CA7703080

AECL-5913

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

VALVE MAINTAINABILITY IN CANDU-PHW NUCLEAR GENERATING STATIONS

by

N.E. POTHIER and W.A. CRAGO

Presented at the Canadian Nuclear Association Symposium on Nuclear Plant Maintainability, Montreal, Quebec, September 1977

Chalk River Nuclear Laboratories

Chalk River, Ontario

September 1977

ATOMIC ENERGY OF CANADA LIMITED

VALVE MAINTAINABILITY IN CANDU-PHW NUCLEAR GENERATING STATIONS *

by

N.E. Pothier and W.A. Crago

* *Presented at the Canadian Nuclear Association Symposium on Nuclear Plant Maintainability, Montreal, Quebec, September 1977.*

Mechanical Equipment Development Branch
Special Projects Division
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0
September 1977

AECL-5913

Maintenabilité de la robinetterie dans les centrales nucléaires CANDU-PHW*

par

N.E. Pothier et W.A. Crago

* Présenté au Colloque sur la maintenabilité des centrales nucléaires, parrainé par l'Association Nucléaire Canadienne et tenu à Montréal en septembre 1977.

Résumé

On identifie et on commente les facteurs qui influent sur la maintenabilité de la robinetterie dans les réacteurs de puissance de type CANDU-PHW. C'est ainsi que le concept, l'application et la disposition des robinets jouent un grand rôle dans leur maintenabilité ainsi que certains facteurs administratifs. On illustre le rôle de quelques facteurs au moyen d'exemples tirés de l'expérience acquise dans les réacteurs prototypes en fonctionnement.

La maintenabilité de la robinetterie employée dans les centrales commerciales CANDU-PHW a été améliorée grâce à des développements au laboratoire et à des analyses de maintenabilité. Les améliorations sont illustrées et commentées.

L'Energie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
Chalk River, Ontario, K0J 1J0
Septembre 1977

AECL-5913

ATOMIC ENERGY OF CANADA LIMITED

VALVE MAINTAINABILITY IN CANDU-PHW NUCLEAR GENERATING STATIONS*

by

N.E. Pothier and W.A. Crago

* *Presented at the Canadian Nuclear Association Symposium on Nuclear Plant Maintainability, Montreal, Quebec, September 1977.*

ABSTRACT

Design, application, layout and administrative factors which affect valve maintainability in CANDU-PHW power reactors are identified and discussed. Some of these are illustrated by examples based on prototype reactor operation experience.

Valve maintainability improvements resulting from laboratory development and maintainability analysis, have been incorporated in commercial CANDU-PHW nuclear generating stations. These, also, are discussed and illustrated.

Mechanical Equipment Development Branch
Special Projects Division
Chalk River Nuclear Laboratories
Chalk River, Ontario KOJ 1JO
September 1977

AECL-5913

TABLE OF CONTENTS

VALVE MAINTAINABILITY IN CANDU-PHW NUCLEAR GENERATING STATIONS

1. INTRODUCTION

The pressurized systems of a CANDU-PHW[(a)] power reactor contain several hundred valves of different types and sizes (Table 1). Many of these are installed in the primary heat transport (PHT), moderator and related ancillary systems. The fluid conditions of the PHT system are quite severe and consist of heavy water at temperatures and pressures up to 300°C and 13 MPa, respectively. For the moderator and some of the PHT ancillary systems, the fluid is also heavy water but at lower temperatures and pressures.

Along with pumps, pressure tubes and steam generators, valves are major components of CANDU-PHW reactors. Hence, the availability of a reactor depends, in part, directly on the maintainability of valves. Since the early operating days of the Douglas Point Generating Station (DPNGS)[(b)], significant improvements have been made to the maintainability of reactor valves. These improvements resulted mainly from lessons learned at DPNGS, valve component development programs, and maintainability analyses.

In this paper, some factors which affect valve maintainability and some improvements made to valve maintainability are illustrated and discussed. However, before proceeding further, one should first define maintainability. Reference 1 provides a good definition and it is repeated below.

Maintainability:

> the quality of the combined features of equipment design and installation which facilitate the accomplishment of inspection, test, checkout, servicing, repair and overhaul necessary to meet operational objectives with a minimum expenditure of time, skill and resources in the expected maintenance environment.

(a) CANDU-PHW : CANada Deuterium Uranium-Pressurized Heavy Water.

(b) DPNGS: A 200 MWe CANDU-PHW Prototype Generating Station.

2. FACTORS AFFECTING VALVE MAINTAINABILITY

2.1 Reliability

Reliability is one of the most significant factors which affect valve maintainability. The relation between reliability, maintainability, and availability is illustrated schematically in Figure 1.

High failure rates can often be attributed to inadequate component design for the specific service or human error. An example of the former can be illustrated from the DPNGS experience. One of the main problems at DPNGS with PHT valves was leakage of heavy water through packed stem seals (2). The basic design of these was based on conventional practice, except that double packings with a leak-off connection between the two packings were used; this was to provide a way to collect and recover leakage passing through the inboard packing. However, despite the provision for leakage collection, gross leakage quickly increased beyond the capacity of the collection system and heavy water escaped through the stem seal outboard packings into the reactor containment space. Repeated re-torquing of the gland bolts or repacking of the valves did little to stop the escape. After a while, the inadequacy of conventional packed stem seals for the service became evident. The solution was to replace conventional stem seals with improved spring loaded packed stem seals (discussed in more detail in Section 3).

2.2 Valve Population

The population of valves in a CANDU-PHW reactor is generally large (see Table 2). Furthermore, many of these valves have similar components; e.g., bellows stem seals, packed stem seals, gasketted joints, pneumatic actuators, etc. For such valves, even if only a small amount of maintenance per valve is required for any common components, the total maintenance load becomes great and this can easily affect the availability of reactor systems. Mainly because of the latter, the valve population has been reduced to the extent possible for the Bruce A and 600 MWe reactors (see Table 2).

2.3 Radiation Environment

Radiation affects maintainability of reactor components in three ways.

- Components of the PHT and moderator systems are inaccessible for maintenance when the reactor is at power, due to high radiation fields. Hence, maintenance on these components can be performed only during reactor shutdowns.

- Due to deposits of small quantities of radioactive crud in the PHT and moderator systems, residual radiation fields remain during reactor shutdowns. Because of these radiation fields, the period a man can spend inside a reactor containment is strictly limited by statutory regulations; the specific period depends on the prevailing radiation fields.

- Because of the possibility of radioactive contaminants in the work area, such as airborne tritium, protective equipment must often be worn.

The difficulties imposed by radiation on valve maintenance quickly became evident at DPNGS. For example, the wearing of ventilated plastic suits significantly decreases the work capacity of a man; this is partly evident from Figure 2. Also, due to radiation exposure limitations, two or three different men were sometimes required to complete simple tasks like re-torquing the gland bolts of a valve. A major task such as repacking and re-gasketting a large valve, depending on the prevailing radiation field, might require eight or more men to complete it. Furthermore, once a man has received the allowable radiation exposure, he is no longer available for in-reactor maintenance for a given period. Hence, within the station staff, the capacity of man-hours for reactor component maintenance is limited.

2.4 Valve Installation Layout

One design criterion for the DPNGS was to minimize heavy water holdup in the reactor systems, mainly because heavy water is costly. As a direct result, valves were generally installed in cramped and congested locations, see Figures 3, 4 and 5. This greatly limits the accessibility of valves which in turn significantly complicates maintenance. For example, grating has to be removed and re-installed, piping and other items of hardware have to be dismantled and reassembled; all in a radiation environment. Also because of the equipment congestion, insufficient space is available to install temporary radiation shielding to reduce local radiation fields.

2.5 Tooling

The time to perform a maintenance task can be affected significantly by the available tooling. This also quickly became evident at DPNGS. For example, little attention had been given initially to tooling for removal of valve packings; hence, this became difficult to do especially in plastic suits, and relatively large personnel radiation exposures were expended in repacking valves. With experience, better tools were developed and the task became much simpler. Torquing of flange bolts on large valves using torque wrenches with torque multipliers also proved difficult; later, hydraulic stud tensioners were used.

The large number of tools sometimes required to perform a maintenance task can become a problem in a radiation environment. For instance, all tools have to be carried manually in and out of the work location inside the reactor containment; sometimes temporary storage near the work is limited. Figure 6 is a photograph of tools used to repack and re-gasket a large isolation valve during the early operating days at DPNGS. This is an example of the extensive tooling sometimes required when maintainability has not been thoroughly considered during design of either the valve or the station. However, the tooling required for similar maintenance tasks in subsequent stations has been significantly simplified by tool development and improvement of valve components.

2.6 Repair Procedures

The lack of prepared detailed repair procedures can sometimes complicate maintenance activities and lead to early component failures. An example can be related again to our experience at DPNGS. During construction of the station, the bonnets of the PHT boiler and pump isolation valves were removed and screens were temporarily installed instead of the discs to collect debris during flushing of the piping. During re-installation of the bonnets, the inner gasket was not held in place and became pinched between the raised portion of the flanges. Excessive gasket leakage resulted from this and the problem reoccurred after subsequent re-gasketting until the cause of the problem with the gasketted joint was identified. Afterwards, detailed procedures were prepared which clearly illustrated how to hold the gasket in place (Figure 7); the problem disappeared after subsequent re-gasketting.

2.7 Component Design Information

Even today, detailed information on valve components, such as materials and dimensions of components, clearances between components, etc. are not generally available to station operators. This can complicate valve maintenance, especially when lantern rings, stems, etc. have to be replaced. Without detailed information for each part, an operator must sometimes dismantle a valve and obtain the information by inspection. This greatly increases repair time and radiation exposure.

Another serious consequence of inadequate information is the discovery in the field that special tooling does not fit or cannot be used because of space restrictions. For example, a check valve, supposedly identical to those in DPNGS, was used to develop bearing replacement tooling. Only upon arrival in the reactor containment was it discovered that the DPNGS valves had a different bearing cap screw thread size. The tooling would not fit. Rush modifications and crew waiting time cost about 150 man-hours and some needless radiation exposure.

2.8 Training

Detailed training in maintenance procedures generally reduces repair times, delays and radiation exposures. But the major benefit to be gained is assurance that maintenance will be completed correctly and reliably. In order to be fully effective, such training requires preparation of carefully detailed work procedures, use of all special tools and parts while practicing the work on identical equipment or mock-ups until each person is competent in his assigned task.

The time required to repack and re-gasket the large PHT valves at DPNGS has been reduced by application of these principles. Re-gasketting during commissioning consumed 32 man-hours per valve. Repacking in 1969 required 16 man-hours per valve. Repacking and re-gasketting by trained crews in 1971 required less than 20 man-hours per valve, although training time added about 150 man-hours per valve. The benefits of training accrue partly in reduction of radiation exposure but mainly from doing the job correctly. Following earlier repair attempts, leakage returned to failure levels almost immediately. By contrast, the expected life of properly repaired valves is five years or more.

2.9 Maintenance Planning

Training, repair procedures, tooling, installation layout, radiation environment, valve population, design information and component reliability have all been cited above as factors affecting maintainability. However, with maintenance planning, beginning with station design and continuing to each and every maintenance task that is undertaken, the effects of these factors can be mitigated. Otherwise, the potential advantage to be gained from knowledge and understanding of these factors can be quickly lost in unproductive or wasted maintenance effort.

3. IMPROVEMENT IN VALVE MAINTAINABILITY

3.1 General

Relative to DPNGS, valve maintainability in subsequent CANDU-PHW stations has been improved greatly. This resulted mainly, from development to improve reliability of valve components, development of new tooling and repair techniques, and greater attention to maintainability by valve manufacturers, station designers and operators.

3.2 Valve Component Development

One major problem with valves at DPNGS was leakage of heavy water through packed stem seals and bonnet-to-body gasketted joints (Table 3). As soon as the magnitude of the problem became evident, a large development program was undertaken to improve these components.

Testing of packed stem seals in the laboratory led to identification and understanding of significant parameters affecting leakage (3), (4), (5). Based on this work, a spring loaded packed stem seal (Figure 8) was developed, tested and evaluated in the laboratory. Sufficient data have now been generated to design packed stem seals for a given leakage criterion, in a deterministic manner (5), (6).

An understanding of the performance of gasketted joints was also developed by means of laboratory tests (7). Better methods to hold the gaskets in place during field assembly on valves were developed. As a direct result, gasketted joints can now be designed in a more deterministic manner.

Considerable development work was also done to understand the performance of bellows for PHT valves. Out of this work, design criteria were evolved and data to predict bellows life were obtained (8).

3.3 Maintainability Analysis

Although, the above development work has greatly improved valve maintainability by improving the reliability of specific valve components, significant improvements have also resulted from maintainability analysis. Maintainability analysis, in essence, consists of identifying and reviewing all possible maintenance activities for a given equipment item, in terms of component down time, effects on system availability, maintenance man-hours, maintenance skills and radiation exposures attributable to maintenance (1), (9), (10). With regard to valves, such analyses generally affect the design of components, valve features, standardization of components, and valve location in a station.

As a result of maintainability analyses, valve maintainability at the Pickering NGS-A and Bruce NGS-A generating stations is greatly improved relative to that at DPNGS. An example of improved maintainability, due to installation and layout, is evident by comparing Figure 9 with Figures 3, 4 and 5. Other improvements resulted from standardization of valve components such as stud and nut sizes, packing type and sizes, and maintenance procedures such as packing blow-out techniques (i.e., blowing out of the packing from inside the valve stuffing box by pressurizing the bottom of the stuffing box (6).)

4. SUMMARY

Valve maintainability depends on several factors, some of which are particular to the valve design, the application environment, and the installation layout. The effects of these factors can be predicted by detailed maintainability analysis. If such an analysis is done at the procurement stage, design changes to improve maintainability can be more easily implemented. Detailed planning and training increase the probability that maintenance is done correctly and that the advantages of experience are utilized. Improved maintainability reduces equipment downtime, reduces radiation exposures and, hence improves availability of reactor systems. The latter is one prime incentive for improved maintainability.

REFERENCES

(1) Atomic Energy of Canada Limited, "Reliability and Maintainability", Specification No. TS-XX-30000-3, Unpublished.

(2) Dixon, D.F., "Valves for Primary Heat Transport Systems for Canadian Power Reactors", Atomic Energy of Canada Limited, Report AECL-3858, February 1971.

(3) Doubt, G.L., "Reference Book for Design of Valve Packings, Sealing High Temperature Water", Atomic Energy of Canada Limited, Report AECL-5120, October, 1975.

(4) Pothier, N.E., "Performance Testing of Prototype Live Loaded Packed Stem Seals for Large Gate Valves in Pressurized Hot Water", Atomic Energy of Canada Limited, Report AECL-5312, November 1975.

(5) Pothier, N.E., "The Application of Belleville Springs as Energy Storage Devices on Packed Valve Stem Seals in CANDU Power Reactor Service", Atomic Energy of Canada Limited, Report AECL-5555, June 1976.

(6) Atomic Energy of Canada Limited, "Class 1, 2 and 3 ASME Section III Nuclear Valves", Specification No. TS-XX-33023-1, Unpublished.

(7) Stevens-Guille, P.D., Crago, W.A., "Application of Spiral Wound Gaskets for Leak-Tight Joints", Journal of Pressure Vessel Technology, February 1975.

(8) Janzen, P., "Evaluation of the Performance of Bellows for Nuclear Valves", Proceedings of the 3rd Symposium on Engineering Applications of Solid Mechanics, University of Toronto, Ontario, Canada, June 7-8, 1976.

(9) Melvin, J.G., Maxwell, R.B., "Reliability and Maintainability Manual Process Systems", Atomic Energy of Canada Limited, Report AECL-4607, January 1974.

(10) Goldman, A.S., Slattery, T.B., "Maintainability: A Major Element of System Effectiveness", John Wiley and Sons, Inc., N.Y., 1967.

TABLE 1 : GENERAL TYPES AND SIZES OF VALVES IN A CANDU-PHW REACTOR

Valve Type	Valve Size (cm)
Large Isolation Gate Valves	15 to 56
Small Isolation Gate Valves	5 to 15
Small Isolation Globe Valves	0.6 to 15
Butterfly Isolation Valves	$\leq$ 122
Control Valves	$\leq$ 10
Flow Check Valves	$\leq$ 56
Diaphragm Valves	$\leq$ 10
Relief Valves	2 to 15
Instrument Valves	$\leq$ 2
Ball Valves	20

TABLE 2 : VALVE POPULATIONS PER UNIT IN PHT AND RELATED ANCILLARY SYSTEMS FOR DIFFERENT CANDU-PHW REACTORS

	DPNGS (200 MWe)	Pickering NGS-A[a] (540 MWe)	Bruce NGS-A[b] (750 MWe)	CANDU-600[c] (638 MWe)
Large Isolation Valves	22	48	5	16
Small Isolation Valves	190	327	185	153
Control Valves	17	18	13	21
Instrument Valves	213	129	46	73
Check Valves	99	70	21	16
Diaphragm Valves	114	13	1	1
Relief Valves	21	3	6	4
TOTAL VALVES	676	608	277	284

(a) Pickering NGS-A: A 4-unit CANDU-PHW Generating Station; capacity of each unit is 540 MWe.

(b) Bruce NGS-A : A 4-unit CANDU-PHW Generating Station; capacity of each unit is 750 MWe.

(c) CANDU-600 : A standardized single unit CANDU-PHW Generating Station; capacity is 638 MWe.

TABLE 3 : MAIN VALVE PROBLEMS EXPERIENCED AT DPGS

Valve Type	Main Problems
Large Isolation Valves	(1) Stem Seal Leakage (2) Body-to-Bonnet Gasketted Joint Leakage
Small Isolation Valves	(1) Stem Seal Leakage (2) Bottom Cover Gasketted Joint Leakage
Control Valves	(1) Stem Seal Leakage
Check Valves	(1) Cover Gasketted Joint Leakage (2) Failure of Disc Shaft Bearings
Butterfly Isolation Valves	(1) Leakage Across Closed Vane (2) Shaft Seal Leakage
Instrument Valves	(1) Stem Seal Leakage (2) Stem Seizure
Relief Valves	(1) Passing at Seat

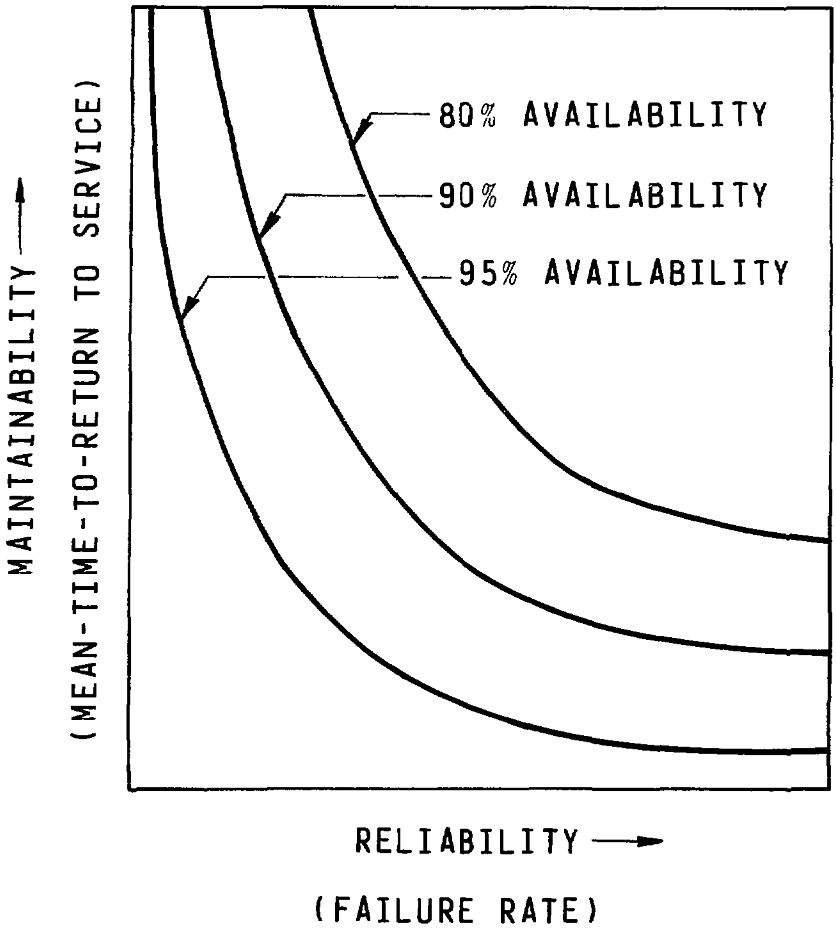


FIGURE 1 : Relation between Reliability, Maintainability and Availability

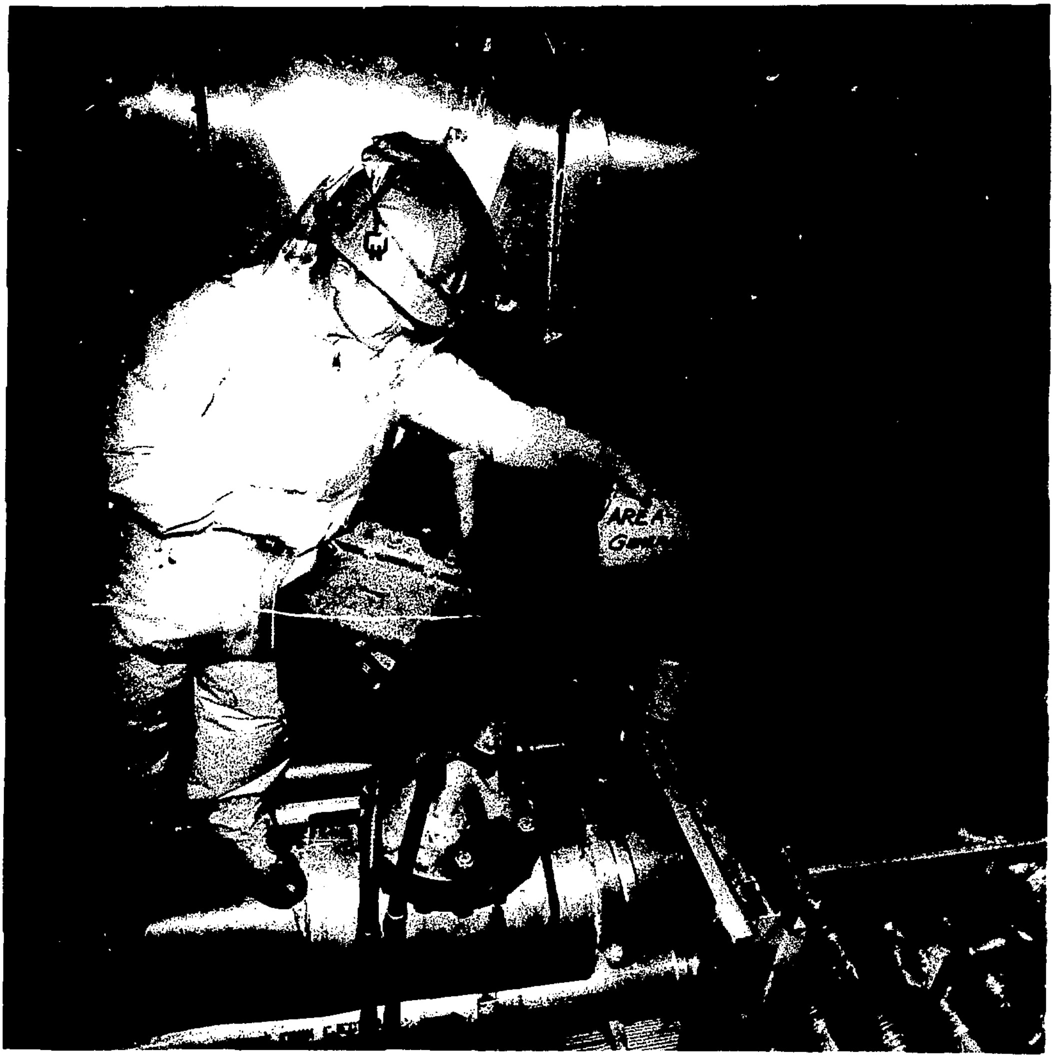


FIGURE 2 : Workman Dressed in a Ventilated Plastic Suit

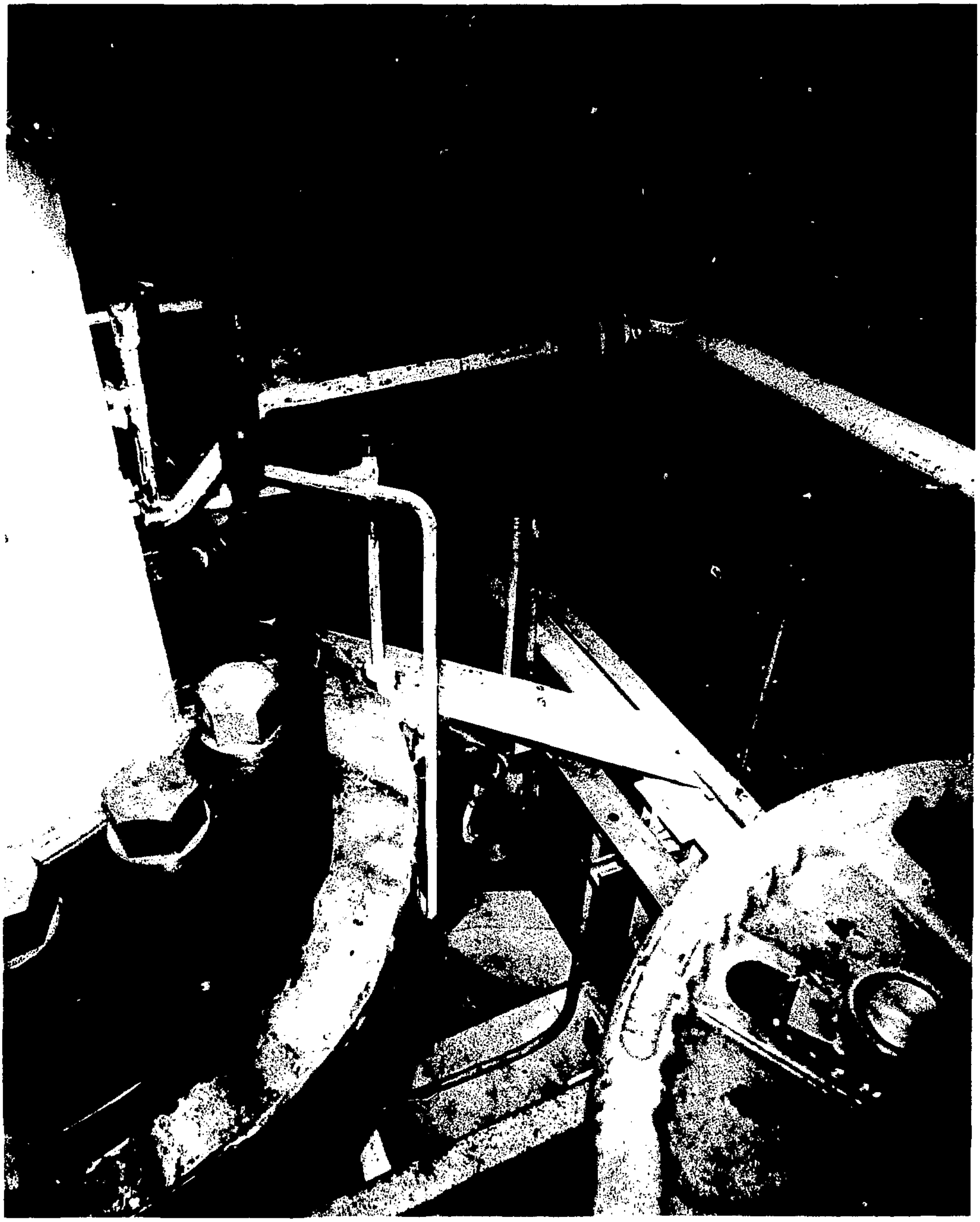


FIGURE 3 : Large Isolation Valve between Pump and Boiler Insulation Cabinet at DPNGS

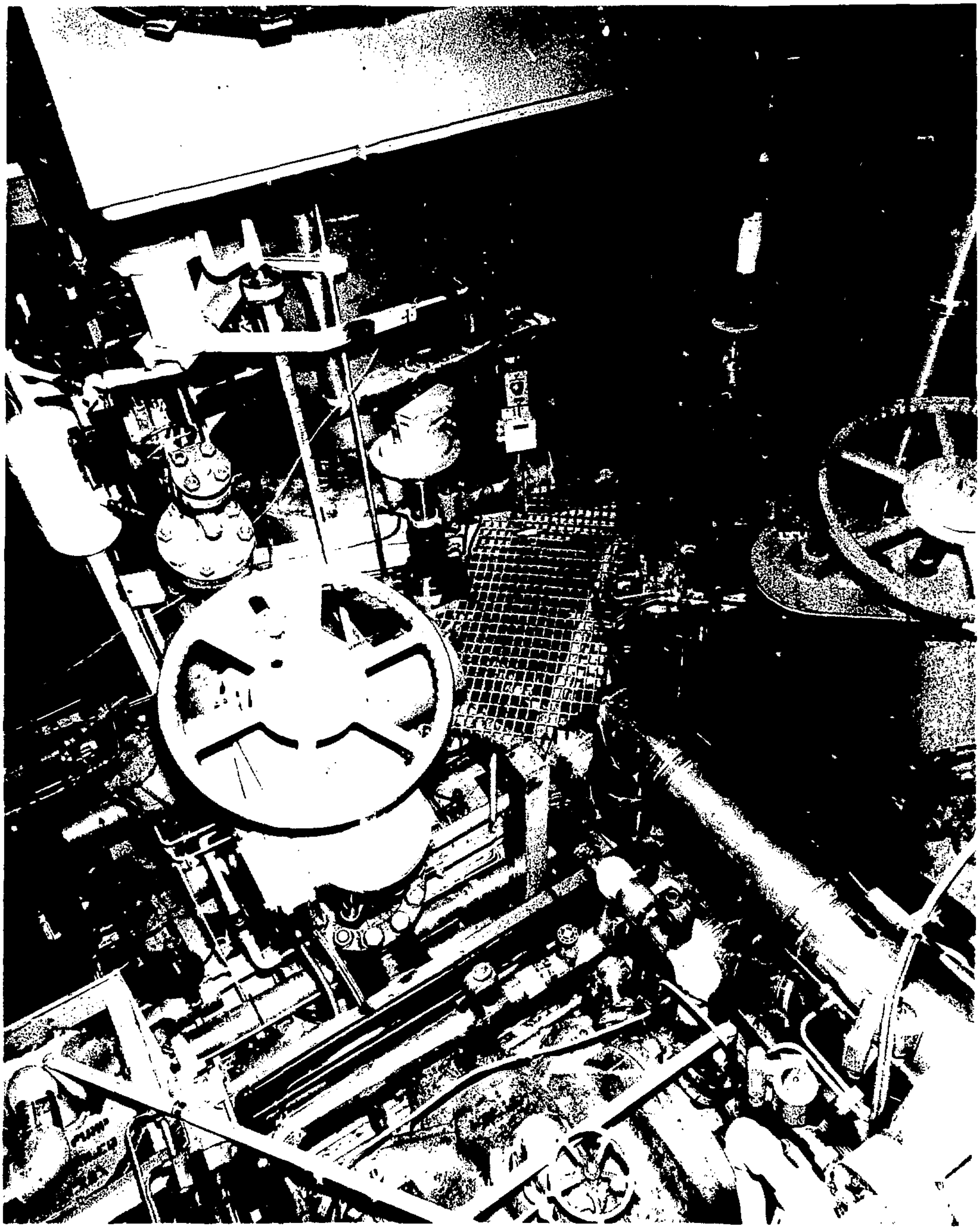


FIGURE 4 : Example of Congested Equipment Layout at DPNGS

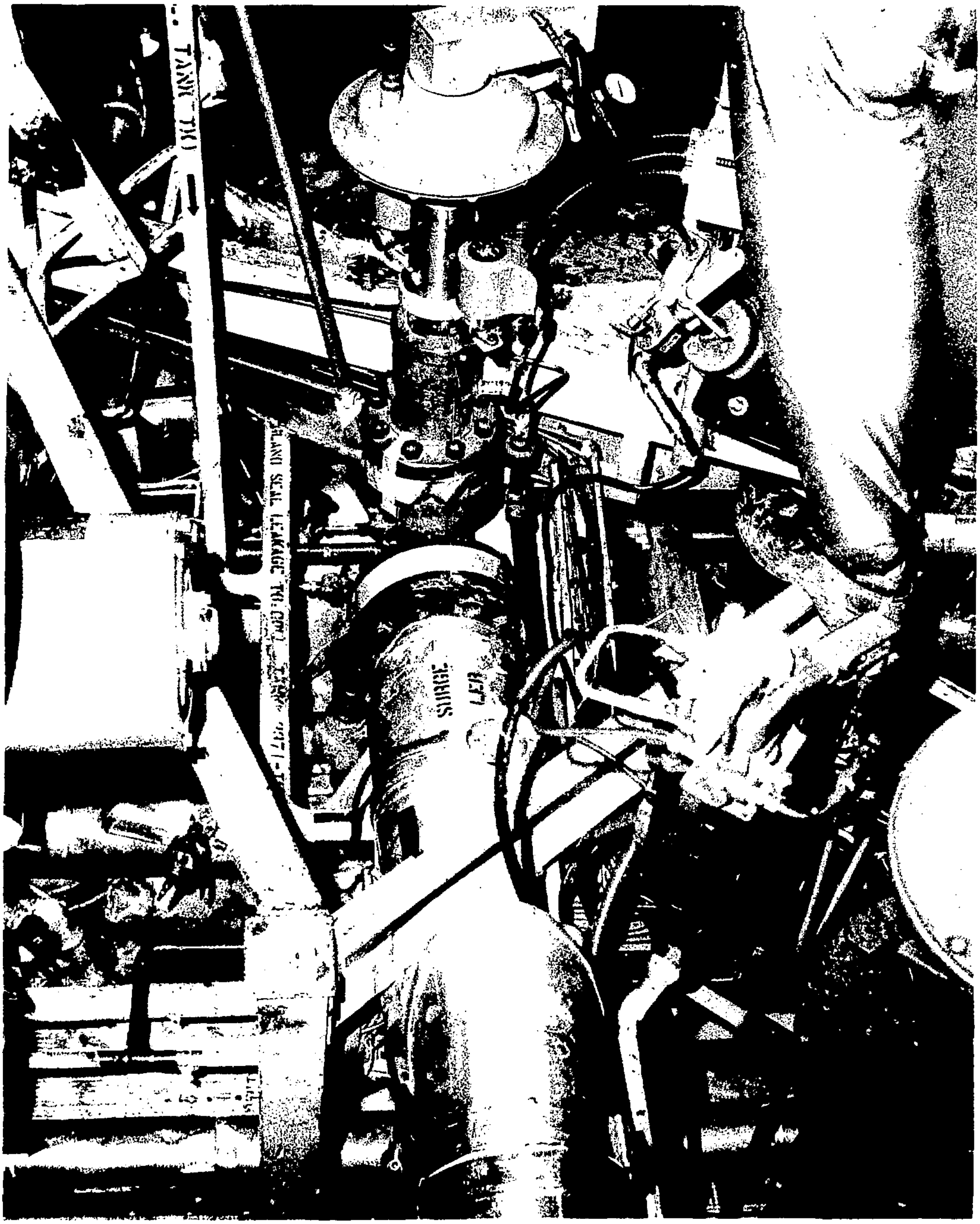


FIGURE 5 : Example of Equipment Layout Underneath Grating and Beams

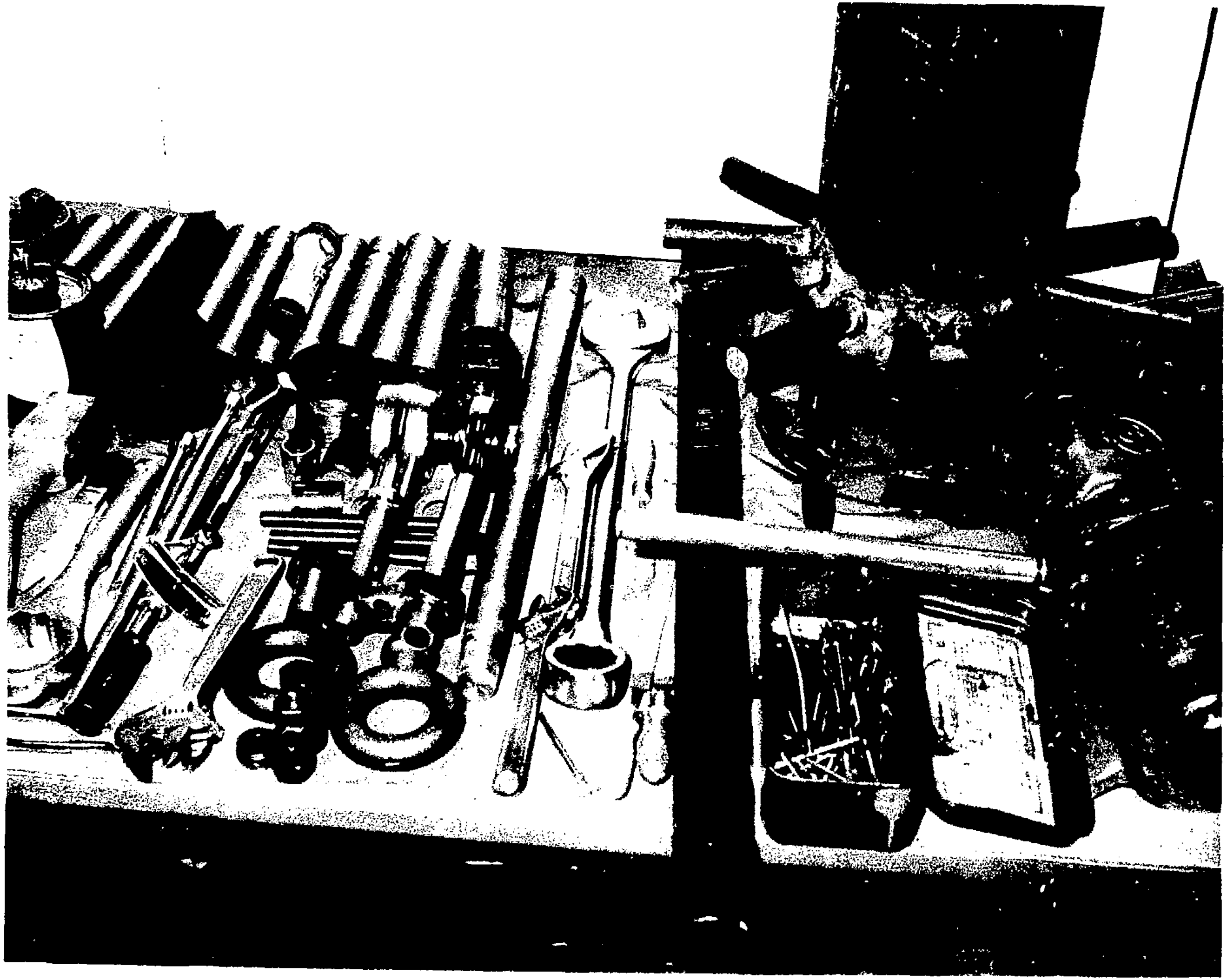


FIGURE 6 : Example of Extensive Tooling Used to Repack and Re-gasket a Large Isolation Valve at DPNGS

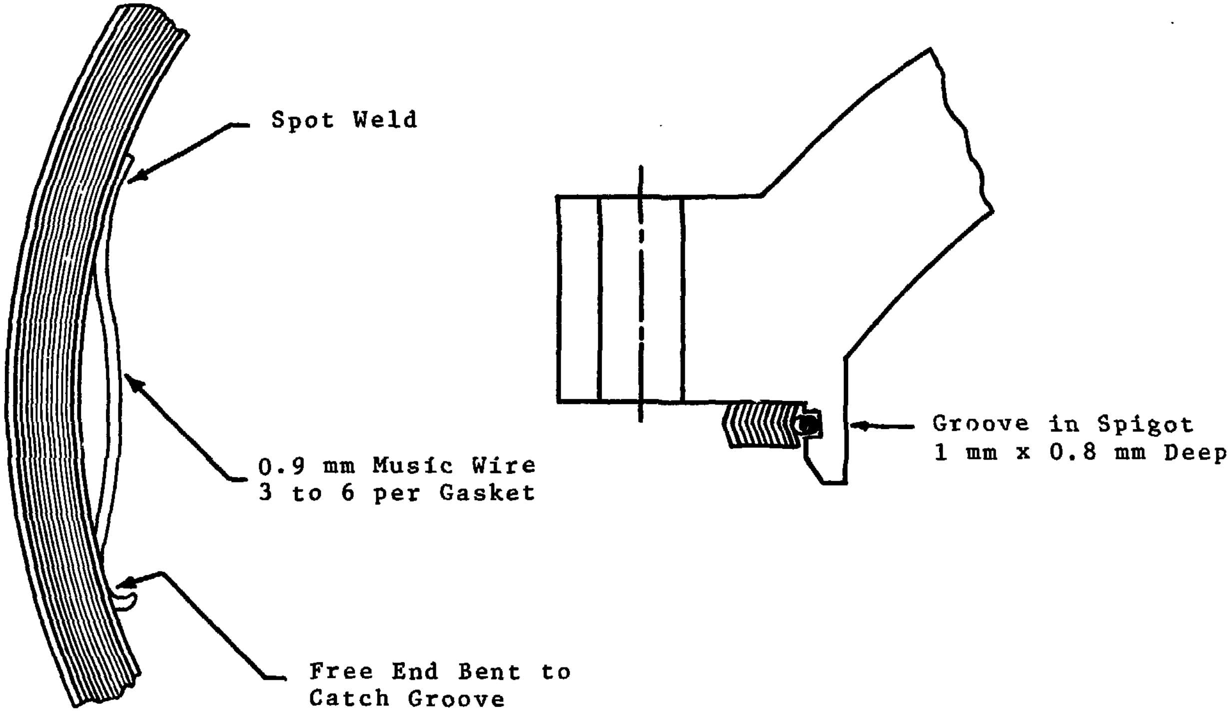
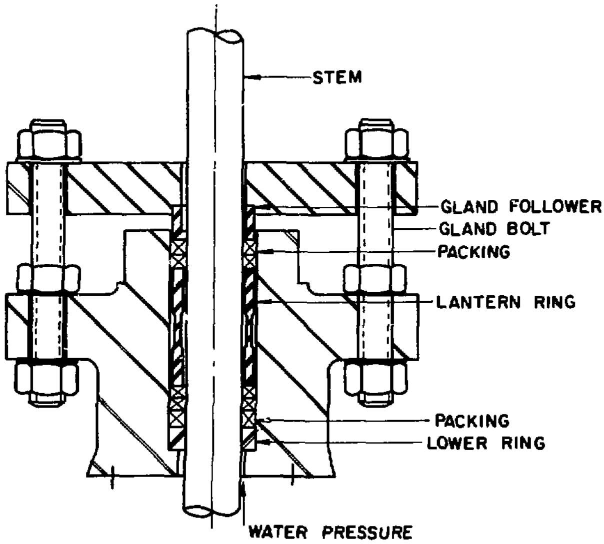
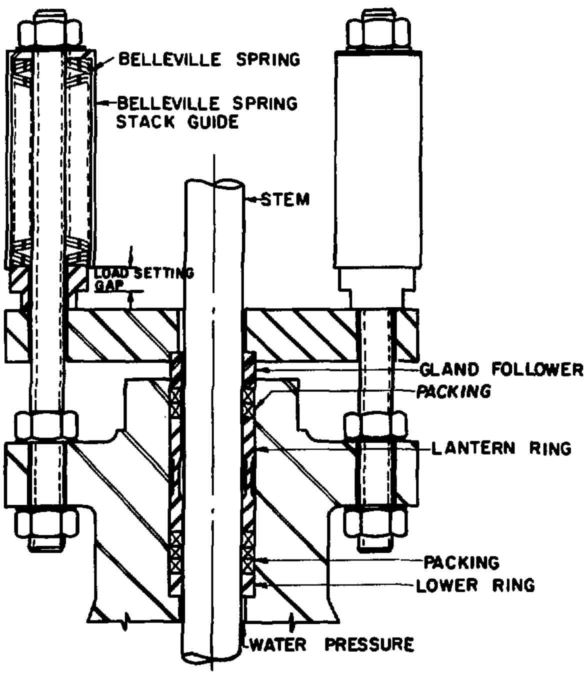


FIGURE 7 : Illustration of Wire Clip Configuration to Hold Gasket in Place During Installation



(A) Conventional Double Packed Valve Stem Seal



(B) Spring Loaded Double Packed Valve Stem Seal

FIGURE 8 : Illustrations of Conventional and Improved Spring Loaded Packed Stem Seals

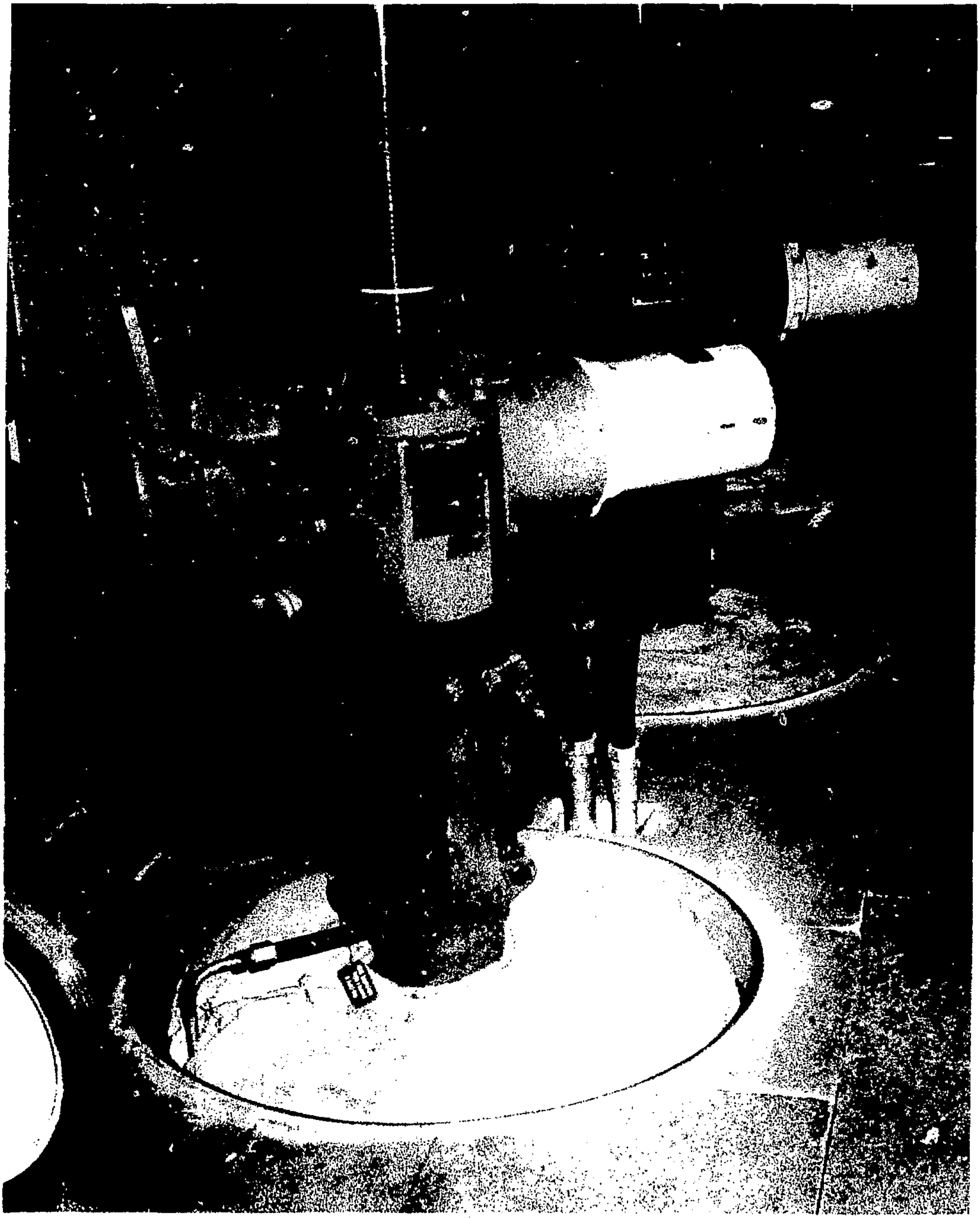


FIGURE 9 : Boiler Isolating Valves at Pickering NGS-A

The International Standard Serial Number

ISSN 0067–0367

has been assigned to this series of reports.

To identify individual documents in the series
we have assigned an AECL–number.

Please refer to the AECL–number when
requesting additional copies of this document
from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada

K0J 1J0

Price $3.00 per copy

1652-77