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DEVELOPMENT OF REMOTE METALLOGRAPHIC EQUIPMENT
FOR THE ANL METALLURGY DIVISION

by
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ABSTRACT

A summary of the early general development of radiometallography and a short discussion of the special problems that had to be faced at that time is given. A description of the remote metallography installation at the Metallurgy Division of Argonne National Laboratory is given by means of 19 illustrations, together with a discussion of the cave and its major items of equipment.

A. INTRODUCTION

Interest at Argonne National Laboratory (ANL) in remote metallography became active in 1950 when a small prototype cave was constructed in the Metallurgy Division for work on general radiation damage. Equipment modified for use in it included a motorized bench microscope with periscope and an L-shaped macro camera.⁽¹⁾ Research on polishing techniques was begun.⁽⁸⁾ At about the same time the first complete remote metallography laboratory was being put into operation at Westinghouse Atomic Power Laboratory,^(2,6) and the development of specialized equipment for the same purpose was under headway at Oak Ridge National Laboratory (ORNL), Knolls Atomic Power Laboratory (KAPL),⁽³⁾ and Hanford Atomic Power Operation (HAPO).⁽⁹⁾ ORNL reported a completed facility in 1952,^(4,7) and cave developments at KAPL were quite appreciable at about the same time.⁽⁵⁾ Installations at ANL and at HAPO were reported in 1954,⁽¹⁰⁻¹³⁾ and other atomic research centers, such as Savannah River, were designing and procuring equipment.

During this period of beginnings, hot metallography did not stand up full grown. The technical problems which had to be solved were very great. Even when high-priority cave space could be assigned exclusively to such functions, an installation for quite a while could be regarded only as a laboratory in which to do experiments rather than a place in which a routine of operations was conducted. Procedures, equipment, and even physical layout were subject to major rethinking.⁽¹⁴⁻¹⁶⁾ There were early successes, but the general period should be regarded properly as developmental rather than operational, characterized by a diversity of approaches to all of the problems. Some degree of standardization may be achieved in the future

as the merits of various ideas are sifted. At least it has been shown that the problems to be faced in the metallographic preparation of highly radioactive materials are not insuperable. By demonstrating this fact, the way has been opened for a rapid expansion of hot laboratory facilities across the nation.⁽¹⁷⁻¹⁹⁾

The ANL installation is described and illustrated in this report. It has already been indicated that development of equipment started in 1950. Activity on procurement and construction of equipment was most intense during 1953-1954. During the latter year the metallographic cave became available but, although the layout was soon functional, "shakedown" of the facility has continued for an indefinite period. Before proceeding with details of cave and equipment it may be of some interest to record briefly the aims and concepts which guided the planning and development.

B. ANALYSIS OF HOT METALLOGRAPHY REQUIREMENTS

On first thought the basic procedures for hot and cold metallography might be considered essentially the same:

1. The specimen must be selected and cut to proper size.
2. The specimen must be mounted and carefully ground to planeness.
3. The specimen must be carefully polished, cleaned and etched.
4. The specimen must be placed upon a microscope for examination, photography and microhardness testing.

Further thought leads to the realization that for hot metallography an additional point should be listed:

5. Equipment must be maintained.

This is not usually considered a step in the basic procedure of specimen preparation because it is relatively easy to service equipment in an efficiently arranged installation for cold metallography. However, in hot metallography the problem of servicing is made very formidable by the presence of radioactive contamination and by the difficulties of remote manipulation. When the layout was first planned at ANL it seemed quite probable that the service effort would equal, and possible that it might far exceed, the effort put into actual preparation of specimens.

Further reflection on the points listed above led to the suspicion that the similarities between cold and hot metallographic procedures are probably more skeletal than substantial. Cold metallography is based on hand work, whereas hot metallography must depend on machines and mechanical manipulators. Initially it could not even be assumed that irradiated specimen materials would react to polishing and etching in the same

way that cold materials do, although experience has shown that the differences are not alarming. It was suspected, therefore, that techniques would have to be rethought and that "cut and try" methods would have to be used in developing them for hot specimens. However, much of the general experience from cold metallography was considered to be valid for steering purposes in the initial planning for a hot metallography installation.

In particular, conventional practice has found it very advantageous to isolate the rough preparation, finish preparation and examination facilities from each other so that cross-contamination of grit may be eliminated and the optical equipment be kept clean. Much lost effort and wasteful service activity is avoided by the thoughtful physical arrangement of equipment. This principle was conceived to be of even greater importance in hot metallography. Therefore, there has never been much doubt that efficiency of operation would be served best by keeping these functions separated when planning the layout. In addition, it was thought that such an arrangement would permit a number of investigators to do their work concurrently with a minimum amount of interference. A three-cell cave was therefore specified.

The equipment service problems foreseen influenced the layout to a considerable degree. It was decided that the specimen preparation equipment should be designed as mobile units which could easily be removed from the cave in case of mechanical trouble and replaced by standby units. The area behind the cave, therefore, was specified as a special room in which equipment decontamination, adjustment, repair, and storage could be done on a routine basis. It was thought that this provision would permit specimen preparation to proceed in the hot cells with a minimum of service interruptions.

Considerable thought was devoted to placement of the research metallographic microscope. It is an instrument of great complexity, with many refining adjustments which permit quality work to be done on it. Placing it in a cave cell and servicing remotely would certainly be inadequate, as well as expensive, and would reduce its usefulness to that of a bench microscope. Therefore, the ANL optical layout was built around the key idea of placing the instrument outside the metallographic cave proper, shielding its stage with a special cubicle, and passing specimens back and forth between cave and stage by means of a special mechanism.

Thus far only those factors which influenced decisions on general layout of the facility have been mentioned. Most of the preoccupation, however, has been with requirements and development of equipment for use in it. Two ideas have shared primary emphasis in facing this difficult task. First, it has been considered very important that quality of metallographic preparation should not suffer because of oversimplification of the equipment. Second, it has been realized that the equipment should be very usable to insure optimum speed in handling work.

The layout which has evolved from these considerations is shown in Figure 1. Its aim was to provide equipment and arrange space so that a flow of work could be maintained without lengthy servicing operations between steps, and so that servicing or decontaminating one operation did not shut down the use of all the others. A short technical description of the cave and major items of equipment, illustrated photographically, is given in the following section.

C. DESCRIPTION OF CAVE AND EQUIPMENT

I. The Metallography Cave

The three-cell cave, its exclusion room and operating areas are located in a corner of the cave room of the ANL Hot Laboratory Building. Placement with respect to other caves and cask handling facilities has been described elsewhere.⁽¹²⁾ Brief technical specifications are given in Table I. Figure 2 is a front view of the cave, as equipped with Model 8 master-slave manipulators.

TABLE I

Features and Dimensions of the Metallography Cave

Overall Dimensions - 10' x 26'6" x 13'8" high, enclosing 3 cells.
Inner Dimensions of Cells - 7' x 6' deep x 12'6" high, steel plate floor.
Perimeter Walls - 2' Magnetite Concrete in plate steel shell.
Cell Division Walls - 9" Laminated Steel, with sliding section 5' x 4' high.
Cell Doors - 5' x 8' x 2' thick, stepped at top and sides, suspended on I-beam tracks.
Windows - Saturated aqueous zinc bromide in 1" plate glass "Fish Tanks" - 39" above floor.
Front - 5' x 33" x 2' thick; End - 3' x 27" x 2' thick.
Lighting - 4 sodium vapor lamps around each front window.
Manipulators - Paired mobile Model 6 or Model 8 master-slave manipulators in each cell.
Manipulator track slots (accordion shielded) are 94" and 115" above floor, respectively.
Utility Access Ports - 29 of 4" diameter, 3 of 6" diameter, and 4 of 12" diameter ports.
Around each front window - 4 of 4" under window, 1 of 4" and 1 of 6" beside window, 2 of 4" above window.
Around each end window - 2 of 4" under window, 2 of 4" beside window, 2 of 12" above window.
Transfer Ports - At each end of cave, one 4" shielded port each for standard transfer drawers and metallograph specimens.
At back of cave - two 4" shielded ports beside each door.
Endless Specimen Transfer Belt in Cave services all cells.
Exhaust Ventilation - 200 cfm from each cell, passed through roughing and CWS filters.

Figure 1. ANL Metallography Cave and Equipment Layout

Figure 2. Front View of ANL Metallography Cave

Designed to shield against intermediate levels of gamma activity, the outer walls, two feet thick, are of plate steel and magnetite concrete. The windows, of the same total thickness, are "fish tanks" of nonbrowning plate glass filled with saturated aqueous zinc bromide solution. The back doors are steel shells filled with packed magnetite. They roll straight away from their respective cave openings on overhead I-beam tracks which are supported at their extremities by lolly columns. The two inner walls separating the cells of the cave have been furnished with sliding doors. The bottoms of these sections are four feet above the floor level. Opening and closing is accomplished manually by screw and crank at the cave face.

Transfer of specimens into the cave may be by cask and dolly through the back doors. However, most of these operations are speeded by horizontal transfer of specimen drawers through shielded ports in the cave ends. A horizontal-vertical transfer cask is available and provides fast transfer to any other cave or to the building storage vault. Fast transfer of specimens from one cell in the cave to another is made possible by an endless belt arrangement which is located under the work table surface at the inside front of the cave. Holes in the table top serve as loading stations for the belt, and these are fitted with covers to minimize the danger of losing specimens.

All utilities (electricity, air, gas, water, "cold" drain) are brought through a peripheral duct to the outside face of the cave and are there introduced to the cave through access ports as needed. All radioactive waste, either liquid or solid, is collected in special containers for disposal. Interior and exterior surfaces are painted with Amercoat and the interior is finished with strippable coating.

The air pressure within the cave is maintained slightly negative with respect to operator and exclusion areas. The exhaust rate from each cell is approximately 200 cfm. Higher velocities are not desired because of the danger of contaminating the polishing laps with dust.

II. Rough Specimen Preparation Layout

The cell at the operator's left (east end of cave) is assigned to rough preparation of specimens. Views of the front face of the cave and of equipment items appear in Figures 3 to 7 (but also see Figure 8). The usefulness of the end face of the cave is somewhat limited by a main aisleway.

Figure 3 shows, mounted under the window and above the utility strip, electric and hydraulic controls for specimen mounting and rough grinding machines in the cell. A specially designed spark discharge cutoff machine is visible through the window. The control console for it is at operator's right. Model 8 manipulators are in use. In Figure 6 may be seen some interior features of the cell, such as sodium vapor light, ventilation filter panel, end window, rear door, and access holes, including specimen cartridge transfer hole.

Specimen Cutoff Machine. The spark discharge cutoff wheel mechanism and control console shown in Figure 4 have been described elsewhere.^(20,21) The electromechanical arrangement for rotating the spark discharge wheel and for bringing the specimen into contact with it are shown at the left. The device is surrounded with plexiglass shielding to prevent spread of contamination. The cutoff compartment is ventilated by means of a flexible hose connection to the stack exhaust. On top of the Elox control console at right is the control box for specimen vise motions and for circulation of dielectric through the spark gap. The closeup view of the wheel, Figure 5, shows the specimen positioned on the V-block anvil under hold-down fingers during a cutting operation. Transformer oil is an acceptable dielectric.

Specimen Mounting Press. An unmodified Buehler, Ltd., Speed Press is used for embedding specimens in Bakelite mounts. It may be seen at the left in Figure 6 within the preparation cell. It is installed at bench level for easy use and servicing. Controls, including hydraulic hand pump and thermocouple gage, are located on the face of the cave (see Figure 3).

Figure 3

View of Cave Face
at Rough Specimen
Preparation Station

Figure 4

Specially Designed
Spark Discharge
Cutoff Machine.

Figure 5. Closeup View of Spark Discharge Cutoff Machine in Operation

Figure 6. Interior of Rough Specimen Preparation Cell,
As Seen through Front Window

Figure 7 Mobile Grinding or Polishing Machine Adapted for Remote Operation

Figure 8 View of Cave Face at Station Devoted to Finish Preparation of Specimens

The specimen mounts are standardized at one inch diameter, and may be $\frac{3}{4}$ to $1\frac{1}{4}$ inches long. They are fitted with an embedded soft iron washer which permits use of magnetic handling devices during grinding, polishing, cleaning and etching operations.

Rough Grinding Machines. In Figure 6 may be seen two rough grinding machines and a stainless steel wall rack in which abrasive discs are stored. The back of a similar machine, with panels removed to show mechanical modifications, is shown in Figure 7. As a complete description has been written,⁽²²⁾ only the main features will be mentioned in this report.

The basic machine consists of a conventional Buchler, Ltd., polishing lap, in a special cabinet, equipped with a head developed at ANL, which automatically sweeps the specimen over the surface of the rotating lap while oscillating it through a small angle. The pantograph design of the automatic head assures that the surface being polished has stable alignment with the lap surface. Massive construction prevents vibration and chatter, and the inclination of the pantograph arms provides a measure of automatic pressure relief to forestall "grabbing" of the lap. The pantograph arm is delicately counterbalanced on ball bearings so that specimen pressure on the lap may be varied accurately by the addition of small weights. Specimens are introduced into the head collet from a loading pedestal, which may be seen in Figure 6. Alignment is automatic, and the specimen is held magnetically in the collet while the latter is tightened or loosened by a motorized chuck wrench.

Lap surface is lubricated by means of an atomizer nozzle mounted on the head and operated by compressed air. The lap is elevated out of the bowl of the machine for servicing by means of a hydraulic ram installed below and operating a push rod through the lap drive shaft. In this position a pickup arm can be swung under the abrasive disc retainer ring to remove it.

Equipment for washing and drying the specimen after grinding or polishing operations is described in the following section.

III. Finish Preparation Layout

The middle cell of the cave is devoted to the final polishing and etching of specimens. The layout and equipment are illustrated in Figures 8 to 12. Remote hydraulic, electrical, mechanical and air controls for these operations are shown in Figure 8, mounted on the face of the cave. Through the window may be seen a bench microscope for use in checking the progress of metallographic polishing. A viewing periscope projects from an access hole to the left of the window, and the control box for stage and focusing motions may be seen directly below. Both

Figure 9. Interior of Polishing and Etching Cell,
As Seen through Front Window

Figure 10. Ultrasonic Specimen Washer and Specimen Tongs

Figure 11

Hot Air Specimen
Dryer

Figure 12

Bench Micro-
scope Adapted
for Remote
Use

preparation cells are equipped with ultrasonic devices for cleaning specimens in carbon tetrachloride. The ultrasonic driver circuit control boxes are seen to the right of each window, and a carbon tetrachloride supply reservoir appears above the windows. At the extreme left is the Elox control console mentioned in the preceding section; at the right are the control boxes for the microhardness tester located in the optical equipment cell (see following section).

Figure 9 is an angle view through the front window of the cell. The rear door appears at the left. The horizontal dividing line in the wall at the right marks the lower edge of a sliding wall panel mentioned above. The crank by means of which it is moved may be seen at the extreme right in Figure 8. At the center rear appears the exhaust ventilation rough filter for this cell.

Polishing Machines. By far the most important unit in the specimen preparation sequence is the polishing machine, for it must provide the finesse needed for high quality and the flexibility demanded by differences in preparation routines.

Three polishing machines are located in the cell and may be seen in Figure 9. They are of the same design as the grinding machines described in the preceding section, but the laps are surfaced with cloth or paper for use with graded diamond paste abrasive. The lap retaining ring has been found quite adequate for holding down any type of cloth or paper, and servicing operations are nearly as easy to perform as for the grinding machines.⁽²²⁾

A simple crank-actuated diamond paste dispenser may be seen at the far right in Figure 9. Paste syringes are slipped into holding brackets. Paste ejected from them is caught on the face of the specimen to be polished and is transferred to the polishing lap by this means.

Specimen Washer and Dryer. Following each grinding or polishing operation the specimen must be washed carefully and dried rapidly. Any grit particle carried on the sample through the washing operation may contaminate the subsequent finer polishing operations. It was found that ordinary swabbing, dip rinsing, or even jet rinsing were often inadequate. Therefore, an ultrasonic washer was designed for cave use. Such a system was first introduced by ORNL.⁽²³⁾

The ANL apparatus is shown (dry) in Figure 10. In this view a specimen is supported on, and rotated by, two driven shafts so located that the specimen face is at a forty-five degree angle in a beam focused by the spherical transducer below. In practice, carbon tetrachloride is the immersant. After thorough agitation it is drained rapidly away and fixed jets rinse the specimen with clean liquid. It is dried in the hot air blast from the drier shown in Figure 11; a microswitch under the basket is activated by the weight of the specimen.

In Figures 10 and 11 may be seen the magnetic specimen tongs designed for use throughout the grinding and polishing procedure. They permit handling of the specimens with minimum danger of grit or radioactive contamination to the general purpose manipulators.

Etching Equipment. Techniques for etching are being developed. Chemical etching by dipping and/or swabbing is routinely performed in the cave, and apparatus for this type of work may be seen at the far right in Figure 9.

Electrolytic etching may be done by direct contact of an insulated cathode wire to the polished surface of a specimen immersed with face up in the electrolyte. This method results in damage at the point of contact, but makes unnecessary the task of providing an electrical contact through the back of the mount.

A more uniform etch may be obtained on wired specimens using the apparatus shown in center foreground of Figure 9. The sample is clamped, with polished surface down, over a gasketed hole in a stainless steel container of electrolyte. The specimen and container then are inverted so that the electrolyte contacts the polished surface of the sample. The wired connection through the back of the mount is made the cathode; the stainless steel container serves as anode. Rectifier and current controls for electrolytic etching are located outside of the cave.

Bench Microscope. A standard Bausch and Lomb metallographic bench microscope is used to examine specimens during the process of polishing. Figure 8 shows its installation in the finish preparation cell at the left, close to the window. Although the optical path through its periscope is an inverted L, the vertical leg has no housing, permitting the periscope to be withdrawn easily from the cave face for adjustment or servicing. A more detailed view of the instrument, located in an alternative position direct-connected to its periscope, is shown in Figure 12. Fine focus and x-y stage motions are motorized. Coarse focusing and changing of objective turret are done by means of the cave manipulators.

IV. Optical Cell Layout

Most of the metallographic optical equipment is associated with the cell at the operator's right (west end of cave). Figures 13 to 19 illustrate the general layout and show features of the equipment. Much of the work done in this cell requires bringing in shielded casks containing specimens for macroexamination.

The operator's view of the front window is given in Figure 13. It will be noted that Model 6 manipulators were still installed when this

Figure 13

View of Cave Face
at Optical Station

Figure 14

Remote Knoop-Tukon
Microhardness Tester

Figure 15

Vacuum Cleaner for
Radioactive Cleanup

Figure 16

Mechanism to Transfer Specimens
from Cave to Shielded Metallograph

Figure 17

Research Metallograph
Adapted for Use with
Radioactive Specimens
Outside the Main Cave

Figure 18

View of Cave Face
at Side Window of
Optical Station

Figure 19. View of Optical Cell Interior, As Seen through Back Door

picture was taken. Two instruments, a microhardness tester and the bench microscope, appear in the view, together with periscopes and control boxes (left and right of window, respectively). The microscope has since been removed to the location described in the preceding section to provide bench space for macroexaminations. At the extreme right is a transfer mechanism to convey specimens from the cave to the shielded metallograph.

It will be seen in Figure 18 that the end face of the cave is well occupied with optical equipment. A Macrocamera and a stereobinocular viewer and camera occupy the large ports above the window. Control boxes are shown in foreground, to left and right, respectively. Metallograph arc light controls and shielded cubicle appear in left background. The main items of equipment are described briefly below.

Microhardness Tester. The microhardness tester is a Wilson Knoop-Tukon instrument carefully modified for remote adjustment. A list of modifications is given in Table II. A closeup view of the cave installation is shown in Figure 14, and the instrument support and wiring may be seen in Figure 19. The plate steel floor of the cell proved to be

TABLE II

Adaptation of Microhardness Tester for Cave Use

Operation	Adaptation
<u>Stage</u>	
Specimen Loading	Unmodified
Horizontal Traverse (x,y)	Motorized, dynamically braked and jogged.
Rotation	Motorized
Vertical Adjustment (z)	Motorized
Traverse to Diamond	Motorized
Alignment with Microscope (y)	Motorized
<u>Microscope</u>	
Objective Turret	Unmodified
Light Controls	Unmodified
Coarse Focus (z)	Motorized and dynamically braked.
Fine Focus (z)	Motorized, dynamically braked and jogged.
Alignment with Stage (x)	Motorized
Filar Micrometer Eyepiece	Removed and placed on periscope.

the source of objectionable vibrations in the hardness tester installation, and special supporting pads had to be anchored in the underlying concrete before the trouble was cured.

An adjustable chair for the operator provides a writing surface for recording data, and a comfortable position for manipulating the eyepiece and the hardness tester control box. It is demonstrated in Figure 2.

Vacuum Cleaner. The schematic cave layout (Figure 1) shows a vacuum cleaner in the optical cell. The use of this unit is not limited to the one area, but it is needed upon occasion in all of the cells and in the exclusion area. Modification for radioactive use is shown in Figure 15. The hose air stream is filtered by passing first through a cyclone cleaner, and then through a CWS unit in which the fine particulate matter is trapped.

Research Metallograph. The decision to place the main metallographic microscope outside the cave made it necessary to provide an easy means of transferring specimens to and from it. The mechanism constructed to do this is shown in Figure 16 as it appears inside the cave window at the time of loading. The device receives the specimen with polished surface up and delivers it upside down to the metallograph stage, ready for viewing. Interlocks make it impossible to start this operation unless the stage shielding is in proper position.

The shielded metallograph is demonstrated in Figure 17. It has been described in detail elsewhere⁽²⁴⁾; therefore, only the main features will be summarized. The basic instrument is a Bausch and Lomb Research Metallograph with carbon arc lamp illumination. A high-quality

instrument capable of high polarized light intensity, its overall design makes it very adaptable to shielding of the stage section. Light source and camera are outside the shield, and no modification of the optics was needed except to lengthen the eyepiece tube slightly.

The shield is a 4 in. thick lead and steel plate box with a rotatable upper turret section. The latter permits the stage to be loaded by hand and also permits direct service by hand to the stage controls as needed. Access by hand to the many adjustments below the stage level is provided by a sliding door in the stationary section of the shield.

The major adaptations of the instrument to remote operation are listed in Table III. All operations which need to be done inside the shield while the specimen is on the stage are either motorized or adapted by hand-operated remote controls. Safeguards are incorporated into the control system to prevent accidents to the equipment or operator.

TABLE III

Adaptation of Research Metallograph for "Hot" Metallography

Operation	Adaptation ^a
Specimen Loading and Unloading	Automatic motorized cycle
<u>Stage Motions:</u>	
Coarse Focus (z)	Motorized. Also remote manual linkage
Fine Focus (z)	Remote manual linkage
Horizontal Traverse (x,y) and Rotation	Motorized, dynamically braked and jogged.
Leveling (x,y)	Motorized
<u>Optical Adjustments:</u>	
Changing Objectives	Remote manual linkage
Bright Field, Sensitive Tint or Polarized Light Selection.	Remote manual linkage
Oblique Illumination	Remote manual linkage
Swing Out Prism	Remote manual linkage
Field and Aperture	Remote manual linkage
Diaphragms	
Filters	Remote manual linkage

^a All operations not mentioned are unmodified.

The main controls have been located for easy use by an operator at the eyepiece viewing station. An auxiliary control box for the stage motions has been provided at the camera viewing station.

Macrocamera. A 5 x 7 in. shielded camera has been designed for cave use. Its installation above the end window is shown in Figures 18 and 19. By means of it, photographs may be made at magnifications of $\frac{1}{4}$, $\frac{1}{2}$, 1, 2 and 4 diameters, either by moving the position of the lens relative to the film or by using extensions of the camera back. The optical path is an inverted L, using a high-quality first surface mirror close to the lens. The instrument may be rotated through a small controlled angle so that stereoscopic pairs of photographs can be taken in series. A special specimen stage installation is shared with the stereobinocular instrument in the same cell, and will be described in the following section.

Stereobinocular Microscope and Camera Macroscopic examinations are greatly facilitated by a stereobinocular microscope installation in the cave, seen in Figures 18 and 19. The basic instrument is a Bausch and Lomb Remote Stereobinocular equipped to take simultaneous stereophotographs on a 5 x 7 in. film. Three sets of paired parfocal objectives and three sets of paired photographic eyepieces permit magnifications ranging from 4 to 38 diameters. A visual objective for lower powers is also provided.

The following ANL modifications have greatly increased the utility of the instrument:

1. Mechanical linkage has been installed to permit operator to change objectives easily while viewing the field
2. Diffuse illumination to the object field has been provided in the form of a circular fluorescent lamp mounted around the optical path at the objective level.
3. Highlight, or direct, illumination to the object field has been provided by the installation of a circular track and motorized spot lamps at the objectives. These lamps are designed with altazimuthal degrees of freedom. This insures that they are always trained on the focal plane in the field of view while being moved to obtain optimum angles from which to illuminate any object being examined.

An extremely flexible stage installation within the cave serves both macrocamera and stereobinocular. As may be seen in Figure 19, it consists of a stage unit incorporating motorized small motions, mounted on cross tracks and screw columns which permit gross lateral and vertical translations. Thus, the stage unit can be remotely moved from one instrument to another and can be rapidly brought to the approximate vertical level desired. Small motors in the stage unit provide limited travel in five degrees of freedom; 1) vertical, 2) rotation, 3) & 4) horizontal (x,y) and 5) tilt. These motions are listed in sequence from bottom to top of stage unit. The axis of rotation, therefore, can be translated only by moving the unit

laterally on its track. Photoflood lamps on adjustable goosenecks are carried by the stage unit for use under the macrocamera. All motor and light switches and rheostats are brought outside of the cave to control boxes at the viewing stations.

D. ACKNOWLEDGMENTS

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- J. L. Armstrong, Central Shops, design of the polishing machine.
- F. Bevilacqua, RCD, design of the spark discharge cutoff machine.
- R. A. Blomgren, RCD, design and construction of shielded metallograph.
- N. J. G. Bohlin, RCD, design and construction of shielded metallograph.
- W. N. Beck, RCD, stereobinocular and stage modifications.
- W. B. Doe, RCD, macrocamera, periscopes and vacuum cleaner.
- R. J. Fousek, Metallurgy, general technical assistance.
- L. W. Haaker, RCD, design and construction of shielded metallograph, and microhardness tester modifications.
- W. J. McGonnagle, RCD, design and construction of ultrasonic washer and specimen dryer.
- D. F. Uecker, RCD, design and construction of universal stage, modification of bench microscope.

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