Rochester Gas and Electric Corporation

R.E. Ginna Incident of January 25, 1982

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DESCRIPTION OF THE INCIDENT

On January 25, 1982, at 9:25 AM, Rochester Gas and Electric Corporation (RG&E or the company) shutdown its R.E. Ginna nuclear power station[1/] due to a tube rupture (or burst) in one of its two steam generators.[2/] Control room operators had no prior warning that a problem existed. The unit was promptly and safely shutdown albeit not without some release of radioactivity to the environment.[3/]

The company's investigation of the damaged steam generator revealed that, in addition to a ruptured tube, several tubes which had been plugged previously, had continued to deteriorate. The failure of plugged tubes is very unusual and was unexpected. The company's response to the accident consisted of the removal

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[1/] The R.E. Ginna nuclear power station is located on Lake Ontario about 16 miles east of the city of Rochester in Wayne County. The unit utilizes a Westinghouse pressurized water nuclear steam supply system rated at 470 megawatts electric.

[2/] The nuclear steam supply system basically consists of a closed system comprised of a reactor vessel, pressurizer, and two similar coolant loops. Each coolant loop contains, among other things, a circulating pump and a steam generator. Each steam generator consists of a vertical shell and 3,260 U-tubes. These tubes form part of the reactor coolant system pressure boundary which is designed to contain fission products in the event of fuel element failure.

[3/] The NRC concluded that all releases made during this incident would result in doses which were significantly less than the 10 CFR 100 guidelines. Potential health impacts from the estimated doses and predicted exposures were insignificant compared with the natural incidence of cancer fatalities and genetic abnormalities. The estimated dose to the total body of the maximally exposed individuals on site and off site from radionuclides released during the event are small fractions of the average annual dose from exposure to natural background radiation in the United States. (NUREG-0909, "NRC Report on the January 25, 1982, Steam Generator Tube Rupture at the R.E. Ginna Nuclear Power Plant," pp. 1-6,7 and 5-25.)

and replacement of these damaged tubes and the identification of the reason for the tube failure.

As the full extent of the problems confronting the company became apparent, it was clear that prompt return of the unit to service could not be accomplished. In February, faced with an extended outage, the company commenced its annual refueling outage which had been scheduled for April 13. From February 19 to April 30 repairs to the steam generator were performed in parallel with other normally scheduled outage activities. By April 30 repairs to the damaged steam generator were essentially complete. On May 25, after RG&E had completed final inspections of the steam generators, the NRC granted the company permission to return the unit to service; and on May 27 the unit resumed power operation.

The outage lasted a total of 122 days.

CAUSE OF THE LEAK

After shutting down the reactor, the company inspected the steam generator to locate the leak and to determine its cause. The burst tube was found to have a large hole in it.[4/] Large portions of three tubes that the company had plugged previously were broken off, and

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[4/] Eddy current inspection results showed that the hole was oriented along the tube axis. It was fish-mouth shaped and about five inches long and was located just above the bottom of the tube.

extensive damage was found on numerous other plugged tubes. These tubes were plugged because wall thickness had been reduced. Routine inspection by the company identified this situation, and the tubes were plugged in accordance with established Nuclear Regulatory Commission (NRC) procedures. The company was not aware of damage to the plugged tubes. When a tube is plugged, it is no longer an operating part of the steam generator and cannot leak. Conventional inspection techniques, e.g., eddy current testing, cannot be done on a plugged tube.

Access and inspection of the inside of steam generators is extremely difficult. Recognizing the need for better inspection capability RG&E developed television video inspection tools for the recent repairs. With these the company found several other foreign objects in addition to the broken off pieces of tubing.

A total of 3 foreign objects were found in the "A" steam generator while 14 foreign objects were found in the "B" steam generator. The largest foreign object was a one-half inch thick piece of metal plate approximately four inches by six inches. Many of the objects were very small, such as small balls of weld material. The largest foreign object is believed to have been a part of the downcomer flow-resistance ring which was removed from each of the steam generators in April 1975. The burst tube was located in the third row (from the outside) of the tube bundle. The plate could only come in contact with the outside row of tubes because of the limited space between tubes. However, as will be explained later, the metal plate played a significant role in precipitating the sequential failure of tubes from the outside toward the inside of the tube bundle.

RG&E retained the services of Westinghouse Electric Corporation to aid in determining the reason for tube failure and to evaluate the possible effects of repairs on steam generator performance. Westinghouse used a full scale model of a portion of the steam generator to study the behavior of the piece of plate. Westinghouse found that the plate was mobile under normal flow conditions and would have a tendency to rest in the area of the damaged tubes. Only the metal plate had sufficient size and mass to strike the tubes with enough force to cause the tube failures that occurred in this situation.

RG&E, on the basis of Westinghouse's evaluation, has concluded that the outage was caused by a domino-effect failure pattern. The foreign object, tossed around by the water normally circulating in the steam generator, repetitively struck tubes on the periphery of the steam generator and weakened their walls. Impact by the metal plate probably caused a plugged tube to collapse. A collapsed, or otherwise damaged, tube no longer has the same degree of support that it had when it was intact. Flow induced vibrations and progressive mechanical damage probably caused a tube or tubes in the periphery of the steam generator to sever at the bottom.[5/] These plugged tubes were free to strike and wear down the walls of adjacent tubes. This wear process or domino mechanism is believed to have continued until an operating tube burst on January 25.

This is the failure mechanism propounded by RG&E. Both staff and the NRC have reviewed photographs, simulation, and analytical results as well as other available evidence and have concluded that the above scenario is the only plausible failure mechanism.

[5/] Each steam generator tube is seven-eighths inch in diameter with a .050 inch thick wall and is made of a nickel-chromium-iron alloy (Inconel 600). Each tube is rolled and welded at the bottom ends into the 22 inch thick tube sheet. Six carbon steel, drilled support plates are spaced equally throughout the axial lenght of the vertical sections of the tubes and are numbered sequentially starting from the tube sheet. The tubes together comprise the tube bundle. The tube bundle is surrounded by a wrapper to which the support plates are wedged and welded. There are a total of 12 wedge location areas equally spaced around the steam generator. Only half are used to support each individual support plate. The use of wedge areas is done on an alternate basis; the first and odd numbered support plates using even numbered wedge areas, etc.

STAFF ANALYSIS

RG&E's Program for Quality Control

The NRC requires utilities to develop and implement the necessary controls over maintenance that would preclude the introduction of foreign objects into areas such as the steam generator. Staff reviewed the NRC's requirements for "housekeeping" that applied to the removal of the steam generator flow-resistance ring. Staff then evaluated the company's commitments to these requirements and reviewed a sample of its procedures to determine whether or not these commitments were in fact implemented during maintenance.

The full requirements of the Code of Federal Regulations, Title 10, Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reproducing Plants," apply and must be adhered to when performing maintenance or otherwise entering the secondary side[6/] of the steam generator. NRC Regulatory Guide 1.39, Revision 0, dated March 16, 1973, "Housekeeping Requirements for Water Cooled Nuclear Power Plants,"[7/]

[6/] The primary side of the steam generator is that side through which primary water flows. It consists of the inside area of all the 3,260 tubes. The secondary side of the steam generator is the area where secondary water flows. It consists of the area on the outside of the tubes. In other words, the tubes themselves are the boundary.

[7/] Revision 0 of US NRC Regulatory Guide 1.39 was the version in effect at the time that the steam generator modifications were made in April 1975. Subsequent revisions show very little change.

described a method of complying with the requirements of Appendix B.

The company in its Quality Assurance Manual committed itself to meeting the requirements of this guide. That manual was developed and implemented on October 1, 1974, prior to the flow-resistance ring removal in 1975. Proper implementation of NRC Regulatory Guide 1.39 requires control over items such as material accountability, personnel accountability, the use of tobacco or food, personnel training, access control, and the use of barriers, screens, and shields.

Staff then reviewed a sampling of maintenance procedures for work on the primary system and the steam generators at the R.E. Ginna nuclear power plant looking for the implementation of the housekeeping practices prescribed in the Quality Assurance Manual. The procedures reviewed typically contained the following housekeeping controls:

- The establishment of a tool control log at an appropriate control point at the access to the clean area.
- The requirement that all tools taken into the steam generator be tied to craftsmen with lanyards.
- The appropriate use of safety harness, breathing apparatus, and lighting.

- The appropriate use of temporary barriers to prevent foreign objects from leaving or falling from the work space.

- The review and signature by a quality assurance inspector that all tools or material which had been logged in were also logged out of the clean area and that the area itself was clean.

Staff also reviewed the specific procedure used by craftsmen to conduct the removal of the downcomer flow-resistance ring. That procedure contains direction and control by management to preclude the introduction of foreign objects into the work area. The procedure called for the blanketing of the work area for the sole purpose of catching items that may fall. The access log to the steam generator shows that the shift foreman responsible for this job frequently entered the steam generator to inspect the work area.

Staff also reviewed the work experience and training of the personnel who performed the flow-resistance ring removal. Each of these people had received the necessary indoctrination and training required for work in a nuclear power plant. Craftsmen working on this job had an average of five-years' experience with the company at the time. The job was supervised by an experienced foreman as well as a quality assurance inspector.

Removal of the flow-resistance ring is a difficult task. The flow-resistance ring is inside the steam generator hanging alongside the top of the generator tube bundle. There are moisture separation equipment, braces, support structures, and internal piping in the immediate vicinity of the ring. The walls are converging around and upon the work area. About ninety percent of the work area surrounding the ring is occupied by equipment. To reach the work site craftsmen must crawl through a manway and carefully maneuver around structures to the ring. There is no acceptable air supply, and so portable fans and blowers are installed to provide fresh air and cool the area. Workers wear special clothing to protect against radioactivity. Workers must bring in their own lighting and tools. Welders must stand on the ring and cut it into sections. There is a blanket and a worker holding a catch trough beneath the work area to capture foreign objects. Because of these difficult conditions, it took two crews of approximately 12 men about three days to complete the removal process. The removal procedure was developed by Westinghouse, and RG&E sent employees to Westinghouse to learn the procedure.

Finally, staff also reviewed the company's experience with regard to the reporting, locating, and retrieval of foreign objects from clean areas. The company encourages employees to report loose objects so they can be retrieved.

Company officials reported an incident in 1976 when a company worker dropped a dosimeter into a steam generator. That dosimeter was removed in accordance with an approved written procedure. There was another incident in 1978 when a worker reported that he had dropped a chisel into one of the steam generators. That chisel was also retrieved.

The company's policy is to train and use its own craftsmen on those jobs that can affect quality. Company officials have confidence in the capability of RG&E craftsmen, specifically noting their integrity as expressed by those incidents where workers, aware of having dropped a foreign object into a clean area, reported the incident.

In a report[12/] subsequent to this incident the NRC has identified the following deficiencies with the flow-resistance ring removal procedure, namely:

[12/] NUREG 0916, "Safety Evaluation Report Related to the Restart of the R.E. Ginna Nuclear Power Plant." May 1982. p. 5-47.

1) The failure to perform a post-maintenance accountability inspection of the removed resistance plates to ensure all pieces were accounted for.

2) Failure to inspect and ensure that the blanket material was properly sealed prior to the initiation of work.

3) Failure to provide a mechanical barrier to catch dropped material of a sufficient design to compensate for the poor blanket seal.

4) Failure to perform an adequate post-maintenance inspection of the steam generator secondary side to assure identification and retrieval of all foreign material.

The NRC has told staff that the purpose of this assessment was to point out that RG&E had improved its practices. The NRC did not believe that RG&E's prior practices were inadequate based upon the information and circumstances existing at the time of the accident. The NRC's current regulations on housekeeping do not prescribe the level of detailed control described in the NRC's report. While it may be argued with hindsight that additional measures could have been taken by the company in order to improve the procedure based upon the evidence of foreign object damage at hand, the procedure used at the time represents a reasonable response to the hazards of foreign objects and demonstrates a conscientious effort to prevent their introduction.

In the area of quality assurance the company's Quality Assurance Manual demonstrates that it was responsive to the NRC's requirements for quality control. The NRC's quality assurance concerns which existed in 1975 were generally implemented in a manner consistent with NRC and industry philosophy at that time.

The company's maintenance procedures demonstrate that the company sought to ensure that its corporate policies as prescribed in the Quality Assurance Manual were put into practice. The specific procedure especially prepared by RG&E to remove the downcomer flow-resistance ring conformed to the NRC's requirements existing at that time and was implemented by qualified personnel who received supervision throughout the progresss of the work. That procedure was followed according to the sign off sheets prepared by the workers.

In summary, RG&E developed maintenance procedures, trained employees, and supervised work so as to prevent the introduction of a foreign object into the steam generator. RG&E's conduct was consistent with NRC regulations and industry practice.

Steam Generator Tube Inspection

One of the issues here is whether the damage to the steam generator tubes should have been detected prior to the tube rupture. Beginning in 1974 the NRC has required utilities to conduct routine examinations of its steam generator tubes in an effort to detect tube deterioration and prevent tube leaks.

The company actually began steam generator tube inspection in April 1972. The NRC's regulations, developed in 1975, require each utility to inspect a minimum of three percent of its steam generator tubes. From April 1972 to December 1979 RG&E typically inspected 60 percent to 70 percent of all its hot leg tubes.[13/] In April and November 1980 and in May 1981 RG&E inspected 100 percent of the tubes in the hot legs of both steam generators. The company has consistently exceeded NRC requirements on tube inspection, and, in fact, RG&E began inspections before they were required.

In April 1981, as part of its routine inspections, the tube which burst in January 1982 was examined. While data at that time indicated that the tube was deteriorating, the extent of deterioration was well within acceptable limits.

[13/] The 3,260 U-tubes are rolled into the tube sheet at both ends. A baffle plate divides the lower plenum of the steam generator in half. Hot water enters the tube and rises up to the hot leg to the U-bend then proceeds to exit the tube via the cold leg. The terms hot and cold are relative in reference to average primary system temperature.

The primary method used for steam generator tube inspection is and was eddy current examination. The eddy current test method has existed for over 25 years. Within the last five years, however, significant improvements in the test method have increased the ability of engineers to interpret data and discriminate the various interferences that affect the output data. The interpretation of the output data remains to an extent an art.

Prior to 1978 RG&E, along with the rest of the industry, used what is known as the single frequency method of eddy current testing. In 1978 RG&E was the first to use a multi-frequency technique in this country. After considerable improvement in this technique, on the part of the company, the multi-frequency technique has become the industry standard. Multi-frequency analysis enables technicians to isolate portions of the instrument signal by eliminating superfluous "noises." Signal refinement can then focus on the tube wall, or other items of interest, in order to more accurately evaluate its integrity. From 1979 to the present RG&E has utilized this state-of-the-art eddy current test method.

The NRC has determined that the present eddy current inspection method being used by RG&E meets and considerably exceeds the NRC's requirements for steam generator tube inspection.[14/]

[14/] NUREG-0916, "Safety Evaluation Report Related to the Restart of the R.E. Ginna Nuclear Power Plant." May 1982. p. 5-7.

Staff noted that RG&E has been performing its own eddy current examinations since 1976. Company engineers, certified as non-destructive examination inspectors, interpret the output data. Data interpretation is checked by an outside consultant in order to obtain a second opinion. Staff also noted that the company has extensively trained its personnel in the art of eddy current examination through the use of a full scale mock-up of its steam generators--an approach which also was pioneered by RG&E.

The extensive level of eddy current examination performed over the years demonstrates the company's concern over possible tube failure and its desire to obtain as much information as reasonably possible to aid in the evaluation of tube problems.

RG&E's record in the development of an improved method for eddy current inspections is exemplary. The company's conduct in this instance has advanced the state-of-the-art for the industry. Since the use of the new measurement technique did not indicate that any tubes needed to be plugged, the company could not have been expected to anticipate the tube rupture before it occurred.

Previous Efforts of the Company to Determine Tube Failure Mechanism

Staff reviewed RG&E's past efforts to solve its tube deterioration problems for an indication of its commitment to maintain the integrity of its plant. The R.E. Ginna steam generator tubes have over the years been subject to various forms of deterioration which have resulted in leaks and/or the need to plug tubes.

Early forms of tube deterioration were due to chemical corrosion attack commonly called "wastage." Steam generator modifications, including removal of the flow-resistance ring, as well as improved operating techniques corrected this form of deterioration. By 1976 tube deterioration due to wastage was declining; however, another phenomena attacking tubes on the periphery of the steam generators was becoming evident. Attempts were made to determine the cause of the peripheral tube failures.

In 1978 a peripheral tube was removed from the "B" steam generator by Westinghouse, under contract with the Electric Power Research Institute, for metallurgical examination. While evidence of damage was identified on the outside of this tube, the possibility of a foreign object was not determined at that time because Westinghouse in extracting the tube appears to have lost the proper orientation of the tube. As a result, Westinghouse did not discern that the deterioration was on that part of the tube facing the periphery of the steam generator. Hence, possibility of foreign objects causing this damage was not considered.

At least one other tube failure mechanism exists at the R.E. Ginna plant today. This mechanism, called "intergranular corrosion," is being reduced by means of a comprehensive program of steam generator cleaning and tube sleeving.[15/] Tube sleeving is also a recent development. RG&E has sleeved approximately 21 tubes at the present time.

The company has over the years been analyzing and correcting those conditions contributing to steam generator tube deterioration. Equipment and procedure modifications such as the 1975 steam generator modifications, changes in secondary chemistry control, and numerous others demonstrate the company's concern and responsiveness to this problem.

[15/] Sleeving is the insertion of a smaller diameter tube inside the tube to be repaired. The sleeve is positioned to span the deteriorated portion of the original tube, and is expanded to seal above and below the degraded region.

Vibration and Loose Parts Monitoring

Sophisticated acoustic monitoring systems called loose parts monitoring systems (LPMS) have been available to the industry for the last several years. This equipment is intended to detect loose parts or foreign objects. Staff examined (1) the NRC's requirements for LPMS's (2) whether loose parts were a significant hazard to steam generators, and (3) the effectiveness of LPMS in detecting loose foreign objects.

The primary requirements for the installation of a LPMS in nuclear power plants are set forth in US NRC Regulatory Guide 1.133, "Loose Part Detection Program for the Primary System of Light-Water-Cooled Reactors." Initially, as issued in September 1977, this guide was applicable to operating license and construction permit applications filed after June 1, 1978. Revision 1 to US NRC Regulatory Guide 1.133, issued May 1981, recommended that all operating reactors install a LPMS. For reactors licensed prior to January 1, 1978, the NRC made special provisions for a case-by-case review. For R.E. Ginna, the NRC had included this item as a topic to be covered in its Systematic Evaluation Program.[16/] Resolution of this item had not been decided for R.E. Ginna prior to this outage. A review of the R.E. Ginna correspondence on this

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16/ The Systematic Evaluation Program is a NRC program to review the applicability of new regulations on older plants. A total of 11 older plants are included in the review.

issue gives us the impression that this item was not a significant priority or concern to either the NRC or the company.

Steam generator tube failures due to foreign objects have been relatively infrequent. As a result, prior to this incident, foreign object damage to steam generators was not considered a significant cause for concern by the NRC, the nuclear industry, or RG&E.

LPMS prior to 1978 received very little attention from utilities. Those which did install them on their own were found by the NRC to be ill-informed on the capability of these systems. Consultants to the NRC had determined prior to 1979:

> *that although loose part monitoring can provide economic and safety benefits to the plant...both prevalent operating practices and current basic LPMS technology will have to be improved before these benefits can be fully realized.*[17]

Also the systems sometimes do not function properly. It is not uncommon for there to be numerous false alarms caused by electric and normal sonic interferences.

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[17] NUREG CR-0524, "Characteristics and Performance Experience of Loose Parts Monitoring Systems in US Commercial Power Reactors." March 1979.

The NRC was evaluating RG&E's need to install a LPMS at the time of the incident. Between 1979 and the time that this incident occurred RG&E appears to have been unaware of the presence of foreign objects in the "B" steam generator and therefore had very little reason to accelerate its review of the applicability of LPMS. The company's conduct in this instance therefore is reasonable.

CONCLUSION

The genesis of the outage goes back to activities in 1975. The company analysis, which we believe correct, is that the tube failure was the result of a metal plate causing damage to steam generator tubes over a number of years. In staff's view, during the 1975 work and subsequently, RG&E, in its quality assurance and testing programs equaled or exceeded NRC's requrements.[18/] In staff's view the company's activities at the time of the repairs in 1975 were proper, the NRC req'irements were met, and the employees were trained and properly supervised.

[18/] The company's performance in areas such as the history of tube inspection which predate NRC's requirements, the extensive number and frequency of tube inspections, the extensive training of personnel in the art of eddy current testing through the use of a mock-up,development of the eddy current inspection method and its development of television video inspection techniques for the steam generator are commendable.

The NRC, in its report, suggests improved methods that would be used now, but are not yet required, and were not required earlier. Staff's discussions with the NRC indicate that RG&E acted properly in 1975. Changes in the work methods made during the 1982 outage were not based upon regulatory guidance but are the result of lessons learned by the company.

Staff concludes that RG&E's conduct was reasonable at the time under the circumstances.