UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Bill M. Morris, Director, Division of Regulatory Applications, Office of Nuclear Regulatory Research

FROM: Eric S. Beckjord, Director, Office of Nuclear Regulatory Research

SUBJECT: GENERIC ISSUE 107, "MAIN TRANSFORMER FAILURES"

The prioritization of Issue No. 107, "Main Transformer Failures," shows that the issue has little safety significance and has been given a LOW priority ranking. The evaluation of the subject issue is provided in the Enclosure.

The enclosed prioritization evaluation will be incorporated into NUREG-0933, "A Prioritization of Generic Safety Issues," and is being sent to the regions, other offices, the ACRS, and the PDR, by copy of this memorandum and its enclosure, to allow others the opportunity to comment on the evaluation. All comments should be sent to the Advanced Reactors and Generic Issues Branch, DRA/RES (Mail Stop NL/S-169). Should you have questions pertaining to the content of this memorandum, please contact Ronald Emrit (492-3731).

Eric S. Beckjord, Director
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Enclosure:
As stated

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ENCLOSURE

PRIORITIZATION EVALUATION

Issue 107: Main Transformer Failures

ISSUE 107: MAIN TRANSFORMER FAILURES

DESCRIPTION

Historical Background

This issue was identified in a DL memorandum[1183] which called for an assessment of the high failure frequency of main transformers and the resultant safety implications. Concern for this issue arose when the North Anna Power Station had seven main transformer failures in 26 months; five of these resulted in reactor trips. Of the seven failures, three included rupture of a transformer tank with two fires occurring. One of the fires spread beyond the transformer bay to the turbine bay. In a report[1184] prepared for the NRC by LLNL, it was concluded that there was a possibility of generic implications arising out of the plant-specific failures reported for the North Anna units.

The potential generic concerns identified in the LLNL report include the fire protection system, overhead conductor/buses, cable trays, storage of flammable materials, and oil-filled transformers in general. In addition, certain secondary aspects of the transformer failures were identified which include cascading effects, extensive electrical/mechanical damage, and missiles/explosions, although the LLNL report noted that these latter items appear to be either indirectly or remotely related to specific safety-significant concerns.

Current NRC regulations and guidance pertaining to fire protection and some of the generic concerns raised in the LLNL report[1184] are embodied in 10 CFR 50 Appendix R,[197] the SRP,[11] and Regulatory Guide 1.120.[1185] This analysis evaluates the need for additional actions by the licensees to prevent main transformer failures and to reduce the resultant risk.

Safety Significance

Safety-related loads in nuclear power plants are supplied from buses that can be supplied from any one of the following sources: (1) the unit auxiliary (main) transformer; (2) the startup transformer (or reserve auxiliary transformer); or (3) the emergency onsite power supply (i.e., diesel generators). A main transformer failure will result in a loss of load or unbalanced load on the main generator. This would lead to turbine/generator trip and power would not be available to the unit transformers for the station power; however, station power can be obtained from the grid through the startup transformer or from emergency onsite power sources. Switchyards have redundant systems to provide sufficient relaying and circuit breakers so a transformer failure is not expected to cause a loss of offsite power.

Other generic concerns associated with this issue include: (1) oil from a ruptured transformer will float on the water delivered to extinguish the fire by the fire protection system such that the fire will move in the direction of drainage; (2) the fire may propagate to overhead cables and buses and create the need for access to adjacent locations (such as building roofs) by fire-fighting crews.

Possible Solutions

Resolution of this issue could involve the following actions:

(1) Evaluation of main transformer design and arrangements by licensees to ensure that the supply of offsite power is protected against transformer fires and smoke. Design requirements should be established for routing and separation of offsite power source feeds to protect against power loss due to a transformer fire.

(2) Review of fire protection system features for the main transformers for adequacy and revision, as necessary, to ensure that a potential fire is prevented from spreading to other plant areas. The review should address the deluge system, drainage system, fire barriers, and fire fighting equipment and procedures.

(3) Review of maintenance and operating procedures for the main transformers for adequacy and revision, as necessary.

(4) Modification of drainage systems, if necessary, to provide drains for each transformer so that liquids flow away from the turbine building, power lines, and safety-related cables to the reactor and related safety equipment. Modifications could include adding drains, building dikes and sloping the transformer yard away from buildings and other transformers.

(5) Modification of fire-fighting equipment and procedures, if necessary. This may include longer hoses, increased ease of access to building roofs, mobility of fire-fighting equipment, and training for personnel.

(6) Relocation of power lines to the safety-related buses, if necessary, so that they would not be affected by a fire in the transformer bay.

PRIORITY DETERMINATION

To establish the priority of this issue, the potential reduction in the plant core-melt frequency as the result of improved main transformer reliability due to implementation of the proposed resolutions is quantified. It is believed that improved reliability of main transformers will reduce the frequency of transients induced due to the main transformer failures, thus leading to enhanced plant safety.

Frequency Estimate

In the representative plant PRAs (Oconee for PWRs and Grand Gulf for BWRs), main transformer failures are integrated into a category of transients that result from loss of network load. The affected PRA parameters are transients other than loss of offsite power requiring or resulting in a reactor shutdown, i.e. T_2 (frequency of 3/RY) and T_{23} (frequency of 7/RY) for Oconee and Grand Gulf, respectively. It is assumed that implementation of the possible solutions will enhance the reliability of main transformers and thus reduce the frequency of the resultant transients. Data in NUREG/CR-3862[1186] on a specific transient category, characterized as a loss of incoming power to a plant as a result of onsite failure (such as main transformer failure), suggest that the transient frequency associated with this category is 0.02 event/RY. In addition, the

IEEE reliability data for liquid-filled transformers (347 to 550 KVA) at nuclear power plants indicate that the main transformer failure rate due to all causes is 2.67/million-hours. This corresponds to an annual frequency of 0.023 failure/year for main power generator or unit transformers. This value will be used as the base case for the failure frequency of main transformers. The second aspect of the main transformer failure, the risk from resulting fire, was determined to be insignificant and was not analyzed further. This conclusion was based on the findings of the Oconee 3 PRA which included the analysis of fires and their potential for causing failures of redundant safety-related components. Also, no particular sensitivity to main transformer fires was identified in NUREG/CR-5088.[1211]

It is assumed that implementation of the possible solutions (i.e., no design improvements to the transformer but improved maintenance and mitigative designs/procedures) would increase the reliability of main transformers by 50%. Therefore, the adjusted case main transformer failure frequency is estimated to be 0.01 event/RY. In addition, the adjusted case frequencies of the resultant transients (T_2 and T_{23}) are estimated as follows:

$$T_2 = (3 \quad 0.01)/RY$$
$$= 2.99/RY$$

$$T_{23} = (7 - 0.01)/RY$$
$$= 6.99/RY$$

Incorporating these values in the Oconee and Grand Gulf PRAs provide reductions in core-melt frequency estimates of 1.4×10^{-7}/RY for PWRs and 3.6×10^{-8}/RY for BWRs.

Consequence Estimate

This issue is assumed to be pertinent to all LWRs and thus has an affected population of 90 PWRs and 44 BWRs with average remaining lifetimes of 28.8 years and 27.4 years, respectively. Based on the Oconee and Grand Gulf PRAs, the associated public risk reduction is estimated to be 0.38 man-rem/RY and 0.25 man-rem/RY for PWRs and BWRs, respectively. Thus, the average public risk reduction associated with this issue is 9.6 man-rem/plant.

Cost Estimate

Industry Cost: Implementation of the possible solutions at the affected plants will require review of existing systems and procedures and hardware changes. It was estimated that the review of the existing systems and procedures will require 15 man-weeks/plant at $2,270/man-week. These efforts include evaluation of the fire protection systems, review of protective circuitry, review of operating and maintenance procedures, revision of operating and maintenance procedures, and revision of staff training. It is also assumed that, as a result of these reviews, about 10% of all affected plants will require hardware changes, modifications to fire protection systems, and rerouting of cables around the main transformer areas. It was estimated that it will require 9 man-weeks to prepare the design modifications and acceptance testing plan, install and test hardware changes, and revise procedures. Hardware and labor are estimated to cost $48,000/plant to provide the following: additional drains, gravel, and concrete to slope the area around the transformers and construct dikes; additional power lines to route power to the buildings; additional breakers to protect equipment connected to the auxiliary transformers; and longer fire hoses. The cost is itemized as follows:

Dike (250 ft. long, 4 ft. high)	=	\$ 3,750
Concrete and Gravel	=	\$15,800
Power lines (1,000 ft)	=	\$ 5,000
Breakers (2 at \$2500 each)	=	\$ 5,000
Fire Hose/Storage Cabinet (110 ft)	=	\$ 500

Note: An escalation factor of 1.8 was used by PNL to convert 1982 dollar values to 1988. Therefore, the cost to implement the possible solutions at 90% of the plants is about \$30,000/plant; for the remaining 10%, the cost is estimated to be \$100,000/plant. The average cost for the affected population is approximately \$40,800/plant.

For the affected plants, periodic review of main transformer procedures, operations, and maintenance was estimated to require 0.2 man-week/RY. At a cost of \$2270/man-week, this amounts to \$450/RY. In addition, those plants requiring hardware modifications (10% of affected plants as discussed above) require 1 man-week/RY (or \$2270/RY) for periodic maintenance/inspection of drains and new diked areas, removal of trash from drains, etc. Plant maintenance and operation costs are recurring costs and are hence adjusted for present worth at a 5% discount rate over the 28.3-year average remaining plant life for the 134 affected plants. This results in an average plant cost (present worth) of \$11,200/plant.

It is believed that improvements to the reliability of main transformers and improvements to fire protection systems could potentially result in: (1) avoided costs of replacing a transformer damaged by fire (3 out of 14 transformer failures resulted in fire, or 0.002 main transformer failure/RY); and (2) avoided replacement power costs associated with reducing the number of reactor trips caused by main transformer failures.

NRC Cost: NRC costs consist of initial regulatory development and the resources required in support of the regulatory implementation. The initial regulatory development cost will involve the issuance of a generic letter or bulletin to the licensees, review of licensees' responses, other related activities (i.e., revised design guidance, assessment of differences in plant design related to transformers, development of potential implementation measures), and the required technical, legal, and administrative staff labor. This portion of resource requirements is estimated to require 40 man-weeks (\$90,000) in addition to potential outside contractor support (estimated to cost \$50,000) for a total of approximately \$140,000. Averaging this over the 134 affected plants results in an approximate NRC cost of \$1,000/plant.

The implementation resource requirements consist of NRC labor to review utility plans to comply with revised guidance and additional inspection and monitoring of transformer maintenance/testing programs during the routine NRC plant inspections. This is estimated to require \$4.1M over the life of all affected plants. These costs are also recurring costs and when adjusted for present worth, as indicated above, result in an average NRC cost (present worth) of \$17,000/plant.

Total Cost: Summing the average costs per plant for licensee implementation, maintenance, and operation and the NRC costs for regulatory development and implementation results in a total cost of $70,000/plant to implement the possible solution to this issue.

Value/Impact Assessment

Based on an average public risk reduction of 9.6 man-rem/reactor and a cost of $70,000/reactor to implement the possible solutions, the value/impact score is given by:

$$S = \frac{9.6 \text{ man-rem/reactor}}{\$0.07\text{M/reactor}}$$

$$= 137 \text{ man-rem/\$M}$$

Other Considerations

(1) Implementation of the possible solutions is assumed not to involve any labor in radiation zones. This is because the main transformers are not located in a building in which radioactive materials are used or stored and thus the radiation dose rates are zero.

(2) The core-melt frequency reductions of 1.4×10^{-7}/RY for PWRs and 3.6×10^{-8}/RY for BWRs results in occupational radiological exposure (ORE) avoidance associated with core-melt cleanup operations of 20,000 man-rem/core-melt.[64] The accident avoidance over the remaining plant life is $[(28.8)(90)(1.4 \times 10^{-7}/RY) + (27.4)(44)(3.6 \times 10^{-8}/RY)]$ (20,000)/134 or 0.06 man-rem/plant. The present worth cost of a core-melt accident is estimated at $1.65 billion considering cleanup and replacement power cost over a ten-year period.[64] The present worth of accident avoidance at each plant is estimated to be $[(28.8)(1.4 \times 10^{-7}/RY)(90) + (27.4)(3.6 \times 10^{-8}/RY)(44)]$ ($1,650M)/134 or $5,000.

(3) Current designs of operating nuclear power plants incorporate various independent means of supplying loads so that main transformer failures will not cause a total loss of offsite power. In addition, the recent promulgation of the station blackout rule (10 CFR 50.63) should reduce the risk further from loss of AC power from that considered in the Oconee and Grand Gulf PRAs.

(4) The implementation of the possible solutions are relatively simple. They can be accomplished during normal plant outages and do not require design modifications or work in radiation zones. The relatively high failure frequency of the main transformers at the North Anna plant highlights a possible need for plant-specific evaluations by some licensees to review their main transformers and to implement an appropriate combination of the alternatives proposed in order to enhance safety.

CONCLUSION

Based on the best estimate value/impact score, this issue is on the borderline between a low and medium issue for existing plants. However, it is likely the risk estimates are high (because the effect of the station blackout rule was not included in the Oconee and Grand Gulf PRAs) and, therefore, the issue would be a LOW priority for existing plants.

REFERENCES

11. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, (1st Edition) November 1975, (2nd Edition) March 1980, (3rd Edition) July 1981.

64. NUREG/CR-2800, "Guidelines for Nuclear Power Plant Safety Issue Prioritization Information Development," U.S. Nuclear Regulatory Commission, February 1983, (Supplement 1) May 1983, (Supplement 2) December 1983, (Supplement 3) September 1985, (Supplement 4) July 1986.

197. Code of Federal Regulations, Title 10, Energy.

1183. Memorandum for W. Minners from L. Engle, "Generic Implications/LLNL Technical Evaluation Report on Seven Main Transformer Failures at the North Anna Power Station, Units 1 and 2," November 16, 1984.

1184. UCID-20053, "Technical Evaluation Report on the Seven Main Transformer Failures at the North Anna Power Station, Units 1 and 2," Lawrence Livermore National Laboratory, March 29, 1984.

1185. Regulatory Guide 1.120, "Fire Protection Guidelines for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, (Draft) June 1976, (Draft) November 1977.

1186. NUREG/CR-3862, "Development of Transient Initiating Event Frequencies for Use in Probabilistic Risk Assessments," U.S. Nuclear Regulatory Commission, May 1985.

1211. NUREG/CR-5088, "Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues," U.S. Nuclear Regulatory Commission, January 1989.