LA-UR- 93-3640

Conf 931023--6

Title:

THE EXPERIMENTAL PHYSICS AND INDUSTRIAL CONTROL SYSTEM ARCHITECTURE: PAST, PRESENT AND FUTURE

Author(s):

L. R. Dalesio, J. O. Hill, M. Kraimer, S. Lewis,
D. R. Murray, S. M. Hunt, M. Claussen, W. Watson,
J. Dalesio

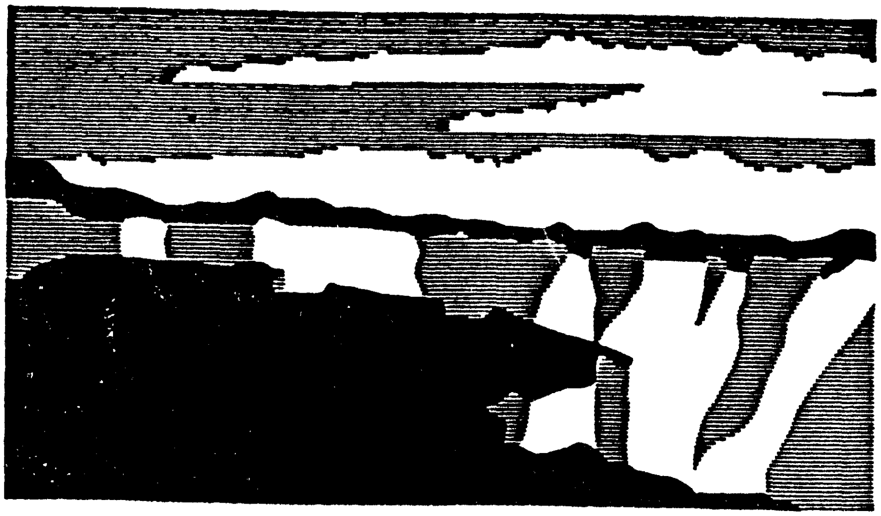
Submitted to:

ICALEPCS '93 Conference
Berlin, Germany
October 18-22, 1993

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Form No. 836 R5
ST 2629 10/91

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THE EXPERIMENTAL PHYSICS AND INDUSTRIAL CONTROL SYSTEM ARCHITECTURE: PAST, PRESENT, AND FUTURE*

Leo R. Dalesio, Jeffrey O. Hill, Los Alamos National Laboratory (LANL)
Martin Kraimer, Argonne National Laboratory (ANL)
Steven Lewis, Lawrence Berkeley Laboratory (LBL)
Douglas Murray, Stephan Hunt, Superconducting Super Collider Laboratory (SSCL)
Matthias Claussen, Deutches Elektronen-Synchrontron (DESY)
William Watson, Continuous Electron Beam Accelerator Facility (CEBAF)
John Dalesio, Tate Integrated Systems (TIS)

Abstract:

The Experimental Physics and Industrial Control System (EPICS), has been used at a number of sites for performing data acquisition, supervisory control, closed-loop control, sequential control, and operational optimization. The EPICS architecture was originally developed by a group with diverse backgrounds in physics and industrial control. The current architecture represents one instance of the 'standard model'. It provides distributed processing and communication from any LAN device to the front end controllers. This paper will present the genealogy, current architecture, performance envelope, current installations, and planned extensions for requirements not met by the current architecture.

* Work supported under the U.S. Department of Energy, Office of Basic Energy Sciences under Contract Nos. (W-7405-ENG-36), (W-31-109-ENG-38) and (DE-AC02-89ER40486)

Introduction:

The Experimental Physics and Industrial Control System (EPICS), has been used at a number of sites for performing data acquisition, supervisory control, closed-loop control, sequential control, and operational optimization. The current EPICS collaboration[1] consists of five U.S. laboratories; Los Alamos National Laboratory, Argonne National Laboratory, Lawrence Berkeley Laboratory, the Superconducting Super Collider Laboratory, and the Continuous Electron Beam Accelerator Facility[2][3][4][5][6]. In addition, there are three industrial partners and a number of other scientific labs and universities using EPICS. This paper will present the genealogy, current architecture, performance envelope, current installations, and planned extensions for requirements not met by the current architecture.

Design History:

EPICS was developed by a group with experience in control of various complex physics processes and industrial control. Three programs preceding the EPICS development were high order beam optics control, single shot laser physics research, and isotopic refinery process control. These systems were all developed between 1984 and 1987. These three programs embodied different aspects of data acquisition, control and automation. They used equipment and methods most appropriate for the time and scope of their respective problems. The Ground Test Accelerator project, where EPICS development began as GTACS[7], required fully automated remote control in a flexible and extensible environment. These requirements encompassed aspects from all of the previous control system experience. The design group combined the best features of their past, like distributed control, real-time front-end computers, interactive configuration tools, and workstation based operator consoles, while taking advantage of the latest technology, like VME, VXI, X-windows, MOTIF, and the latest processors (table 1). The major enabling innovation was the channel access communication protocol. Since the collaboration began, major steps have been made in portability between sites, extensibility in database and driver support, and there is added functionality like the alarm manager, know manager and interfaces to Mathmatica and PV-Wave. The EPICS name was adopted after the present multi-lab collaboration began.

	One shot laser physics	High Order Beam Optics	Isotopic Refinery Process Control	GTACS/EPICS
Architecture	Hierarchical	Single Computer	Distributed	Distributed
Signal Count	~4,000	~300	~4,000	~30,000
Field Bus	STD/CAMAC	CAMAC	Industrial	VME/VXI/ GPIB/Industrial Bitbus/CAMAC
Front end	VAX	VAX	6800	680x0
Operator Interface	VAX	VAX	6800 w/ lexidata	SUN/HP/ Decstation
Network	DecNet/RS232	DecNet	MAP	TCP/IP
Special I/O	200 TDRs Positioning	Video Diagnostic Positioning	High Rep Rate Closed-loop control	Full Complement
Offline Configuration Tools	none	displays	displays, alarms, I/O, control, and archive requests	displays, alarms, I/O, control, and archive requests

Table 1. Architectural History

Current Architecture:

The EPICS architecture[8] represents an instance of the 'standard model'.[9] There are distributed workstations for operator interfaces, archiving and global data analysis. There is a local area network for communicating peer-to-peer and a set c^f :ngle board computers for supporting I/O interfaces, closed-loop control, and sequential control.

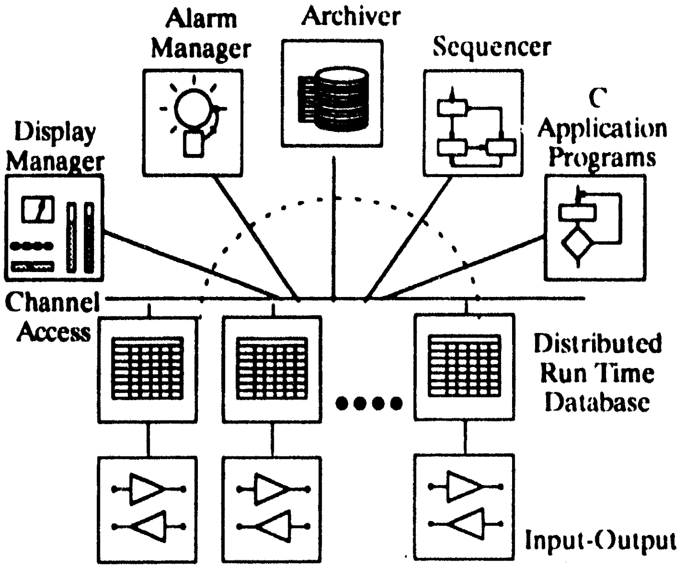


Figure 2. Software Architecture

The software design incorporates a collection of extensible tools interconnected through the channel access communication protocol[10][11][12][13][14][15][16] (figure 2). The software architecture allows the users to apply EPICS on the single board computers (SBC) to implement control and data acquisition strategies, to create state notation programs, and to implement sequential control. (figure 3). All data is passed through the channel access protocol using gets, puts, or monitors (notification on change). One can extend the basic EPICS system in the SBC by creating new database record types, calling 'C' subroutines from the database, extending the driver support, and creating independent vxWorks tasks. Workstation based tools are frequently developed to accommodate unique operator requirements, to integrate physics codes or to take advantage of some commercial package. Some examples are video diagnostics, WingZ, PV-Wave, Mathmatica, and a serial knob manager. The EPICS software architecture provides a flexible environment for resolving problems that extend beyond its own limitations.

Performance:

The I/O Controller provides a physical interface to a portion of the machine. The limiting factors in the performance of the IOC are the CPU bandwidth and memory. Table 2 shows the measured performance of analog, binary inputs, and monitors. Analog inputs read a value, convert it to engineering units, and compare the alarm limits. If channel access notification is required, an additional 100 us is incurred. It is important to note that most signals are not monitored by channel access clients and that monitors are only sent on change of state or excursion outside of a dead-band. In the average case, a signal being processed will not post monitors. Periodic scan rates vary from 60 Hz to once every 10 minutes. In addition, records can be processed on end-of-conversion and change-of-state. For binary inputs, change-of-state support in the device driver significantly reduces the CPU utilization as discrete values rarely change. For analog inputs, scanning on end-of-conversion significantly reduces the latency between gating a signal and processing the record. This may be useful for pulse to pulse closed loop control. The scheduling and dead-bands should be selected to best fit the situation. For instance, a transducer that may change within 50 msec but is accurate to 2 units should be pro-

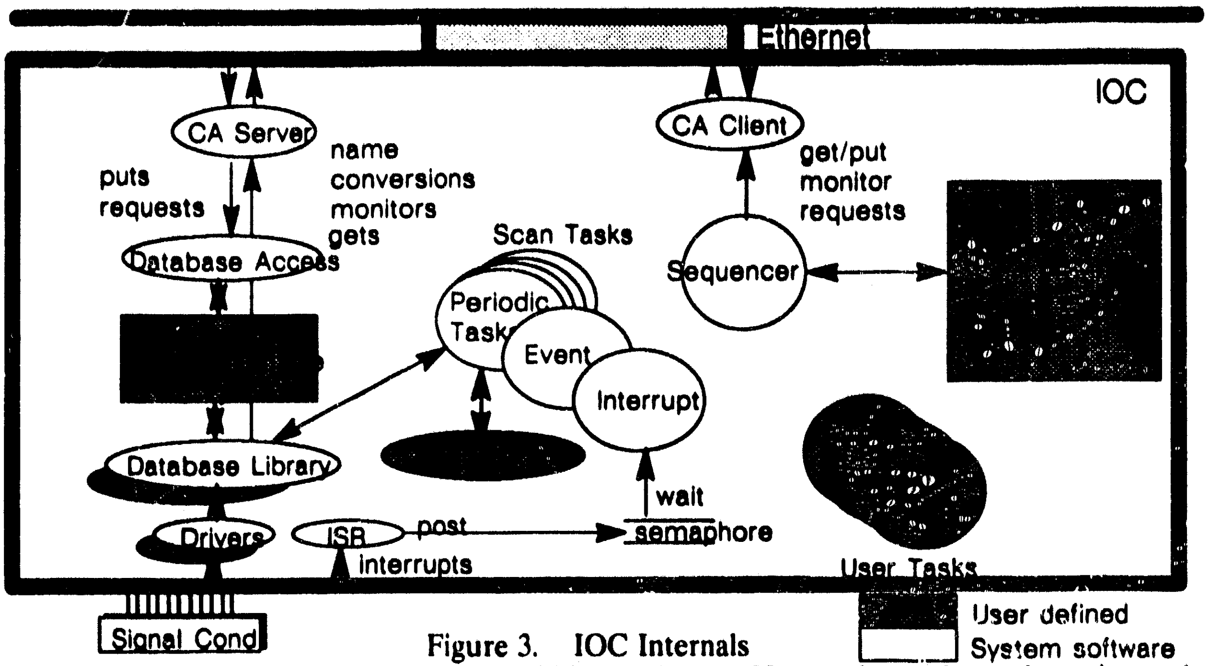


Figure 3. IOC Internals

cessed at 20 Hz with a dead-band of 2. It will be read every 50 msec but only send monitors when the value changes by more than the jitter. The database scanning is flexible to provide optimum performance and minimum overhead.

	number of bytes per instance	instances to use 1.5 M Bytes	useconds each 68040 (MV167)	CPU Usage @ 1,000/second
A/D Conversions	576	2,600	61 usec each	06.1%
Binary Inputs	480	3,100	52 usec each	05.2%
Monitors	32,000 / client	46 clients	100 usec each	10.0%

Table 2. I/O Controller Measured Resource [17]

Communication performance is limited by the channel access protocol, TCP/IP packet overhead, and the physical communication media. Channel access optimizes its use of the TCP/IP packet overhead, by attempting to pack each message up to around 1 KBytes. For a point to point connection, 1,000 monitors per second will use about 3% of the 10 Mbit ethernet band-width. To avoid collisions and therefore avoid non-determinism, the ethernet load is kept at 15%. At this level, we can issue 5,000 monitors per second. Performance can be doubled by optimizing the channel access protocol from a fixed to variable command format and by compressing timestamps on monitors. However, most of the potential performance gain comes from using commercially available hardware. By applying bridges or an etherswitch, the bandwidth can easily be tripled. Going to a 100 Mbit ethernet yields a 10 times performance improvement. Using 100 Mbit FDDI provides a 10 times faster media but also has 4 times more available bandwidth (60% utilization), since it is a token based scheme. The Ground Test Accelerator, with 2,500 physical connections and 10,000 database records distributed among 14 IOCs and controlled by 8 workstations, used only between 5-7% of our 10 Mbit ethernet during operation. Standard communication hardware provides performance improvements to about 400,000 notifications per second which should comfortably support systems of up to 60,000 physical connections.

Installations:

EPICS is in use at a number of scientific laboratories, universities and commercial installations. Table 3 presents a summary of some of these installations, the number of signals, IOCs, and workstations installed and the projected number of signals on completion. The EPICS software is typically used in systems between 200 and 30,000 signals. The SSC is a unique case at 1,000,000 signals projected. Although we have run a number of tests to characterize the operating parameters for EPICS, the largest installation that has been operated has only 2,500 physical connections and 10,000 database records. The CEBAF, APS, and GTA isntallations will be growing at a very rapid rate over the next 12 months where each will bringing thousands of new connections on-line. The real test of the extensibility of EPICS will come as these installations reach full operation.

	Signals implemneted	Single Board Computers Installed	Workstations Installed	Signals on completion
Ground Test Accelerator	2,500	14	8	10,000
Advanced Photon Source	~ 1,200	8	6	30,000
Gammasphere	150	8	6	3,000
Superconducting Super Collider	200	3	1	1,000,000
CEBAF	0	0	0	50,000
Duke Mark III IR FEL	380	1	2	380

Table 3. Installations of EPICS

Extensions:

There are a number of extensions required to meet the needs of the laboratories currently specifying EPICS. The major shortcomings in the EPICS environment revolve around configuration tools, communication support issues, and some general system functions. The manpower required to do the effort is distributed among the collaborating labs and is certainly adequate to make these additions.

We have several significant development and tool integration efforts going on at several sites to bring the configuration tools up to modern standards. Most of these efforts are directed at graphical configuration tools. Another critical aspect of these configuration tools is the maintenance of very large configuration files over the lifetime of the programs. The most promising combination seems to be a graphical configuration tool that interfaces to a relational database. This combines easy visualization during configuration of a specific portion of the application with the ability to use the querying capabilities for locating things after the fact.

Needed extension for configuration tools	Solution	Work in progress
Graphical database configuration	Use Objectviews as basis for tool Use schematic capture program	ANL, SSCL LANL, CEBAF
Graphical state notation language	Use Objectviews as basis for tool	SSCL
Extend Graphical Display Configuration	Motif based X-based	ANL LANL
Graphical Alarm Configuration	Motif-based	ANL
System Configuration	Use a relational database - D-BASE - INGRES	Tate CEBAF
Graphical Archive Configuration	Use Alarm Configuration tool as basis	None

Table 4. Configuration Extensions

The communication support issues are just being addressed, as the channel access protocol is the basis for all compatibility. We have run the same version of the channel access protocol for the past three years. The requirements forcing us to finally revisit channel access are support for serial communication media, incorporation of different data stores, and the need to support user facilities. We are maintaining compatibility at the subroutine interface level so that all of the current channel access clients and servers will only require recompilation and relinking. These requirements are driving the current channel access upgrade.

Problem	Solution	Work in progress
Need dedicated point to point communication	Add an option to use a name server Add drivers for serial and T1	Tate, SSCL, LANL
Access protection	Add access control based on user, location, channel, and machine mode	ANL, LANL
Need closed-loop control across the network	Add multi-priority channel access connections	LANL
Connect to alternate data stores	Port the channel access server to different data stores	DESY, LANL
Support a multitude of operator interfaces	Create a data gateway to clients that are able to withstand a single point of failure and the added latency	LANL
IOC memory limitations	Size server queues according to need	LANL
Socket and task limitations in the IOC	Take advantage of the newly working vxWorks Select	Tate, LANL
Long time-outs on disconnect	Add a time-out heartbeat when there's no traffic on a connection	Tate, LANL

Table 4. Channel access extensions

Other system wide functions are needed by several of the facilities. The ability to add and delete signals during operation, redundant IOCs for critical processes, and a general save and restore of operating parameters are necessary functions for many of these facilities.

We are currently exploring options for providing the much needed support for planning extensions, reintegration of new functionality, testing new releases, doucmenting new releases and functionality, distributing new releases, and offering support for installation, application, and upgrades of EPICS installations. In the past, we supported the EPICS installations through direct program funding. As the collaboration has grown, this has proven to be more difficult. We have recently identified this integration need as requiring dedicated manpower and equipment with an explicit charter to provide this support.

There are significant pieces of development required to make EPICS a complete solution for experimental physics. Most of the tasks are currently under development at the collaborating labs or the industrial partners. We are exploring options for providing good user support for the EPICS community. The functional specifications and design for these added tasks have been reviewed by the collaboration members and have been approved. The collaboration works as a single group to specify and design additions to EPICS, drawing from the strength and numbers available through a collaboration.

Conclusion:

The EPICS toolkit provides an environment for implementing systems that range from small test stands requiring several hundred points per second to large distributed systems with tens of thousands of physical connections. The application of EPICS requires a minimum amount of programming. The EPICS environment supports system extensions at all levels, enabling the user to integrate other systems or extend the system for their needs. Work is underway to provide a more integrated application development environment. The base software is also being extended to support some of the fundamental needs of the projects that are controlling user facilities. Through the modular software design which supports extensions at all levels, we are able to provide an upgrade path to the future as well as an interface to an installed base. With the addition of a support group, we will be able to provide a stable starting point complete with an upgrade path, for those programs choosing to use the EPICS toolkit.

Acknowledgement

There are now several chapters in the EPICS story with close to one hundred folks contributing thus far. The decision to collaborate with member labs has responsilibities to support your fellow collaborators as you would your own programs. This responsibility has received the necessary managerial support from each of the five member laboratories to provide the environment for a successful collaboration. The ability to develop system software in a collaborative environment requires a real dedication to finding the best solution. The system designers that have been involved in this collaboration have been egoless in their search for the best answer resulting in concensus design. Finally, there are the application engineers who have continually provided suggestions for upgrades and extensions. Their dedication to using these tools make it possible to create a toolkit. The application engineers at every site have supported our efforts even through some challenging times. All of the teams at Los Alamos National Laboratory, Argonne National Laboratory, Lawrence Berkeley Laboratory, the Superconducting Super Collider Laboratory, and the Continuous Electron Beam Accelerator Facility are responsible for the success in codeveloping software. It is certainly rewarding to work with such a wide range of experience and knowledge.

References

[1] Knott, M., Thuot, M., Gurd, D., Lewis, S., "EPICS: A Control System Software Co-Development Success Story, " submitted to International Conference on Accelerator and Large Experimental Physics Control Systems, Berlin, Germany October 18-22, 1993.

[2] Gurd, D., "Control System Plans and Progress at the SSC," submitted to International Conference on Accelerator and Large Experimental Physics Control Systems, Berlin, Germany October 18-22, 1993.

[3] Knott, M.J., McDowell, W.P., Lenkszus, F.R., Kraimer, M.R., Arnold, N.R., Daly, R.T., Gunderson, G.R., Cha, B.K., and Anderson, M.D., "The Advanced Photon Source Control System," in *Proceedings of the 1991 IEEE Particle Accelerator Conference*, (San Francisco, California, 1991), pp. 2526-2528.

[4] Clausen, M., "Control for the TESLA Test Facility - Status and Future Plans," submitted to International Conference on Accelerator and Large Experimental Physics Control Systems, Berlin, Germany October 18-22, 1993.

[5] Watson III, W. A., Barker, D., Bickley, M., Gupta, P., Johnson, R. P., "The CEBAF Accelerator Control System: Migrating From A TACL To An EPICS Based System" submitted to International Conference on Accelerator and Large Experimental Physics Control Systems, Berlin, Germany October 18-22, 1993.

[6] Young, J. A., et. al."Status of the Advanced Light Source Control System," submitted to International Conference on Accelerator and Large Experimental Physics Control Systems, Berlin, Germany October 18-22, 1993.

[7] Kozubal, A. J., Kerstiens, D. M., Hill, J. O., Dalesio, L. R., "Run-time Environment and Application Tools for the Ground Test Accelerator Control System," in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, D. P. Gurd and M. Crowley-Milling, Eds. (ICALEPCS, Vancouver, British Columbia, Canada, 1989), pp. 288—291.

[8] Dalesio, L. R., Kraimer, M.R., Kozubal, A. J., "EPICS Architecture," in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, C. O. Pac, S. Kurokowa and T. Katoh, Eds. (ICALEPCS, KEK, Tsukuba, Japan, 1991), pp. 278–282.

[9] Kuiper, B., "Issues in Accelerator Controls," in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, C. O. Pac, S. Kurokowa and T. Katoh, Eds. (ICALEPCS, KEK, Tsukuba, Japan, 1991), pp. 602–611.

[10] Dalesio, L. R., "The Ground Test Accelerator Database: A Generic Instrumentation Interface," in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, D. P. Gurd and M. Crowley-Milling, Eds. (ICALEPCS, Vancouver, British Columbia, Canada, 1989), pp. 405–407.

[11] Dalesio, L. R., "The GTA Control System Database: Configuration, Runtime Operation and Access," in *Proceedings of the 1989 IEEE Particle Acelerator Conference*. (PAC, Chicago, Il., USA, 1989), pp. 1693—1694.

[12] Hill, J., Kerstiens, D., and Dalesio, L.R., "A Virtual Control Panel Configuration Tool for X-Window System, " in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, C. O. Pac, S. Kurokowa and T. Katoh, Eds. (ICALEPCS, KEK, Tsukuba, Japan, 1991), pp. 468–470.

[13] Kraimer, M.R., Cha, B.C., and Anderson, M.D., "Alarm Handler for the Advanced Photon Source Control System," in *Proceedings of the 1991 IEEE Particle Accelerator Conference*, (San Francisco, California, 1991), pp. 1314-1316.

[14] Hill, J. O., "Channel Access: A Software Bus for the LAACS," in *Proceedings of International Conference on Accelerator and Large Experimental Physics Control Systems*, D. P. Gurd and M. Crowley-Milling, Eds. (ICALEPCS, Vancouver, British Columbia, Canada, 1989), pp. 288—291.

[15] Kozubal, A. J., L. R. Dalesio, J. O. Hill, and D. M. Kerstiens, "A State Notation Language for Automatic Control," Los Alamos National Laboratory report LA-UR-89-3564, November, 1989.

[16] Cole, R., Atkins, W., "Real-Time Data Archiving for GTA," Los Alamos National Laboratory report LA-UR-92-2420, AUgust, 1992.

[17] Botlo, M., Romero, A., "EPICS Performance Evaluation", SSCL-644, 1993.

END

DATE FILMED

12/22/93