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NUCLEAR REACTOR PULSE ANALYSIS, AN APPLICATION OF A REAL-TIME COMPILER

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
Defense Atomic Support Agency
Bethesda, Maryland

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NUCLEAR REACTOR PULSE ANALYSIS, AN APPLICATION OF A REAL-TIME COMPILER

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FOREWORD
(Nontechnical summary)

Computer programs used to process scientific data or solve scientific problems are almost always written in a problem-oriented compiler language such as FORTRAN or ALGOL. These languages are flexible, and greatly simplify the writing of routines for arithmetic and input/output operations, thus permitting a program to be made operational in a minimum of time. However, because of the nature of most software systems under which compiled programs are executed, the programmer does not have absolute control of the timing and core storage allocation which are made by the compiler.

Unfortunately, this control is necessary in on-line, real-time data acquisition under computer control, and thus programming for such operations is most often done using the much more laborious symbolic assembly language of the particular computer being used.

A Real-Time FORTRAN (RTF) Compiler combines the flexibility and simplicity of a compiler language with timing and storage allocation control capability, and thus enables the implementation of data acquisition-system operations with less effort and in less time than that required if only an assembly language is used.

With the hope that an illustration of a real-time compiler application will stimulate the development and use of real-time compilers, this report describes a hardware-software system used to collect and process data at the Armed Forces Radiobiology Research Institute. An RTF Compiler was used to program the system which acquires on-line data from a TRIGA reactor and computes the reactor period and reactivity as a function of time. Our description notes how the RTF Compiler saved time and effort in implementing the data collection and processing system.

ABSTRACT

The use and advantages of a Real-Time FORTRAN (RTF) Compiler are illustrated by describing the collection and processing of data acquired from a TRIGA nuclear reactor on the Armed Forces Radiobiology Research Institute Data Acquisition System. The system computes the reactor period and reactivity as a function of time from data acquired on-line during a reactor pulse. The hardware components of the system, comprised of an SDS 920 digital computer and special-purpose interface equipment, are described, as is the software package which makes use of an RTF Compiler. The illustration shows how the flexibility and programming simplicity of a problem-oriented compiler language in a real-time environment enables the implementation of an on-line data acquisition system operation with less effort and in less time than that required when a standard symbolic assembly language is used.

I. INTRODUCTION

At the Armed Forces Radiobiology Research Institute (AFRRI) research programs frequently require high-speed data collection and processing. When a digital computer system accepts real-time, high-speed data, programs controlling the data collection by use of the computer-interrupt system must be written in either machine or symbolic language. Two alternatives are then available for the processing of these data. One can remain in execution and analyze the data immediately after collection using machine or symbolic language programs, or one can save and subsequently reload the data for analysis with programs written in a compiler language. Disadvantages exist in each alternative. Preparing analysis programs in machine or symbolic language is inefficient from both a man-hour and machine-hour standpoint during the program writing and debugging phase, but saving data, and reloading compiler-coded analysis programs is also inefficient during system operation. A Real-Time FORTRAN (RTF) Compiler overcomes these disadvantages by allowing data collection and computer-interrupt programming to be done in a compiler language, yet retaining the capability of uninterrupted execution of both sets of programs.

The Real-Time FORTRAN Compiler[4] designed by Scientific Data Systems and Beckman Instruments for SDS 920/930 machine configurations is in use on the AFRRI Data Acquisition System (DAS). To illustrate the use and advantages of an RTF Compiler, a typical application currently in operation on the AFRRI DAS is described. This application involves the collection and analysis of data obtained during a nuclear-reactor pulse. It is hoped that this illustration will not only be of assistance to those faced with collecting similar data but will also serve to stimulate a greater utilization of real-time compilers. These permit the use of problem oriented language programming which can be useful when one is faced with the task of collecting and subsequently processing high-speed data.

A brief description of the AFRRI DAS is given, followed by an outline of the nuclear-reactor pulse-analysis problem. A detailed explanation of the RTF hardware and software system developed to solve the problem is also presented.

II. AFRRI DATA ACQUISITION SYSTEM (DAS)[2]

The DAS (Figure 1) is controlled by an SDS 920 Central Processor (CP) which contains 8192 words of 24-bit memory, 48 priority-interrupt channels and one input/output communication channel. Input/output equipment presently consists of a paper tape punch, one 15 kc magnetic tape unit, a digital graph plotter, a paper tape reader and an on-line typewriter. An interface, consisting of various special purpose electronic equipment including an analog-to-digital converter, scalers, an oscilloscope, clocks and logic circuitry, is also connected to the CP. This interface, the components of which can be computer controlled, enables the computer to perform real-time experimental monitoring and control as well as data acquisition. In addition the DAS can be used in a standard data processing and computation mode.

III. NUCLEAR REACTOR PULSE ANALYSIS

A TRIGA Mark F nuclear reactor[1] is used by the AFRRI in its research program. This reactor can be operated at a steady-state power level and also in a pulse mode. The latter is used to provide a short burst of nuclear radiation of very high intensity. When the reactor is pulsed, the power pulse produced (Figure 2) has a width at half maximum in the 10- to 20-millisecond range. The amplitude of the pulse (which may be controlled by the operator) can peak as high as 2000 megawatts from a very low initial power level.

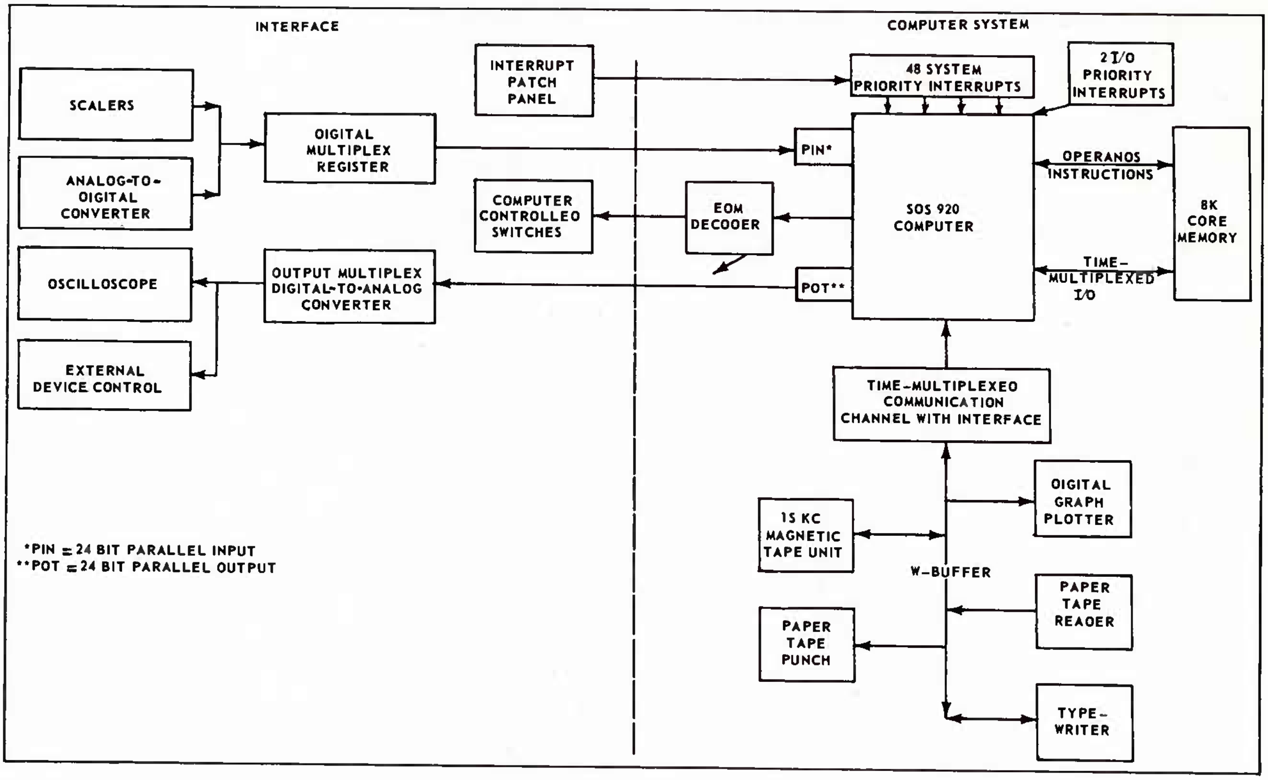

Figure 1. AFRRI data acquisition system

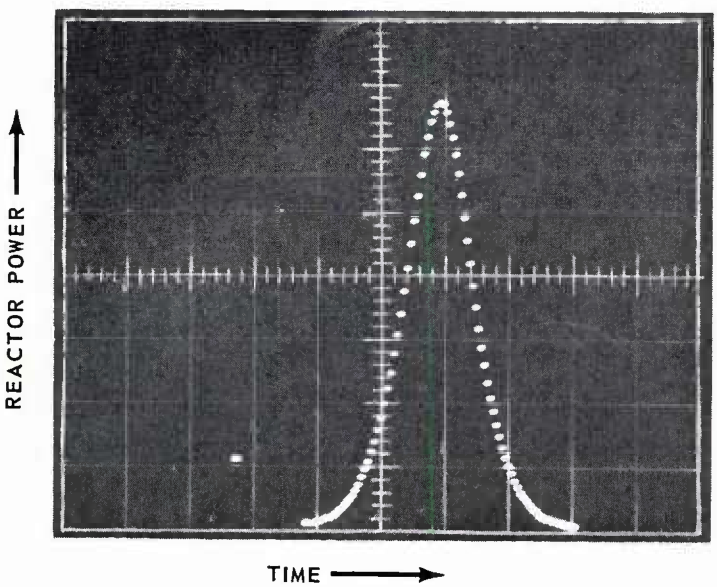

Figure 2. Digitized reactor power pulse

An analysis of this power pulse wave form provides the reactor physicist with certain information necessary to study and control the dynamic behavior of the reactor system. The AFRRI DAS is used to obtain the reactor period and reactivity as a function of time.[3]

A signal, whose voltage is proportional to the instantaneous power of the reactor, can be obtained with any of several types of radiation detection instruments placed in or near the reactor core. If this signal is sampled at short time intervals, $t_1, t_2, \ldots, t_i, \ldots,$ the instantaneous reactor period P and reactivity R can be computed at time t_i by the relations

$$P(t_i) = \frac{\Delta t}{\ln V(t_i) - \ln V(t_{i-1})}$$

$$R(t_i) = \frac{C}{P(t_i)} + \sum_{j=1}^{6} \frac{\alpha_j}{1 + T_j \; P(t_i)}$$

in which

$V(t_i)$ = magnitude of the voltage at time t_i

$V(t_{i-1})$ = magnitude of the voltage at time t_{i-1}

Δt = $t_i - t_{i-1}$

and C, α_j and T_j (j = 1, 2, ... 6) are known constants peculiar to the reactor. The theory of reactor kinetics and the derivation of the relations pertinent to the present analyses may be found in Reference 5.

The system described below, comprised of the DAS hardware and the real-time FORTRAN software, is used to sample the reactor power signal and store the resulting digital values $V(t_i)$ and then, while still in execution, to compute the quantities $P(t_i)$ and $R(t_i)$.

IV. REACTOR PULSE ANALYSIS HARDWARE

Figure 3 shows the DAS hardware configuration during the operation of the RTF reactor pulse analysis system. The analog voltage signal from the reactor is fed into the analog-to-digital converter (ADC), whose digitization rate is controlled by a 2.5 kHz clock (clock #1). The ADC requires 100 μsec to digitize the analog voltage (dynamic range, +10 V to -10 V) and store the digital value in a 14-bit register (13 bits plus sign). When conversion to a digital value in the ADC is complete, an electronic pulse called a complete pulse is generated in the ADC. This pulse is used to initiate a computer interrupt which activates a subroutine that transfers the data from the ADC to the computer memory. This is discussed more fully in the description of the software configuration.

The reactor pulse starts when the reactor pulse rod is physically ejected from the reactor core. A microswitch on the control rod senses when the rod begins to move (approximately 100 msec prior to the pulse) and sends a "start" signal which SETS an electronic switch interposed between clock #1 and the ADC. Digitization can occur only when this electronic switch is in the SET state; thus the reactor itself is used to initiate data acquisition. The electronic switch is RESET under computer program control.

A visual oscilloscope presentation of data stored in the computer memory is available and is controlled by the software. A slow clock (clock #2), generating pulses at a rate of 7.5 Hz, is used to time the oscilloscope display.

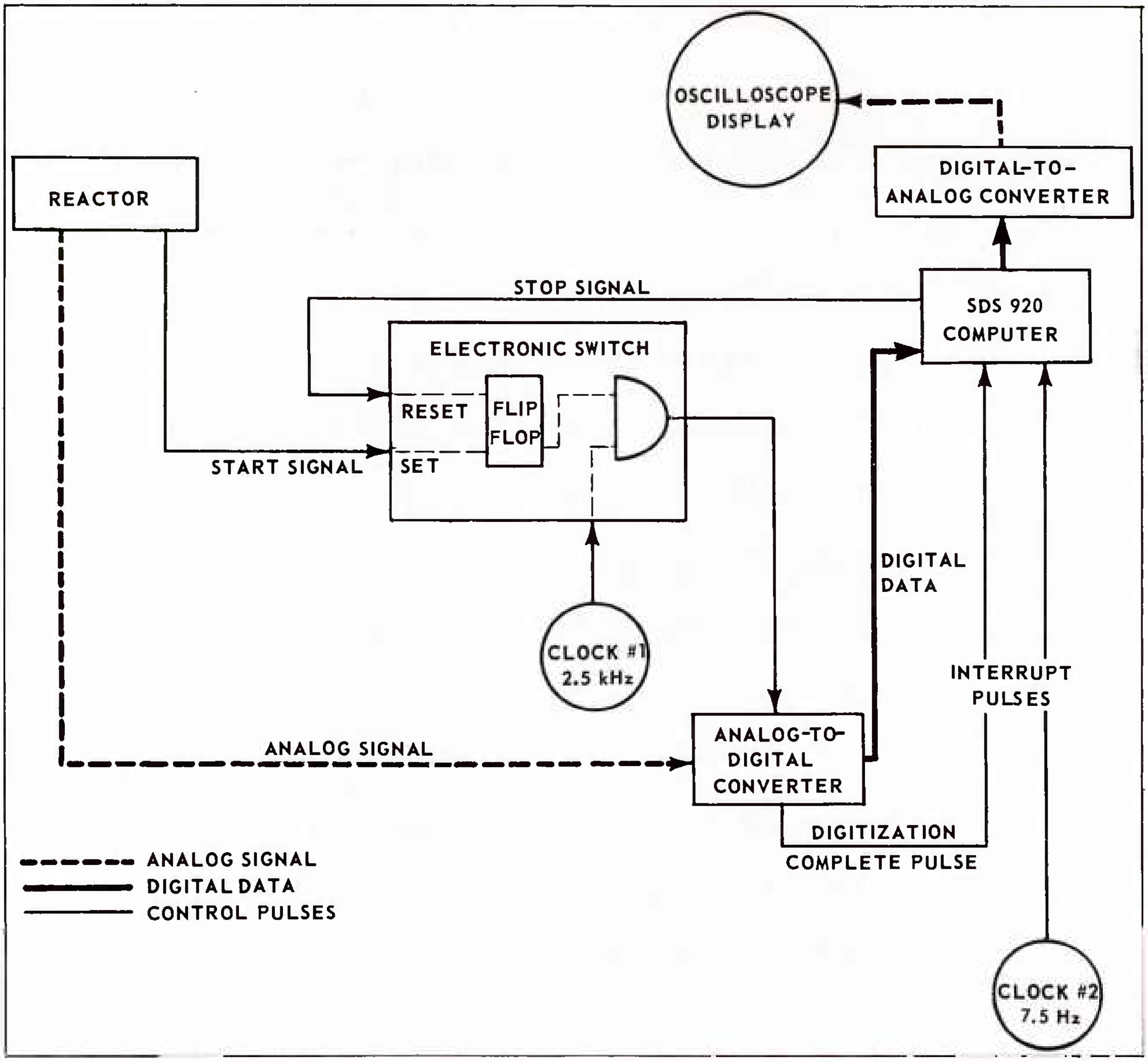

Figure 3. DAS hardware configuration during the operation of the RTF reactor system

V. REACTOR PULSE SOFTWARE CONFIGURATION

The Real-Time FORTRAN system[4] is composed of a compiler, a loader, a run-time monitor and a program library. In addition to standard FORTRAN compilation, the system allows for the symbolic coding of subroutines which are required whenever an optimum code must be generated to handle system interrupts or other crucial timing problems. The assembly of such subroutines is accomplished with the standard assemblers for the computer configuration used. In the present case, the SDS SYMBOL assembler was used. The RTF loader is utilized to integrate the symbolic routines into the system at run time.

The run-time monitor contains constants, flags, subroutine linkages and special routines, all used by the operating program at run time. It accomplishes system initialization and provides for the saving of recursive variables and items that are destroyed during interrupt processing. The library contains standard general purpose subroutines (mathematical functions, input/output, etc.).

A schematic of the reactor pulse software configuration is shown in Figure 4. Resident in core at run time is the RTF run-time monitor, the RTF subroutines and a reactor executive routine, written to operate in conjunction with the monitor to control operation of the reactor pulse analysis system. This executive routine accepts input parameters, outputs results, and interrogates computer break points. These are denoted as Type A programs and include the RTF system and those special purpose FORTRAN-coded routines that accomplish the reactor-pulse analysis. The routines that compute the period and reactivity are included in the RTF reactor-subroutine group, as are the output routines.

Also resident in core are two Type B routines written in symbolic language to handle the system interrupts that occur during execution. They include the high-priority Store-Data subroutine which controls the transfer of data from the ADC to memory, and the Scope-Display subroutine (lower priority) which controls the oscilloscope. As shown in Figure 4, the Store-Data interrupt routine can interrupt both Type A programs and the Scope-Display interrupt routine, while the latter can only interrupt Type A programs.

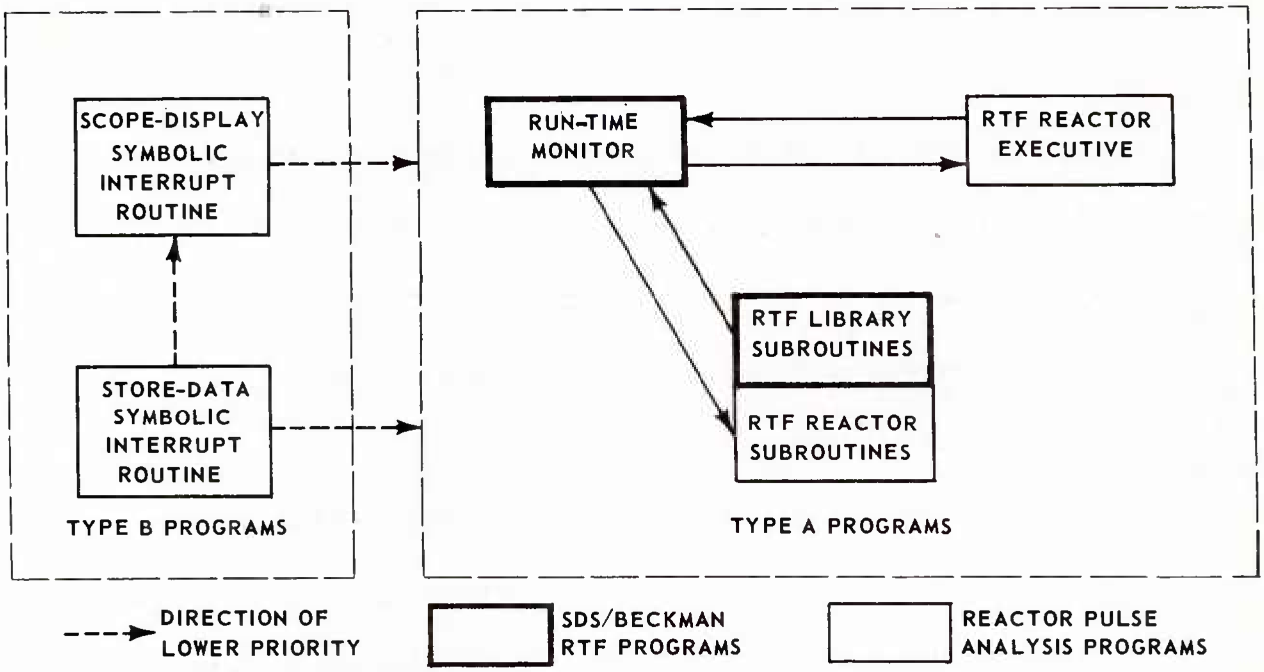

Figure 4. RTF reactor software configuration

Before the reactor pulse is initiated, the system is under control of the reactor executive routine. The system rests in a wait loop, being interrupted by the scope display (discussed below) at a slow rate. When the start signal is generated at the reactor, indicating that a reactor pulse is about to occur, digitization is begun. Each time the ADC generates a complete-pulse interrupt, control is given to the Store-Data subroutine which stores the digitized values sequentially in the RTF Common area.

After 500 values have been digitized, the Store-Data routine resets the ADC electronic switch, terminating the digitization process, and then gives control back to the run-time monitor and reactor executive for the analysis phase. The acquisition of the 500 data points takes 200 msec, with the reactor pulse occurring about midway in the interval.

During the data collection phase, timing is controlled by the 2.5 kHz clock and only 400 μsec are available to the Store-Data subroutine between successive digitizations. Control is not given to the run-time monitor after each complete-pulse interrupt has been generated since the run-time monitor requires about 5000 μsec to perform its initializations and accomplish the argument transfers between programs. Rather, the Store-Data routine performs its own housekeeping and, by using the RTF Common area for data storage, the reactor executive routine can have access to the data without the need for argument transfers through the run-time monitor.

After the data acquisition is complete, the analysis phase is entered. During this phase, the pulse data in the RTF Common area are displayed by the Scope-Display subroutine, activated 7-1/2 times per second by the interrupt pulses from clock #2. The oscilloscope screen retention is such that this rate is fast enough to give a continuous image of the data on the oscilloscope face. Execution of the Scope-Display subroutine requires 20 msec; thus about 850 msec in each second are available for the analysis programs.

The FORTRAN-coded analysis programs that compute the quantities $P(t_i)$ and $R(t_i)$ are straightforward computational programs with associated input/output routines. Provisions are made to interrogate the operator via the on-line typewriter and breakpoint switches for parametric information and option choices.

VI. CONCLUSIONS

High-speed data collection and processing using a real-time compiler are illustrated by a description of the AFRRI-reactor pulse analysis system. Where timing is critical (e.g., processing high rate computer interrupts), subroutines can be coded in symbolic language. For computations and input/output, the flexibility and programming simplicity of a problem-oriented language (in the present case, FORTRAN) are available. Through the use of the compiler Common area, easy and fast communication between subprograms in the system is assured. The latter also makes it feasible to design problem-oriented, efficient executive routines to control data handling when high-speed data rates preclude standard compiler monitor-system control.

At the AFRRI, the systems which provide real-time, on-line acquisition and processing of experimental data also permit the scientist to interact with the systems, have a continuous visual display of his data and be provided with results either during an experiment or, as in the reactor-pulse analysis system, seconds after its termination. The introduction of a Real-Time FORTRAN Compiler has allowed such efficient and flexible software packages to be developed with less effort and in less time than that previously required.

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The use and advantages of a Real-Time FORTRAN (RTF) Compiler are illustrated by describing the collection and processing of data acquired from a TRIGA nuclear reactor on the Armed Forces Radiobiology Research Institute Data Acquisition System. The system computes the reactor period and reactivity as a function of time from data acquired on-line during a reactor pulse. The hardware components of the system, comprised of an SDS 920 digital computer and special-purpose interface equipment, are described, as is the software package which makes use of an RTF Compiler. The illustration shows how the flexibility and programming simplicity of a problem-oriented compiler language in a real-time environment enables the implementation of an on-line data acquisition system operation with less effort and in less time than that required when a standard symbolic assembly language is used.

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