tape storage, disk storage, memory, operating system, and stored programs. By 1965, most large businesses routinely used "modern" computers such as the IBM 1401 to process financial information. These machines used new high-level languages such as COBOL and FORTRAN to develop an ever-broadening array of financial and technical applications.

From Site startup in 1951, Savannah River scientists and engineers had only limited access to computers: a Card Punch Calculator 7 was acquired in April 1953; an IBM 650, in 1955; and an IBM 703, in January 1962. In 1966, SRS acquired its first solid-state computer, the IBM 360/65. Punched cards were still used as an input medium, printed paper as the output medium, and, for reasons of cost, magnetic tape was the preferred medium for storing large volumes of data. Random access, hard disk storage was available for rapid access to data in large volumes, but this capability was very expensive. Computer terminals with cathode ray tubes and keyboards were available, but they had essentially no processing capability. They simply transmitted one character at a time from the keyboard to the computer to which the terminal was attached or transmitted one character at a time from the computer to the terminal screen. These computers, as installed, had modest impact on the important work of designing and analyzing efficient and safe nuclear reactors for SRS.

In the early 1960s, other nuclear installations in the United States had acquired "modern" solid-state computers. A number of computer programs had been written to perform some of the basic neutron physics calculations required for nuclear reactor design. In fact, the conceptual "inventors" of the JOSHUA System, H. C. Honeck and J. E. Suich, had both received doctorate degrees in nuclear engineering at Massachusetts Institute of Technology. During their academic work and subsequent work at Brookhaven National Laboratory on Long Island, Honeck and Suich had each authored some of the most advanced computer programs used for calculating neutron physics characteristics that occur in nuclear reactors. Honeck's work, represented by the THERMOS program, described the transport of neutrons as they bounced around within nuclear reactors and interacted with the fuel, moderator, coolant, cladding, and structural materials. One of the most important of these interactions is the "slowing down" (i.e., "thermalization") of "fast" neutrons to lower velocities at which they become more effective in producing a fission event (i.e., the "splitting" of an atom of fuel material) and sustaining the chain reaction. Suich's work represented a significant refinement of this approach. He treated in greater detail and with greater accuracy the "slowing down" of the fast neutrons through the so-called "resonance" velocities, during which the neutrons are particularly susceptible to being captured parasitically by materials in the reactor and thus being removed from contributing to a sustained chain reaction. After Suich's employment at SRS, he and Honeck, during his tenure with Brookhaven National Laboratory and later with the Atomic Energy Commission, collaborated to meld their separate computer programs, plus some new ancillary programs, into an integrated package called HAMMER. HAMMER, although it operated on the "antiquated" computers of the 1950s, became the first significant computational tool for reactor design and analysis at SRS. An important reason for this success was the extensive work at SRS to refine the computational methods and data. Calculated results were normalized to agree with the wealth of measured data from the experimental reactors, engineering test facilities, and from the Savannah River production reactors.

However, even with the availability of HAMMER, the design and analysis of nuclear reactors at SRS was expensive, cumbersome, and very slow. The calculations were performed in a variety of computer programs that were executed in a multi-step, iterative fashion. Each of these calculations was normalized to experimental nuclear, heat transfer, and hydraulic results. Increased understanding of the reactors, coupled with the demand for more detailed reactor safety analyses, led to a highly complex technology requiring a massive system of strongly coupled computational and experimental procedures. New reactor cores were designed, and cores were analyzed during the course of their operation in the SRS reactors. By the late 1960s, the time required from the beginning of a reactor design until its initial operation had increased to almost 18 months. During this period, an average of 150 separate computer jobs had to be performed each month. Considering that there were several concurrent design projects, and that relatively few people were available to lead these design efforts, there was a clear need to simplify the routine use of these programs by better organizing them and better controlling their execution. It became evident in the late 1960s that calculations of this type required a new computing environment, that of the modular data-based system. Thus was the advent of JOSHUA.

Description of the JOSHUA System

JOSHUA is a nuclear reactor design and analysis computational system. Development of the system began in 1968 and continued for more than a decade. The system was developed to perform the extensive nuclear reactor engineering and physics calculations required in the design and analysis of Savannah River reactors with emphasis on operational safety and production efficiency. Subsequent development extended the applications of the system to other, non-reactor areas, including especially the environmental sciences.

JOSHUA Operating System

JOSHUA is a modular, data-based scientific computing system for the multi-step iterative design and analysis of nuclear reactors. JOSHUA consists of an operating system and an applications system. The operating system facilitates data management, program execution, and computer terminal use. The applications system is a collection of computational modules that perform the numerical operations representing the science and engineering models.

What does “multi-step, iterative” mean? Nuclear reactor design requires many computational steps. One such step might be the calculation of the heat produced in one fuel assembly. Another step might be the calculation of the fluid temperature in a coolant channel, as heat is transferred from the fuel to the coolant. Steps are often repeated using different sets of input data, or different models to perform the particular calculation.

Furthermore, groups of steps are often repeated until some reactor design criterion is met. This process is composed of multiple steps (i.e., multi-step), and it involves repeated executions of one or more particular steps (i.e., iterative.)

What do “modular” and “data-based” mean? In the early 1960s when a calculation was performed by a computer program, the input data were punched on cards, and the computed results were printed on paper. If some output data from one step were required as input data to a subsequent calculation, these data were manually transcribed from the printed report to an input card. In the mid 1960s, random access, disk storage devices became available at reasonable prices and thus made it practical to save results from one step to be made available to subsequent steps. When selected output data from a step are placed in a “pool” of data residing on disk storage and made available to all other steps, the resulting system is called a “data-based” system and the computational steps, or computer programs, are called modules. Modules can execute other modules to facilitate development of complex computational procedures, such as those required for nuclear reactor design and analysis.

From the beginning, it was planned that JOSHUA would make use of named data records. One collection of material property data required by reactor calculations is the set of neutron fission cross sections for each of multiple neutron energy groups in the U-235 isotope. Prior to JOSHUA, such data might be stored on magnetic tape that was read by the computer as tape unit 20, record 12,456. Although perfectly satisfactory to the computer, this name had no meaning to the reactor designer. With JOSHUA, these data were stored on a random-access disk in a record named MULTIGRP.U235.FISSION. JOSHUA allowed records of up to 16 names of no more than 8 alphanumeric characters in length, separated by periods.[8] The resulting database can be represented as a hierarchical, tree structure, and JOSHUA implemented a relatively sophisticated data management system to facilitate data access, data modification, data creation, access security, search facilities, and other important data management capabilities. These data management capabilities served the computer programs, which were written in an extension to the FORTRAN programming language, and human users of computer terminals.

Also from the beginning, it was planned that JOSHUA would make extensive use of computer terminals as the principal input/output interface between the computational system and the reactor design engineer. Use of computer terminals provided for the following:

- Entry of data directly into the database
- Inspection of results in the database
- Modification of data in the database
- Execution of modules (i.e., computer programs comprising the computational steps)

These capabilities are important in the reactor design process. They allow the reactor designer to dynamically control the database and the computational sequence that is performed, without resorting to using punched cards and printed reports, or other antiquated media. This greatly reduces the time required for a reactor designer, or a group of designers on a team, to go through a complicated computational process.

JOSHUA Applications System

The task of nuclear reactor design and analysis is basically one of simulating mathematically the state of the nuclear reactor in static and transient situations. Reactor design considers the static case, and reactor safety analysis considers the transient case. The "state" of the nuclear reactor is defined as the space- and time-dependent parameters primarily associated with power density (e.g., heat generation rate), neutron density, temperature of solid and fluid materials, density of solid and fluid materials, and fluid velocity. All of these state parameters have different values at each location within the reactor (i.e., the "space dependence") and at each point in time. Further, the neutron density depends also on the neutron velocity, since the density of "slow" neutrons at a point in space and time may be different than the density of "fast" neutrons at the same point in space and time. Neutron density, temperature, material density, and fluid velocity are described mathematically by a set of differential equations. These equations are coupled because the coefficients in the equations, representing collections of material properties (e.g., neutron cross sections, heat capacities, thermal expansion coefficients), are themselves functions of the state parameters, especially temperatures and densities. The modules that comprise the JOSHUA applications systems are a collection of computer programs, which employ the JOSHUA system facilities used by the reactor designer to solve the aforementioned sets of equations. The overall design problem is broken down into smaller component problems that balance solution accuracy with solution cost and permit the designer to approach the overall design problem in smaller steps.

The heart of the applications system is comprised of modules that model the nuclear characteristics of the system and of other modules that model the engineering characteristics of the system. The nuclear modules are of two basic types. One set of nuclear modules uses the methods of integral transport theory (or alternative transport theories, such as Monte Carlo or response functions) to compute the neutron densities in one, or a few, reactor assemblies. These transport calculations are performed as static calculations in two-dimensional space representing a horizontal plane within the assembly. The other set of nuclear modules uses the methods of neutron diffusion theory to compute the neutron densities throughout the entire reactor. These diffusion calculations are performed as either static or dynamic calculations in one-, two- or three-dimensional space. Both sets of nuclear modules perform the calculations under an assumed or given set of engineering parameters (e.g., temperatures and densities). The engineering modules use an assumed or given distribution of power densities (i.e., heat generation rate) and compute engineering state parameters (e.g., temperatures and densities) in the metal and coolant of a reactor assembly and throughout the moderator space of the reactor. These calculations can be either static or dynamic, and they are inherently three dimensional.

In addition to these nuclear and engineering modules, there are ancillary modules that are used to process nuclear, thermal, and hydraulic properties required in the calculations. This processing treats the dependence of neutron cross sections on temperature and density, for example. Other modules are used to process input data (e.g., reactor geometry, fuel concentrations, moderator purity) to select amongst various calculation options and to prepare output reports of calculated results.

These basic and ancillary modules can be combined in iterative, multi-step calculations for a variety of design and analysis purposes. The JOSHUA operating system facilities permit the development of special control modules, which direct the execution of the basic nuclear, engineering, and ancillary modules, for the wide variety of design and analysis purposes required. Some of the more important of these design and analysis capabilities are listed below:

- Assembly design. This calculation supports the selection of fuel and target tube dimensions and material compositions for a particular reactor assembly design.
- Charge design analysis. This calculation is used to predict the normal operating characteristics as a function of fuel depletion throughout the life of the reactor core.
- Flow-zoning analysis. This calculation is used to distribute coolant flow among assemblies within a particular reactor design.
- Confinement protection analysis. This particular safety analysis predicts the pressure surge in the reactor confinement system for a variety of hypothetical accidents in which the safety system fails. The results are used to design charges and define operating limits that ensure that the reactor confinement system will not be breached.
- Thermal-hydraulic limits analysis. This particular safety analysis predicts the transients in assembly effluent temperature that would result from hypothetical accidents terminated by automated safety systems. Analyses of these accidents are used to define limits on normal operating temperatures.
- Film-boiling burnout analysis. This particular safety analysis predicts the extent of fuel damage due to film-boiling burnout under static and transient conditions. These analyses are used to define limits on the heat flux at the fuel-coolant interface. Quantitative analysis of the phenomenon is based on experiments from which the degree of damage can be corrected with Burnout Safety Factor, the ratio of burnout heat flux to the actual heat flux.

The Results, Significance, and Impact

The JOSHUA System was on the leading edge of modern, scientific computing technology. As one millenium ends and another begins, it is difficult to recall the state of technical computing in 1968 when the development of JOSHUA began. In the subsequent three decades, we have seen a revolution in computing. During the last two decades of the twentieth century, the cost of computing power decreased about 30% annually and microchip performance power doubled every 18 months. Computing power costs have fallen more than 10 millionfold since 1968. The JOSHUA system could not have been built a decade earlier because computer hardware simply did not exist to support the data management, computer terminals, and other facilities provided by the system. Further, the computational power required for the nuclear reactor design and analysis calculations was prohibitively expensive even for national defense purposes. Had the JOSHUA system been built three decades later, it would have made full use of modern servers, workstations, personal computers, data management systems, and the Internet. The system development would have used “off the shelf” technology and would have required considerably less ingenuity and innovation. Its development would have required much less time, at much less cost than was the case in 1968. One impact of JOSHUA is that it demonstrated to computer scientists the utility and power of the computational facilities that the system supported.

JOSHUA incorporated into a single, modular system the very best of nuclear physics and engineering models available at the time. The utility and power of such a comprehensive design and analysis tool was demonstrated to the entire nuclear industry and influenced the development of nuclear physics and engineering models at other sites.

Another, and perhaps the greatest, significance of the JOSHUA system is that its application significantly enhanced the efficiency, effectiveness, accuracy, and safety of nuclear reactor design and analysis capability at Savannah River Site.

Contributors

Many individuals contributed directly and significantly to the design, development, and application of the JOSHUA System. Their success was built upon the brilliant work of technology pioneers in nuclear, thermal, and hydraulic science and engineering. This paper has attempted to reflect the appropriate credit to early pioneers and to the early Savannah River Plant people. All of them were an important part of the legacy that led to JOSHUA.

Singling out an individual contributor risks overlooking important work of others. However, in the case of the JOSHUA System, three individuals should be acknowledged for their exceptional contributions. Dr. John E. Suich and Dr. Henry C. Honeck were responsible for the initial concepts of the JOSHUA System, both in the operating system and in the applications system. Their engineering and computational insight, vision, and commitment inspired the effort. Suich and Honeck were most fortunate to find themselves in an organization that at the time was led by J. W. Croach, Technical Director of DuPont's Atomic Energy Division. Mr. Croach possessed a solid understanding of physics, engineering, and computer science. He understood the need for a modular, data-based system such as JOSHUA, and he provided the executive support and encouragement.

To those of us who had the pleasure of working in the presence of such talent, we remember these three leaders with continued appreciation and admiration.

References[9]

Honeck, H. C., 1975, "The JOSHUA System," USDOE Report DP-1380, Savannah River Site, Aiken, SC 29808.

Endnotes

1. The name JOSHUA is not an acronym and was chosen largely arbitrarily by H. C. Honeck and J. E. Suich soon after they conceived the system. Suich had developed an earlier program that he named JERICHO. The name JERICHO led to the name JOSHUA from the Biblical story of Joshua at the battle of Jericho, where the blowing of trumpets and the shouts of the people caused the city walls to crumble. When a JOSHUA computer program failed, an error message was printed, "And the walls came tumbling down." After JOSHUA development had progressed for several years, Honeck and Suich sponsored a contest among the system developers for the cleverest acronym associated with the name JOSHUA. Propriety prevents the reporting in this paper of the winning suggestion.
2. The thermal-hydraulic experiments at Columbia University used large amounts of DC electrical power to simulate nuclear heating in mock fuel assemblies. The story is told, perhaps apocryphally, that these experiments were conducted late at night because the New York subway system also used large amounts of DC power and conducting the experiments during daylight hours would have overloaded the electrical system!
3. We sometimes felt that the computers we were using contained as much steel as the reactors we were trying to analyze, and that

the computers generated almost as much heat as the reactors.

4. The Mark I, built in 1944 by a joint Harvard-IBM team, was an electronic relay computer which used electromagnetic signals to move mechanical parts. The computer was about half as long as a football field and contained about 200 miles of wiring. It required 3-5 seconds per calculation in a sequence of calculations that could not be changed.
5. The ENIAC consisted of 18,000 vacuum tubes, 70,000 resistors, and 5 million soldered joints. It consumed 160 kilowatts of electric power but had computing speeds more than 1,000 times faster than the Mark I.
6. Although transistors were clearly an improvement over vacuum tubes, they still generated significant amounts of heat. This problem was solved by the development of the integrated circuit in 1958 by Jack Kilby, an engineer at Texas Instruments. This development was continued with more and more electronic components being packed onto a single chip. In the 1970s, large-scale integration (LSI) permitted hundreds of components on one chip. In the 1980s, very large-scale integration (VLSI) extended this to hundreds of thousands of components on one chip. And by the late 1980s, ultra large-scale integration (ULSI) extended that number to the millions.
7. The Card Punch Calculator or CPC was an electro-mechanical device in which the user inserted one punched card in order to simulate the actions of an adding machine!
8. Rather than "periods," we should have called them "dots" as in "JOSHUA-dot-com."
9. There is only one reference given in this paper. That reference contains a complete description of the JOSHUA System as of 1975, plus a complete list of published reference materials from 1968 through 1975 regarding the development of the JOSHUA System.

Acknowledgment

The author gratefully acknowledges the many comments, suggestions and careful reviews of this paper by his colleagues M. R. Buckner, G. F. Merz, T. F. Parkinson, and D. A. Ward.

Biography

During his undergraduate studies, John Stewart was employed as an engineering co-op student with Du Pont at the Savannah River Plant and Laboratory in Aiken, South Carolina. During his graduate studies, he was a part-time employee of Oak Ridge National Laboratory. He was granted B.S., M.S., and Ph.D. degrees in nuclear engineering by the University of Tennessee. Following graduate studies, John was employed in 1969 as an engineer at the Savannah River Laboratory and assigned to reactor design, analysis, and computational modeling work. There, he participated in the development of JOSHUA, a comprehensive computational system for design and analysis of nuclear reactors, in both technical and supervisory roles. In 1975, Mr. Stewart was granted a leave-of-absence to accept a one-year appointment as a visiting research associate at MIT, leading the development of a major power reactor safety analysis computer program. In 1976, he returned to Savannah River and held a variety of management positions in research, development, engineering, manufacturing, and employee relations in the Laboratory and Plant. In 1984, he was named Technical Manager of the Atomic Energy Division in Wilmington, Delaware, and in 1987, he was named Design Manager in DuPont Engineering-Atomic Energy Division. In 1988, he became a product development manager in the Electronic Imaging Division. John returned in 1990 to Du Pont Engineering and served as manager of energy engineering and leader of the corporate energy conservation program until his retirement from Du Pont in 1998. He currently lives in the Atlanta area.

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