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A unique rod lens/video system designed to observe flow conditions in emergency core coolant loops of pressurized water reactors

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Lawrence Livermore Laboratory

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A UNIQUE ROD LENS/VIDEO SYSTEM DESIGNED TO OBSERVE FLOW CONDITIONS IN EMERGENCY CORE COOLANT LOOPS OF PRESSURIZED WATER REACTORS

ABSTRACT

This report describes techniques and equipment used for video recordings of the single- and two-phase fluid flow tests conducted with the PKL Spool Piece Measurement System designed by Lawrence Livermore Laboratory and E.G.& G. Inc. The instrumented spool piece provides valuable information on what would happen in pressurized water reactor emergency coolant loops should an accident or rupture result in loss of fluid. Field testing of the 80.8-mm and 113.0-mm internal diameter spool pieces was conducted at the Wyle Laboratories Experimental Test Facility in Norco, CA. The video recordings of the various flow parameters were made between February and April 1979. The complete closed-circuit television video system, including rod lens, light supply, and associated spool mounting fixtures, is discussed in detail. Photographic examples of test flows taken during actual spool piece system operation are shown.

INTRODUCTION

The sophisticated Spool Piece Measurement System is a key portion of a major reactor technology research program being conducted by the German Primarkreislauf (PKL) Test Facility by Kraftwerk Union (KWU) in Erlangen, West Germany. This system was constructed to perform and evaluate loss-of-coolant experiment (LOCE) reflood tests for the pressurized water reactor (PWR). The Lawrence Livermore Laboratory (LLL) and E.G.& G., Inc., San Ramon Operations, were responsible for design, development, and testing of the four spool pieces, including the associated computerized Data Acquisition System (DAS). A separate report detailing spool design, instrumentation, and test results is given in LLL formal report UCRL-52855.[1] Prototype testing also included the use of the LLL Rod Lens/Video Imaging System (Fig. 1) to view and record dynamic fluid flows produced during spool calibration and instrumentation testing.

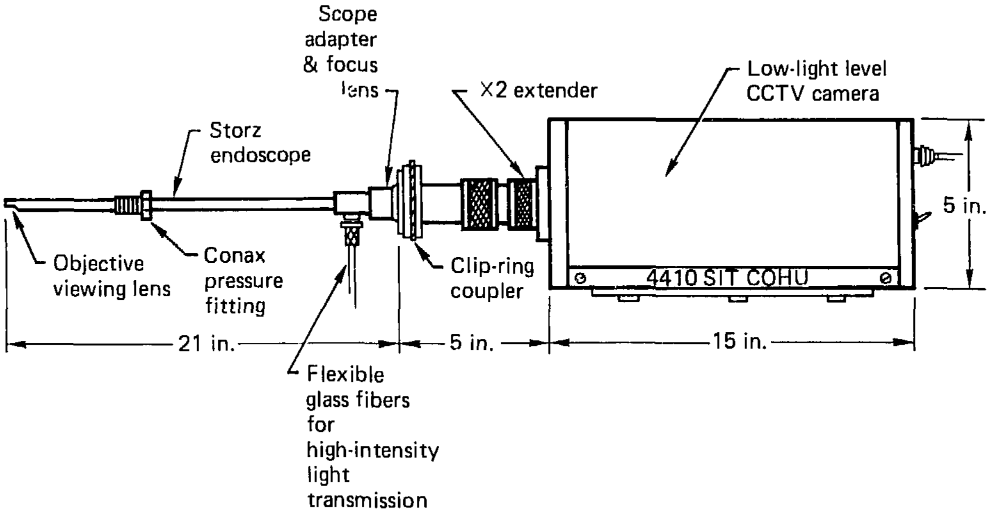


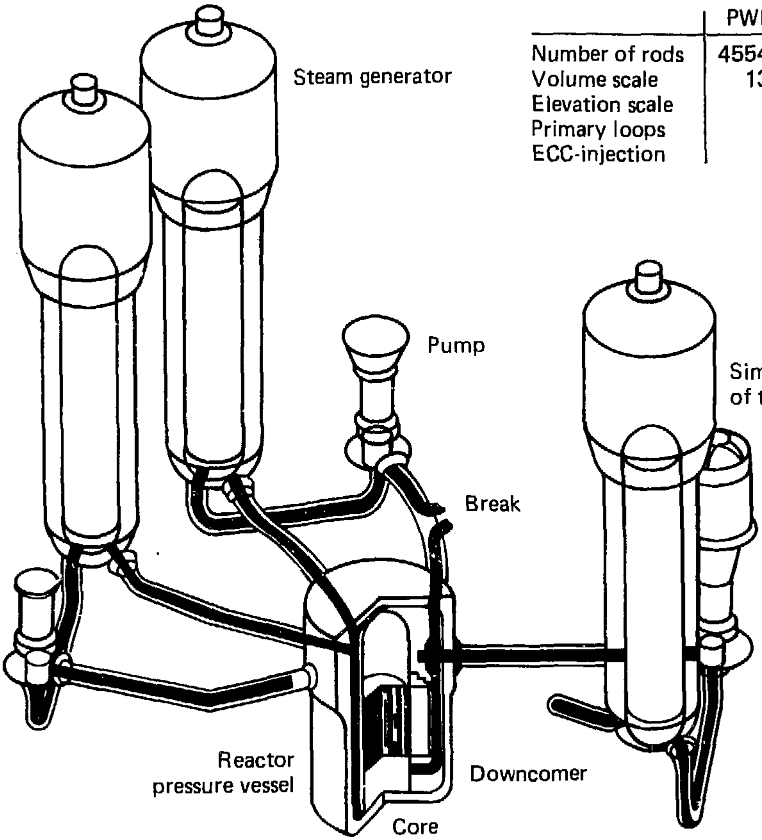
FIG. 1. View of a typical Rod Optic Video System.

This report addresses specifically the rod lens/video system used during PKL spool piece testing and evaluation.

The instrumented spool pieces were developed and tested for the U.S. Nuclear Regulatory Commission (NRC), Division of Reactor Safety Research, under the 3-D Technical Support and Instrumentation Program in conjunction with the governments of West Germany and Japan working on a joint cooperative Reactor Safety Research Program.

SPOOL PIECE MEASUREMENT SYSTEM

Four instrumented spool pieces (three of 80.8-mm diam, and one of 113.0-mm diam) were fielded; they were designed to measure single- and two-phase fluid flow conditions during reflood tests. The instrumentation package associated with each spool piece resolves: temperature measurements of the wall, fluid, and steam; pressure measurements (absolute and differential); fluid velocity; momentum flux; and fluid density. The video-coupled rod lens system added another dimension to the spool piece instrumentation; namely correlation and verification by visual real-time *in situ* viewing of events occurring within the pipe section as shown by the spool system's instrumentation sensors. It should be noted that the use of the video/rod lens system



	PWR	PKL
Number of rods	45548	340
Volume scale	134	1
Elevation scale	1	1
Primary loops	4	2 + double
ECC-injection	8	4 + double

FIG. 2. PKL simulation of a four-loop pressurized water reactor (PWR).

was intended *not* as a possible replacement for the various spool-piece instrumentation sensors, but rather to visually enhance and supplement them, thereby establishing confidence in sensor integrity and system reliability.

During field testing of the spool-pieces, a total of 28 different test sequences were recorded by the video/rod lens system. These included water calibrations, annular mist, slug flow, superheated steam, and wave motion.

KWU PKL TEST FACILITY

A model of the Primarkreislauf (PKL) Test Facility by Kraftwerk Union (KWU) in Erlangen, West Germany, is shown in Fig. 2. The reflood test simulates conditions that could be encountered should breaks develop in either hot

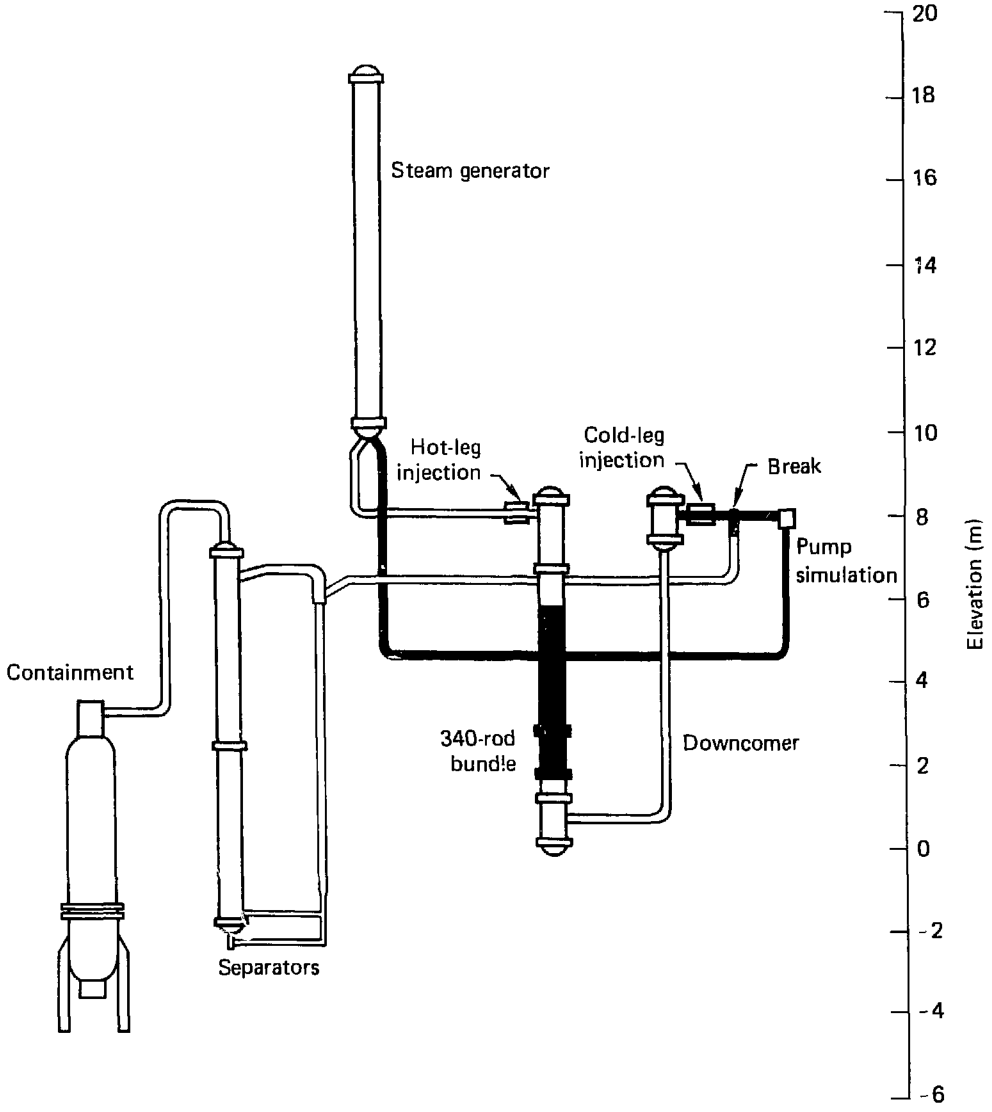


FIG. 3. Cold-leg break simulation in the PKL reactor.

or cold coolant loops of a pressurized water reactor (PWR). Figure 3 shows a break in one of the cold coolant loops. Relative locations of the four PKL instrumented spool pieces are shown in Fig. 4.

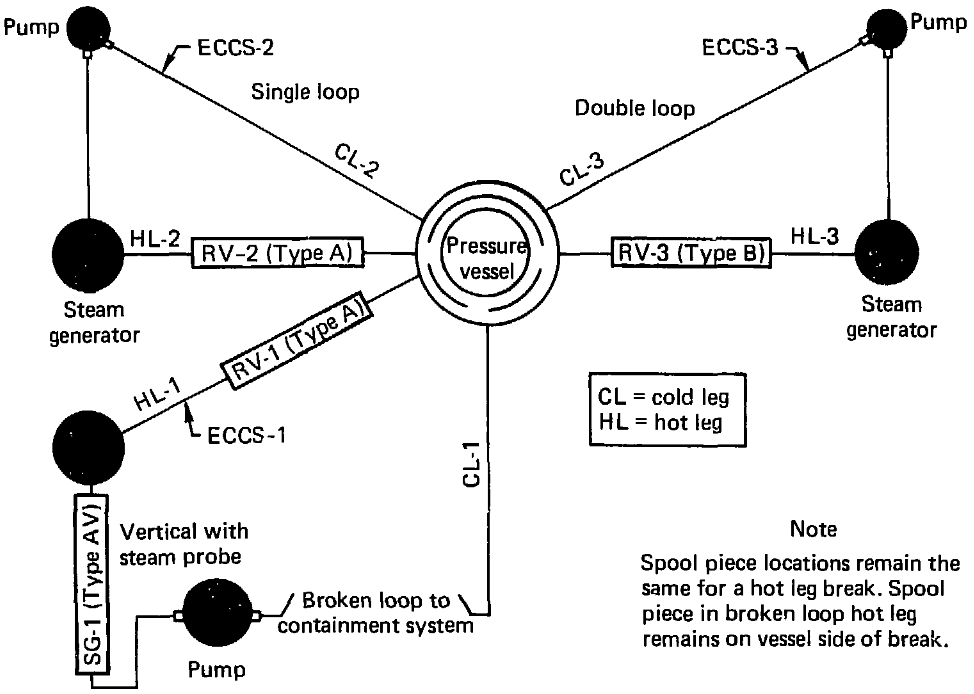


FIG. 4. PKL Reflood Test Facility schematic (cold-leg break).

WYLE LABORATORIES EXPERIMENTAL TEST FACILITY

The Wyle test facility located in Norco, California was the site chosen for PKL instrumented spool piece calibration and testing (Fig. 5). Figure 6 shows the flow diagram for the two-phase flow tests and location of the PKL spool piece test section.

FIG. 5. Wyle experimental facility, Norco, CA site of the single- and two-phase flow testing program for PKL spool pieces.

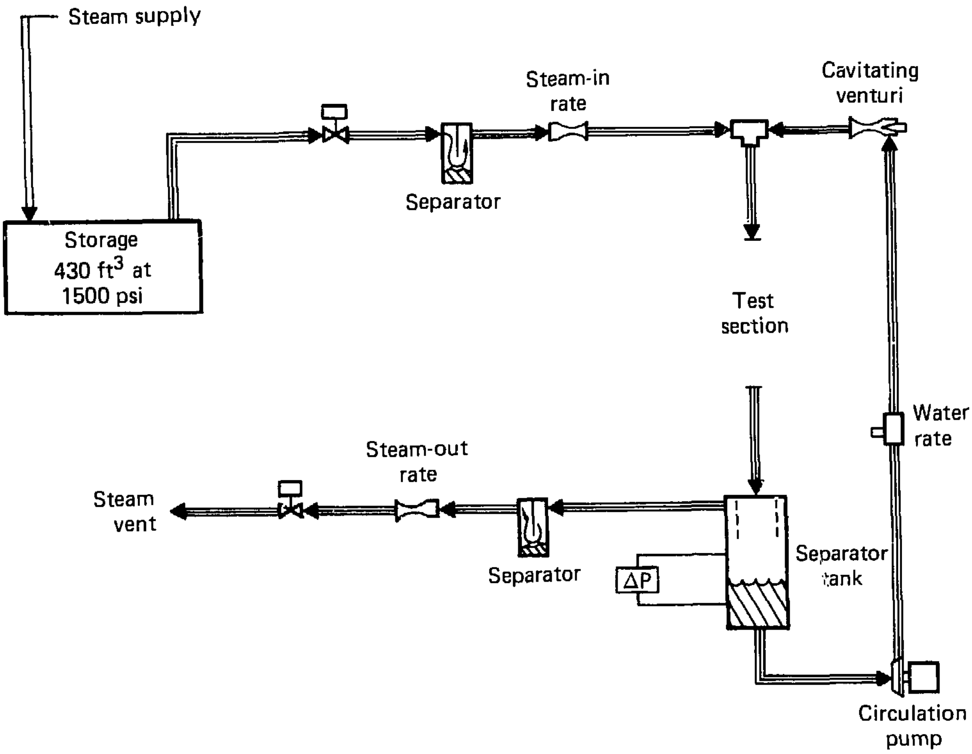


FIG. 6. Two-phase test facility flow diagram.

PKL VIDEO IMAGING EQUIPMENT

ROD LENS

The rod lens selected for the PKL instrumented Spool Piece Testing Program is a commercially available 0.5-m-long cylindrical optical system with a cross-section diameter of approximately 5 mm (Fig. 7). The rod lenses, which are manufactured by Storz Company in West Germany, were originally designed and developed as a medical instrument intended primarily for internal photography, hence designated "endoscope" by the manufacturer in preference to the medical profession. Since our particular scientific endeavors employing "endoscopes" lean more toward industrial uses, we prefer to characterize the intelligence-gathering optic system as a rod lens.

The basic construction of the Storz endoscope/rod lens consists of a series of solid imaging lenses surrounded by a built-in bundle of light-transmitting glass fibers (Fig. 8). One of the unique features of the rod

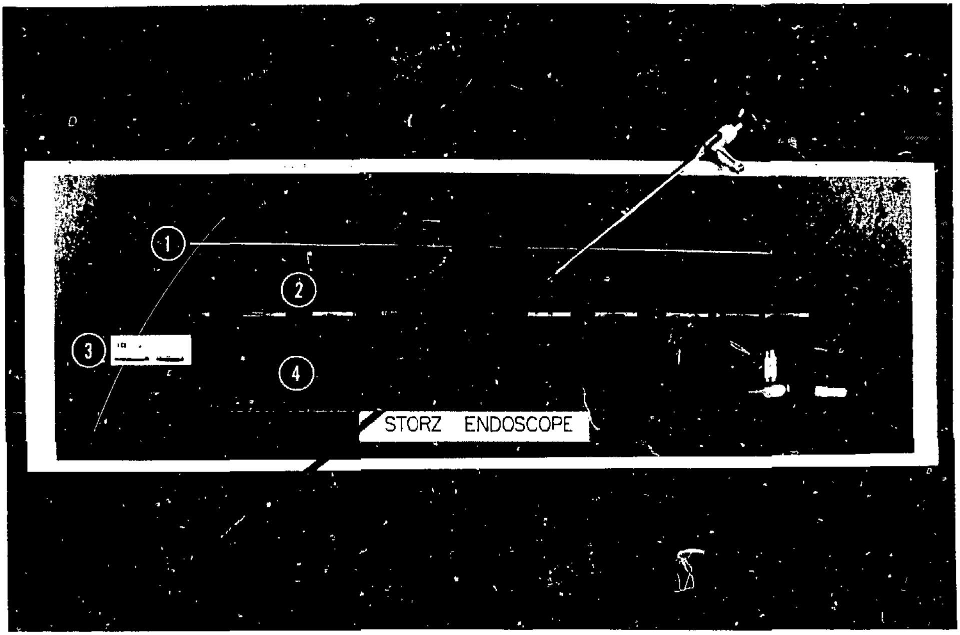


FIG. 7. Rod lens configuration: (1) lens tube, (2) rod lenses and separators, (3) objective lens assembly, (4) outside tubing (containing light fibers) and eyepiece.

lens endoscopic system is demonstrated by the method devised to transmit high intensity light for object illumination. Supplying internal illumination by the rod lens system, particularly in regard to the spool pieces, is in part accomplished by the use of a quartz halogen light source whose output is focused and transmitted through a cablelike, flexible fiberoptic to the rod lens unit. Light arriving at the rod lens unit through the fiberoptic cable, is in turn transmitted through a bundle of minute glass fibers that fill the annulus between the rod lenses and an external structurally supporting length of metal tubing. In general, both the input light fibers and output lenses are integral parts of the reflected light transmission system. Thus, illumination which is transmitted to the object through the fiberoptics is reflected and returned by the series of solid lenses.

Several other manufacturers of endoscopes possessing similar qualities are also commercially available such as the Nikon Endoscopic System[2] produced by Nikon camera, and the Olympus-Selfoc System employing a unique light-retention, self-focusing lens assembly[3-8] developed by Olympus camera.

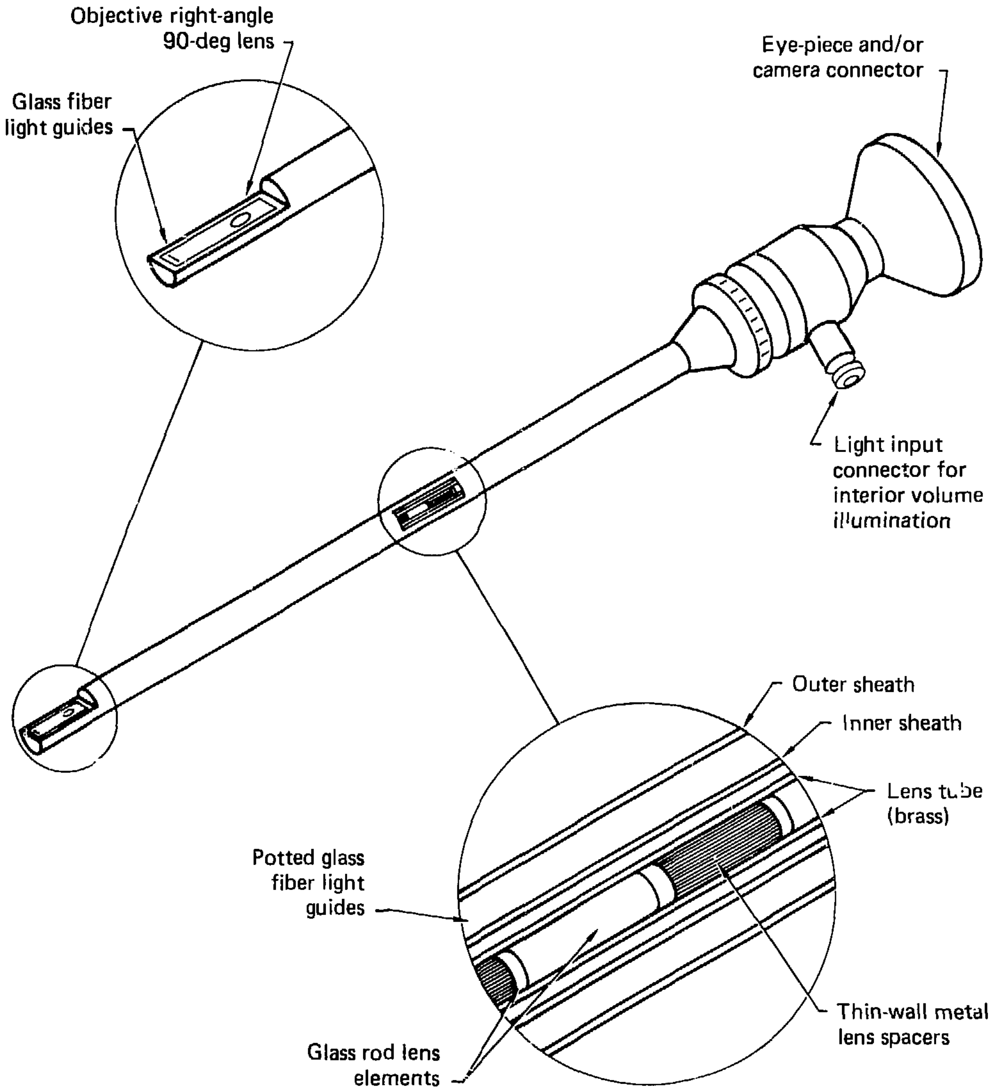


FIG. 8. Storz rod lens optic system.

The Storz rod lens assembly has been used in previous experiments[9-12] conducted at LLL and has shown no adverse effects to prolonged environmental test temperatures (steam/water) of 100°C and pressures approaching 2500 psia (17.5 MPa).

Although rod lenses can be purchased with various viewing angles (0, 30, 60, 90, and 120 deg), we selected the 90-deg angle which would allow us to direct the view up or down the axis of the spool piece. Rotation of the lens unit (0 to 360 deg) allows 360-deg observation. It can also be moved vertically to examine underwater conditions, subsurface, above surface, and vapor flow characteristics. The rod lens could also, due to modifications incorporated into the design of the spool pieces, be inserted into the spool either vertically (0 deg) or horizontally (90 deg) through modified Conax pressure fittings. Teflon seals were used in the Conax fittings, which allowed lens depth-of-insertion and rotation adjustments even under pressurized test conditions.

VIDEO CAMERA (CCTV)

Although the rod lens is a vast improvement over conventional borescopes due to its low transmitted light loss and increased depth-of-field viewing, it still does not transmit sufficient light to record dynamic two-phase flow events using standard Vidicon CCTV cameras. Therefore, we coupled the rod lens to a Cohu low-light level B/W television camera with a light intensity gain of 40,000:1. This increased sensitivity is achieved by the use of a silicon-intensified target (SIT) 250 times more sensitive than the standard Vidicon camera. Typical horizontal resolution of the SIT is 700 lines with image tube sensitivity of approximately 2×10^{-4} lumens/ft^2 (fc). The camera also incorporates an automatic gain control with automatic bandwidth reduction at low light levels which compensates for bright/dark images, thereby eliminating the need to adjust video levels during rapid brightness changes occurring in dynamic two-phase flow events. This automatic video level adjustment also acts to protect the SIT tube from damage (burns) due to sudden and intensely bright reflections.

FOCUSING LENS

Coupling the rod lens to the video camera is achieved by using a specialized adapter which screws directly into the camera faceplate C-mount. The rod lens is secured to the adapter by a spring-loaded clip-ring which allows 360-deg rotation of the rod lens without removal from the camera. A variable focusing lens is an integral component of the adapter and can be used to focus on objects as close as 1 mil from the objective viewing lens, or change the depth-of-view field to infinity. This is particularly important if one wishes to view vapor droplets at extremely shallow depths of field or increase the viewing angle to include the total system. It should be noted that as you increase the depth-of-field, vapor droplets or bubbles within the field view volume become somewhat transparent or opaque.

CAMERA SUPPORT FIXTURE

The rod lens used for the PKL flow tests, as previously stated, were 90-deg (right-angle viewing) models which could be rotated 360 deg to provide complete control over the internal view volume. However, rotating the lens also requires rotating the video camera to keep the video image portrayed on the television monitor in proper orientation to the internal spool piece view. The camera support fixtures were designed and fabricated by LLL and E.G.& G.'s San Ramon Operations Design Group (Fig. 9). The overall design is similar to that used on the LLL/NRC 1/5-scale Mark I Pressure Suppression Experiment[10] in that they allow the camera and lens system to rotate together through 360 deg with rod lens spool penetration adjustable from 0 to 113 mm.

The initial intent during fixture design was merely to support the protruding rod lens, adapter lens, and the low-light level video camera in a rotatable, lightweight structure mounted either directly to the spool piece or supported by an adjustable tripod adjacent to the spool. After studying the design criteria established for the spool pieces, it was imperative that the video/lens system supporting fixture be an integral part of the spool and, although protruding at a right-angle from the test pipe approximately 100 cm, that it also be able to withstand repeated shock loads in the vertical and horizontal modes of at least 10 g's. The resulting structure was somewhat

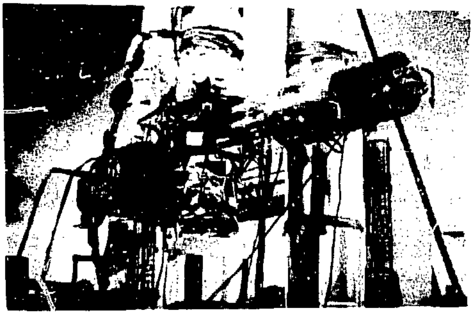


FIG. 9. Rod Lens/Video Imaging System in support fixture mounted on PKL vertical spool piece.

massive but functional and proved to be extremely stable throughout the PKL Spool Piece Test Program.

VIDEO RECORDER/MONITOR

The record/playback system consisted of a Sony EV-320F 1-in., reel-to-reel video recorder and a Sony Unimedia UMT-1203 12-in. B/W/Color video monitor. The Sony reel-to-reel was selected because of its specialized slow-motion, stop-action playback capabilities.

The video monitor and recording equipment were centrally located approximately 50 ft from the Spool-Piece Test pad in an instrumentation trailer provided by Wyle Labs.

ENVIRONMENTAL PROTECTION

Field testing of the spool pieces was conducted during one of the wettest years ever recorded in the Norco (Wyle Test Facility) Area. Further complicating the environmental situation was the complete absence of any protective covering over the spool piece test pad area. Needless to say, the video cameras, rod lenses, and high-intensity light supplies were *not* of the hermetically sealed, environmentally protected, waterproof variety. Surprisingly, even though installation and removal of the video system was performed numerous times in heavy rain, no moisture-related video system failures occurred. Long-term protection was afforded by "bagging" the video equipment in clear plastic allowing sufficient volume to dissipate system-generated heat.

PKL SPOOL PIECE TESTING

The Rod Lens/Video Imaging System was installed into the PKL 80.8-mm horizontal spool piece on February 16, 1979. The *in situ* viewing ability of the video coupled rod lens system allowed on-the-spot assessment of real-time internal spool conditions during single and two-phase fluid flow testing. By merely glancing at the displayed internal image of the spool shown by the CCTV monitor, it became immediately evident if the test conditions selected were in fact occurring, i.e., dry pipe, water level, flow movement (forward, still, reverse), wave motion, steam/vapor, sloshing action, bubbles, steam/water mixture, superheat/saturation point, etc.

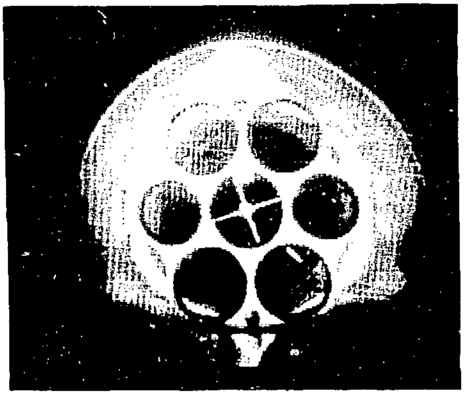


FIG. 10. Downstream view of the 80.8-mm horizontal spool (produced by rotating the rod lens 180 deg) looking directly at the drag screen. The flow meter vanes can clearly be seen behind the center hole of the screen. A thermocouple probe, partially hidden behind the drag screen, is visible in the lower right-hand quadrant. The system is being purged with full steam flow to dry out the spool preparatory to test run. Note evidence of small water flow which was the result of a valve malfunction not suspected nor discovered until seen on the rod lens/video monitor.

In fact, the rod lens/video system proved its value in reactor spool piece flow systems when, during the first series of tests, the monitor display showed a significant water flow within the spool when other instrumentation reported a high-temperature, dry pipe condition (Fig. 10). Subsequent investigation revealed a water flow-valve seal malfunction whose failure and results thereof were not detected by spool facility flow system instrumentation. Thus, by visually viewing the internal pipe conditions, the rod lens/video system is capable of immediately detecting problems or failures occurring with flow system instrumentation and/or system hardware.

PHOTOGRAPHIC EXAMPLES

Typical photographic examples of spool piece internal views and test flows are shown in Figs. 10 through 17.

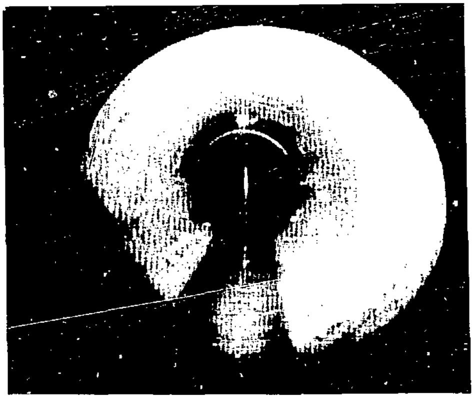


FIG. 11. Photo taken following steam injection with water flow in the 80.8-mm horizontal spool piece (upstream view). Spool temperature is approximately 90°C. The white line in the center of the spool is an inserted thermocouple probe. The bright dots are moisture droplets condensed along the wall reflecting the rod lens supplied high-intensity light. Note the clarity of machining tool marks and lens depth of field.

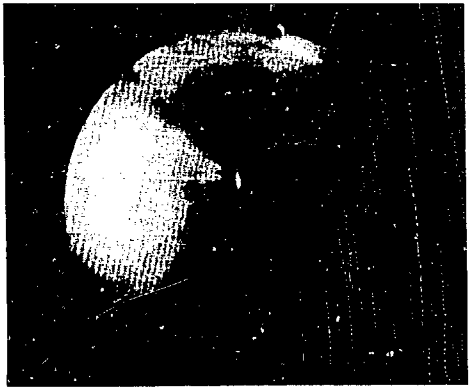
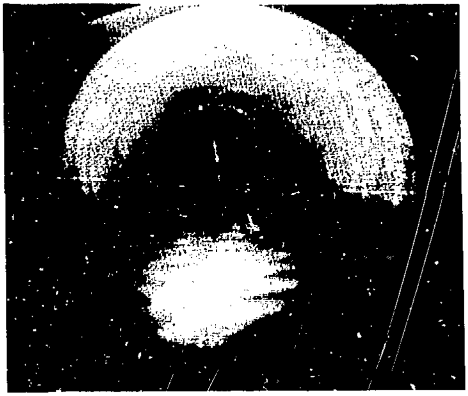


FIG. 12. Some fogging and vapor flow appear when water is introduced into the 90°C spool piece.

FIG 13. Stratified flow with wave motion created by steam injection. Internal spool temperature is 90°C at 60 psi.



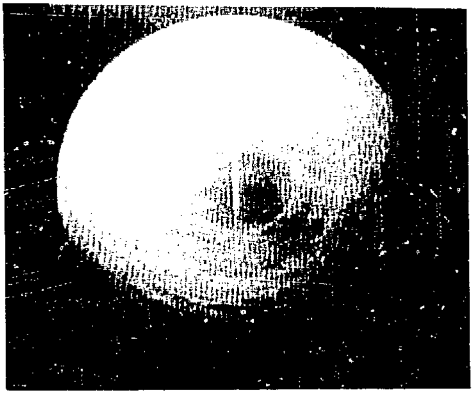
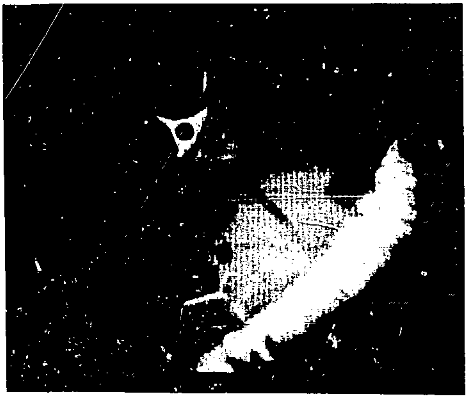


FIG. 14. Full water flow with steam. Swirling, fast moving steam vapor and bubbles can be seen in the upper portion of the spool piece.

FIG. 15. A closeup of the wall and partial drag screen. Spool temperature is approaching superheat (164°C) conditions. Notice rivulets of water condensate being accelerated along the walls toward the drag screen by the steam injection.



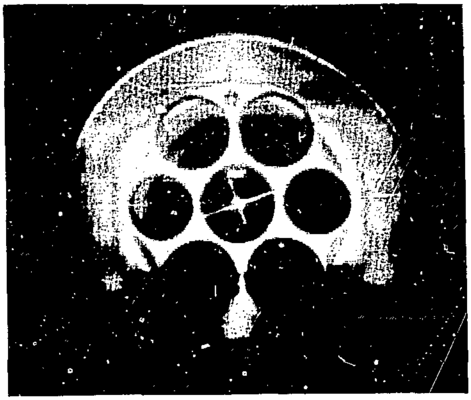


FIG. 16. A view of the drag screen with steam flow during water fill. The fogginess is the result of water vapor and steam injection. The spool system is at atmospheric pressure; temperature is 85°C.

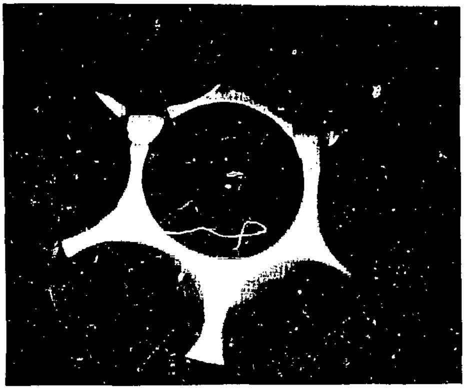


FIG. 17. An extreme closeup of the 80.8-mm vertical spool drag screen. The spool system is filled with water at approximately 90°C. The vertical view is looking directly upstream toward flow. Note the three trapped bubbles on the center edges of the drag screen. Minute bubbles form and grow larger until displaced. The bubble growth cycle continued throughout the spool test. A thermocouple probe is visible in the lower-left-hand background.

No major problems were encountered with the video/lens system during the first series of tests even though the rod lens remained inserted into the spool piece environment from early morning to late night (approximately 12 hr). Although it was not necessary to view and record a continuous 12 hr of daily testing, the rod lens could not be removed from the spool without complete spool piece test facility shutdown, cooling, and depressurizing. (Test system pressures ranged from atmospheric to 90 psia; internal temperatures varied from ambient to 170°C; maximum flow velocities were approximately 60 m/s.)

During the second series of tests (week of 21 February 1979) numerous difficulties plagued the test program which resulted in several long-term soakings of the rod lens at superheat temperatures and pressures (164 degrees C at 60-90 psia). As spool temperatures, pressures, and flow conditions were cycled, condensation and lens fogging began to interfere with the displayed internal video images. When stabilization of superheat temperatures were reached, the lens-portrayed video images were excellent; but when internal spool temperatures or pressures dropped, so did the quality of the rod lens projected images resulting in partial and distorted views of flow conditions. Distortions and lens fogging continued, sometimes visually clearing followed by rapid degradation until the total view image was darkened and finally lost altogether.

Immediately following spool system shutdown, the rod lens was removed and examined. Cursory inspection revealed that although sufficient light was being transmitted by the fiberoptics to the object, it was not being returned via the lens assembly to the video coupling/eye-piece unit. Also, the exposed portion of the 90 degree right-angle objective lens potting material showed signs of erosion and pitting caused by the ablative action and high temperature effects of the steam/fluid flow. The suspected cause of failure was possibly due to prolonged exposure to temperature (164 degree C and above) and steam flow impinging directly upon the 90 degree viewing lens.

At this point it was decided to insert a new rod lens, repeat the test series and during the superheat tests, rotate the lens 180 degrees thereby viewing downstream and not directly into the stream/fluid flow. This, hopefully would minimize exposed lens damage and avoid subsequent failure of the rod lens unit. Using this method of lens protection, we were able to finish the second series of spool testing with good video results although picture quality near the end of the series was rapidly degrading similar to that experienced with previous rod lens failure.

Complete laboratory disassembly of the units revealed broken and cracked lens segments located slightly below the interface of the Conax pressure fitting. Slight discoloration of the lower section (immersed portion) of the sheath tubing ended midway through the area corresponding with the broken lens segment. Further examination revealed discoloration (brownish) and obvious degradation of the adhesive used to bond individual lens segments. This apparent damage and lens failure was confined *only* to the lower portion of the rod lens assembly.

The fractured lens segments are believed to be the result of thermal expansion effects caused by extreme temperature gradients.

The protruding portion of the rod lens (above the Conax pressure fitting) was subjected to ambient temperature ranges (10 to 25°C), while lens elements at the interface and below were soaking at spool and fluid flow temperatures sometimes exceeding 170°C. Microscopic examination of the exposed

90-deg objective lens potting material also showed slight damage (erosion and pitting) due to effects of ablative action combined with the high temperature of the steam/fluid flow.

It appears that prolonged exposure or immersion in fluid flows at temperatures above 160°C results in eventual lens failure with usable lens life (good video/brightness quality) being directly related to the proportional limits of time/temperature.

Replacement of the cracked and discolored adhesive-bonded lens segments in the lower portion of one rod lens assembly (approximately 10 cm) restored the unit to a usable condition and was reserved as a standby lens. The other damaged rod lens unit was deemed not repairable due to extensive fractures and darkening of the exposed 90-deg objective right-angle viewing lens.

The third series of tests on the 113-mm horizontal spool piece (week of March 13, 1979) was modified slightly to allow removal of the rod lens unit during system preheat and testing at superheat temperatures. Rod lens and pipe temperatures were kept below 145°C; internal pressures varied from ambient to 60 psia.

The fourth series of testing commenced during the week of March 27, 1979, using the 80.8-mm spool piece mounted in the vertical position. Spool and flow temperatures were approximately 145°C with internal pipe pressures ranging from 0 to 60 psia. Midway through this test sequence, we lost another rod lens. This unit had been used previously in test series three. Again, failure of the lens assembly was attributed to long-term temperature effects. The lens was replaced and the test series was completed without further complications.

Typical photographic views as portrayed by the rod lens are shown in Figs. 10 through 17. These internal PKL spool piece images were photographed directly from the television monitor during playback, stop-action analysis and, although of outstanding quality, each actually represents only one-half the available video scan lines necessary to produce a full 525-line television picture. This is due to the design characteristics inherent within most television and recording systems, namely the playback stop-action mode is only capable of freezing a single field, not frame, of video. To form a complete picture or frame of video requires interlacing sequentially one odd and one even raster scan, each consisting of approximately 262 lines and taking 1/60th of a second to record. Thus, we arrive at the conventional U.S. N.T.S.C. (National Television System Committee) television design standard of 30 frames/s monitor scan display. Sophisticated electronic disk storage units are available that can store the odd-even fields and, upon demand, display these two fields interlaced to form a stop-action single frame. In our particular case, it is more advantageous to view only a single-field scan of captured dynamic flow conditions because of the rapid movement or velocity of events. Interlacing two sequential fields during stop-action replay results in a blurred image since each field corresponds to events occurring *only* during that particular 1/60th of a second.

ROD LENS/VIDEO SYSTEM ANALYSIS

VISUALIZATION METHODS

Rod lenses used in conjunction with closed-circuit television/recording systems to monitor two-phase flow conditions are an extremely valuable addition to conventional spool piece instrumentation. The ability to visually view and substantiate internal dynamic test conditions occurring in a closed volume more than justifies the small additional cost of the rod lens/video-coupled recording system. Of similar importance is the ability to immediately playback and analyze the flow system by either slow or single-framing methods inherent in video recording devices. Stop-action can be used to perform precise measurements on bubble or droplet size and their associated velocities within the view volume. Further analysis can be achieved by the use of analog or digital electronics enhancement imaging systems, video "window" type detectors for particle/bubble size level determinations, and related electronic video scan systems to differentiate the various flow densities occurring in two-phase flow regimes. For flow systems whose velocity approaches or surpasses limitations imposed by the video scan rate of conventional closed-circuit television systems (30 frames/s), there are commercially available low-light level video cameras which now incorporate a selectable one-to-fourfold increase in framing rates (60, 120, 180 and 240 fields per second).[9]

One additional method for capturing dynamic flow events not previously discussed in this report is the use of still photography techniques in conjunction with rod lenses (Fig. 18). Good quality black and white photographs can be produced using, for example, 35-mm Kodak Tri-X pan negative film with an ASA film speed of 400. Very good image resolution can be expected in most static scene situations. The exposure time will of course depend upon weighted scene brightness and lens light transmission ability.

The obvious disadvantages of still photography include film processing time, loss of event correlation timing, relatively long exposures resulting in blurred images of dynamic events, and, most importantly, the possible loss of the entire photographed test sequence if camera and film development techniques are not letter perfect.

High-speed, fast-framing film cameras are not generally compatible with rod lens systems used in single or two-phase flow environments because of the large amount of light necessary to ensure adequate film exposure when transmitted through small-diameter optic lenses. Comparison studies have been made in relation to still photography versus video systems in both black and white and color experiments.[12]

TEMPERATURE COMPENSATION

Although we lost several rod lenses due to spool piece operating temperatures which apparently exceeded the limitations imposed by the optic system design, it appears that modifications could improve rod lens temperature-resistive characteristics to 500°C or better. Several methods suggested include an optical protective thermowell, heat-sink cooling jackets similar to heat-pipes, or even possible replacement of the low-melting alloy seals and epoxy lens-mounting materials.

One interesting concept to consider is a spool-mounted thermowell providing protection for the rod lens from extreme temperature and ablative flow conditions until such time as an automated system or operator activates lens insertion into the spool environment for quick-look and video recording. Immediately following inspection, the rod lens unit could be withdrawn back into the protective confines of the thermowell. This method would increase the usable life of the rod lens by at least several orders of magnitude and not require extensive modification of the basic rod lens for high temperature compensation.

These and other rod lens temperature protective measures were discussed prior to, and during, the PKL spool piece field test but could not be implemented due to program budgetary constraints.

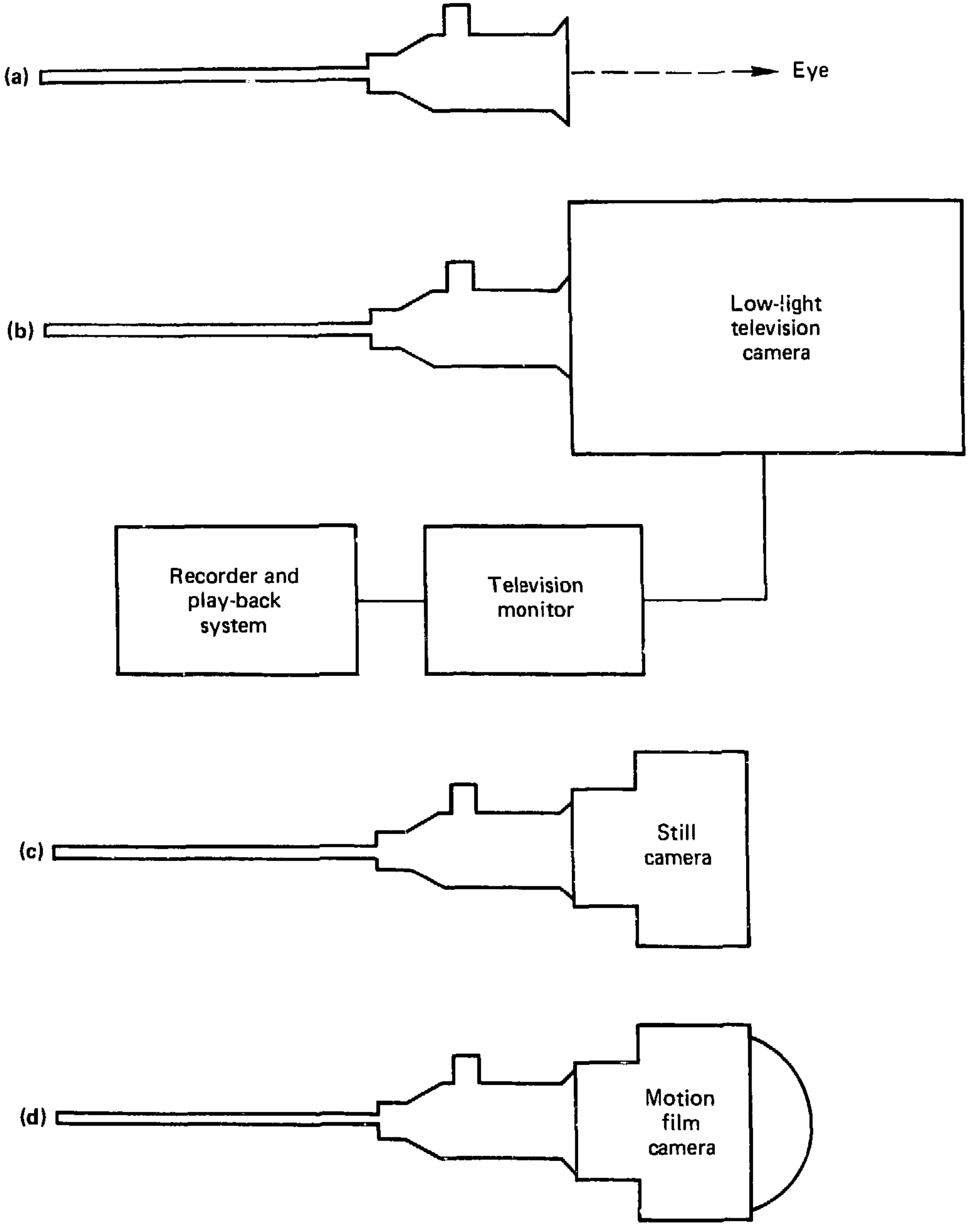


FIG. 18. Visualization methods and image recording: (A) rod optic, light source, human eye; (B) rod optic coupled to low-light video system; (C) rod optic coupled to still camera; (D) rod optic coupled to motion film camera.

ACKNOWLEDGMENTS

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- William Aymer, E.G.& G, Las Vegas Operations, who supplied mechanical system support throughout the PKL Test Program.
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- Ernest Wilson, E.G.& G., San Ramon Operations, who provided technical electronics support.
- Melvin Hatch, E.G.& G., San Ramon Operations, who assisted with the mechanical and technical aspects of this program.

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APPENDIX

VIDEO LOG OF PKL INSTRUMENTED SPOOL PIECE TESTS

Video Data Tape No. 2 (Tape No. 1 was recorded calibration and system test set-up)

Run:	No. 35
Regime:	water
Date:	Feb. 16, 1979
I.D.:	80.8 mm, horizontal
Steam:	0
Water:	219 gpm

Run:	No. 36
Regime:	Slug flow, 60 psia
Date:	Feb. 16, 1979
I.D.:	80.8 mm, horizontal
Steam:	0.154 lb/s
Water:	0.430 lb/s

Run:	No. 37
Regime:	annular mist, 60 psia
Date:	Feb. 21, 1979
I.D.:	80.8 mm, horizontal
Steam:	1.300 lb/s
Water:	0.450 lb/s

Run:	No. 38
Regime:	superheated steam, 60 psia
Date:	Feb. 21, 1979
I.D.:	80.8 mm, horizontal
Steam:	1.330 lb/s
Water:	0

Video Data Tape No. 3

Run:	No. 41
Regime:	slug flow, 60 psia
Date:	Feb. 22, 1979
I.D.:	80.8 mm, horizontal
Steam:	0.150 lb/s
Water:	0.410 lb/s

Run:	No. 42
Regime:	annular mist, 60 psia
Date:	Feb. 22, 1979
I.D.:	80.8 mm, horizontal
Steam:	1.300 lb/s
Water:	0.430 lb/s

Run:	No. 43	Run:	No. 44
Regime:	annular mist, 60 psia	Regime:	wave motion, 60 psia
Date:	Feb. 21, 1979	Date:	Feb. 21, 1979
I.D.:	80.8 mm, horizontal	I.D.:	80.8 mm, horizontal
Steam:	0.770 lb/s	Steam:	0.100 lb/s
Water:	1.440 lb/s	Water:	0.333 lb/s

Run:	No. 45	Run:	No. 46
Regime:	annular mist, 90 psia	Regime:	annular mist, 90 psia
Date:	Feb. 22, 1979	Date:	Feb. 22, 1979
I.D.:	80.8 mm, horizontal	I.D.:	80.8 mm, horizontal
Steam:	0.560 lb/s	Steam:	1.560 lb/s
Water:	0.620 lb/s	Water:	0.470 lb/s

Run:	No. 47	Run:	No. 48
Regime:	superheated steam, 90 psia	Regime:	annular mist, 90 psia
Date:	Feb. 22, 1979	Date:	Feb. 22, 1979
I.D.:	80.8 mm, horizontal	I.D.:	80.8 mm, horizontal
Steam:	1.070 lb/s	Steam:	1.360 lb/s
Water:	0	Water:	0

Video Data Tape No. 4

Run:	No. 57	Run:	No. 58
Regime:	slug flow, 60 psia	Regime:	annular mist, 60 psia
Date:	Feb. 23, 1979	Date:	Feb. 23, 1979
I.D.:	80.8 mm, horizontal	I.D.:	80.8 mm, horizontal
Steam:	0.160 lb/s	Steam:	1.270 lb/s
Water:	9.470 lb/s	Water:	0.460 lb/s

Run:	No. 59
Regime:	slug flow, 90 psia
Date:	Feb. 23, 1979
I.D.:	80.8 mm, horizontal
Steam:	0.340 lb/s
Water:	6.100 lb/s

Run:	No. 60
Regime:	wave motion, 90 psia
Date:	Feb. 23, 1979
I.D.:	80.8 mm, horizontal
Steam:	1.140 lb/s
Water:	0.920 lb/s

Run:	No. 61
Regime:	superheated steam, 60 psia
Date:	Feb. 23, 1979
I.D.:	80.8 mm, horizontal
Steam:	1.350 lb/s
Water:	0

Run:	No. 63
Regime:	superheated steam, 60 psia
Date:	Feb. 23, 1979
I.D.:	80.8 mm, horizontal
Steam:	0.220 lb/s
Water:	0

Run:	No. 146
Regime:	slug flow, 60 psia
Date:	Mar. 13, 1979
I.D.:	113.0 mm, horizontal
Steam:	0.300 lb/s
Water:	1.800

Run:	No. 147
Regime:	annular mist, 60 psia
Date:	Mar. 13, 1979
I.D.:	113.0 mm, horizontal
Steam:	unknown
Water:	unknown

Run:	No. 158
Regime:	annular mist, 60 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	1.540 lb/s
Water:	2.880

Run:	No. 159
Regime:	annular mist, 60 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	2.400 lb/s
Water:	0.710

Run:	No. 160
Regime:	wave motion, 60 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	1.190 lb/s
Water:	0.630

Run:	No. 161
Regime:	slug flow, 60 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	0.300 lb/s
Water:	1.820

Run:	No. 162
Regime:	annular mist, 30 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	1.550 lb/s
Water:	1.280

Run:	No. 164
Regime:	slug flow, 30 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	0.230 lb/s
Water:	1.280

Run:	No. 165
Regime:	wave motion, 30 psia
Date:	Mar. 14, 1979
I.D.:	113.0 mm, horizontal
Steam:	0.095 lb/s
Water:	1.260

Video Data Tape No. 5

This video data tape contains spool-piece test runs No. 204-211 and No. 224. All test runs were of the vertically positioned 80.8-mm spool piece.

Test dates were March 27 and 28, 1979. Spool tests No. 204 through 211 were made at ambient temperatures and pressure. Several later tests were made at 145°C and 60 psia.