UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF INSPECTION AND ENFORCEMENT
WASHINGTON, D. C. 20555

December 22, 1982

IE INFORMATION NOTICE NO. 82-53: MAIN TRANSFORMER FAILURES AT THE NORTH ANNA NUCLEAR POWER STATION

Addressees:

All nuclear power reactor facilities holding an operating license (OL) or construction permit (CP).

Purpose:

The purpose of this information notice is to describe seven main transformer failures, including one that resulted in a fire and one that caused extensive damage to the main generator, at the North Anna Nuclear Power Station, to alert other nuclear power facilities to the causes.

Description of Circumstances:

The North Anna main transformers consist of three 330MVA single-phase Westinghouse transformers for each unit which are cooled by a forced oil/forced air cooling system. The 22kv low-voltage windings of these transformers are supplied from the main unit generator by an isolated phase bus system. The 500kv voltage windings supply power to the transmission system by an overhead line to the station switchyard.

The North Anna main transformers have experienced seven failures in the past two years, the first five of which involved the Unit 2 transformers and the last two involved the Unit 1 transformers. Of these, the third and seventh caused the most damage and also posed the greatest threat to the health and safety of plant personnel. The third failure generated sufficient forces and heat to rupture the transformer's casing and an oil line. The oil that erupted from these two breaks ignited and the resulting fire engulfed and shorted out an overhead three-phase bus system that supplies offsite power to the normal and emergency buses of the North Anna facility from a reserve station transformer. The seventh failure also generated sufficient forces to rupture the transformer's casing; however, the rupture was at the upper portion of the transformer such that the total oil discharged was significantly less than that of the third failure. Although no fire ensued in the immediate vicinity of the transformer, the total damage and risk to personnel posed by the seventh failure were greater than those of any of the previous events. For example, the effects of the fault were propagated to the main generator where significant damage was done to the main generator and its appendages (e.g., the neutral grounding transformer and its feeder cable and enclosure were destroyed, the neutral enclosure was severely damaged with the north side being blown out, a fire was created in the neutral enclosure but little damage ensued, the hydrogen lines to the generator around the nuetral enclosure were badly damaged but no leaks occurred).

It has been determined that three of the failures involved both the high-voltage and low-voltage windings. In addition, it was found that the failures were either winding to ground faults, as experienced in the first and fourth failures, or high-voltage bushing to ground failures, as experienced in the second and third failures. The investigation also suggests that the following circumstances contributed to the failures:

1. <u>Exposure to Other Faulted Units:</u> At least once before their respective failures, the transformers involved in the second, third, fourth, fifth and seventh failures had been used in a bank of transformers where one of the companion units had failed.

2. <u>Improper Storage:</u> The high-voltage bushings for these transformers were improperly stored (i.e., in a near-horizontal position). This improper storage, coupled with subsequent over-voltage conditions, is believed to be a major contributor to the second and third failures.

3. <u>Overvoltage</u>: Before the first, second, and third failures, the North Anna Unit 2 main transformer bank had been subjected to several documented over-voltage conditions. In addition, as a consequence of the third transformer failure, the transformer associated with the fourth failure was subjected to an overvoltage condition of unknown magnitude for a short period of time.

<u>Discussion of Failures and Postulated Causes</u>:

The paragraphs that follow address each failure and highlight factors believed to have had a bearing on the failure.

1. <u>First Failure:</u> On November 29, 1980, the Phase A transformer of the North Anna Unit 2 main transformer bank experienced a winding to ground failure. Although the transformer was operating at 100 percent load, the hot oil temperature, hot spot temperature, and nitrogen system trouble annunciators were inoperable. Had these annunciators been operating, the failure may have been averted. This transformer had previously failed while on loan to Georgia Power Company. The following factors contributed to this failure:

   - On January 31, 1979 and October 19, 1980, the transformer was subjected to overvoltage conditions of 31kV and 25kV, respectively.

   - Approximately 6½ hours before the transformer failed, its mechanical relief device (MRD) operated. Although the station electricians detected no oil, they found only two coolers running; therefore, they reset a tripped circuit breaker to start three other coolers. In addition, the indicated temperature of the oil on the top of the tank and of the windings were found to be 90°C and 0°C, respectively. The winding temperature indication was obviously in error and may have been the reason for some coolers not operating. Further examination of the transformer verified MRD operation and detected oil on the cover of the transformer. Operation of the additonal oil coolers reduced the temperature to 50°C at the time of failure.

The oil expansion calculations performed by Westinghouse indicated the oil level was approximately 2½ inches below the top of the tank at the time the MRD operated. Since the inert gas system was isolated, this oil expansion would produce a gas pressure of about 19 psig in the absence of MRD operation; however, the MRD apparently opened at approximately 10 psig and relieved the pressure. Soon after the reseal, the inerting gas cylinder was isolated in an effort to silence the MRD alarm, and three additional coolers were started manually, thereby increasing the cooling units by 150 percent. As a consequence the temperature of the oil on the top of the tank dropped about 18°C in the first 2½ hours and an additional 22°C in the next 4 hours. This reduction in oil temperature caused the oil level to drop approximately 3½ inches, and since the inert gas pressure system was inoperable, a partial vacuum was created.

It is postulated by Westinghouse that the vacuum condition resulted in the release of previously dissolved nitrogen gas from the oil, and that this released gas rose as bubbles. It is also postulated that these gas bubbles entered the cylindrical insulation structure around the high-voltage bushing and distorted the electrostatic field surrounding the high-voltage lead. The distorted electrostatic field, coupled with the reduced dielectric strength caused by the gas within the high-voltage bushing, allowed electrical arcing which resulted in the low-and high-voltage windings being shorted to ground.

2. <u>Second and Third Failures:</u> On June 19 and July 3, 1981 respectively, the Phase C and Phase B transformers of the North Anna Unit 2 main transformer bank experienced high-voltage bushing to ground failures. Before these failures, these two units had been exposed to overvoltage stresses of 31kV on one occasion and 25kV on four other occasions. Other factors that may have contributed to these failures include:

   - These units and their companion unit were initially installed at North Anna on July, 1974. On April of 1976 they were shipped to a Georgia Power Co. facility where, on May 6, 1976, they were exposed to the aforementioned failure of the companion unit. After the failure of the companion unit, they were shipped to the Westinghouse factory in Muncie, Indiana for inspection and test before being returned to the North Anna facility. While at North Anna, these units were again exposed to the failure of their companion unit described above in Item 1.

   - From September 25 to October, 1976, the Phase B and C transformers were stored out of the oil at North Anna for 5 and 6 months, respectively. During this time, their bushings were stored in shipping crates at an 8° to 9° angle, but they should have been stored at a minimum angle of 20°.

Initial inspections of the failed transformers disclosed internal failures of the high-voltage bushings; burning was more severe on the bushing of Phase B transformer. Although no other causes for failure were evident, examination of Phase B transformer revealed secondary flashover points and a ruptured cover that raised the high-voltage bushing and lead. Phase C transformer on the other hand, evidenced no tank distortion.

Factory inspections of these bushings (see attached Figure 1) disclosed burning of the tap and ground foils on the straight portion of the condenser where the flange and ground sleeve are attached (Region A of Figure 1). The insulating paper between these foils was wrinkled and burned on the edges in this region and across the surface of the condenser from Region A to the bottom end of the condenser taper. Arc marks were found on the lower bushing corona end shield and the ground sleeve of Phase C transformer, and on the HV lead tank wall of Phase B transformer. Based on the factory inspections, it was concluded that the failures originated as arcs between the ground and tap foils in the straight portion of the condenser (Region A). These arcs then propagated across the surface of the tapered portion of the condenser (Region B). On Phase C transformer, the gas generated by this burning disintegrated the lower portion of the bushing and established an arc path from the lower corona shield to the steel ground sleeve. The arc path on the Phase B transformer included the high voltage lead connected to the bottom of the bushing, the tank wall, and windings.

Since the bushings were improperly positioned (i.e., in the near-horizontal position) during their transportation and storage periods, portions of the condenser were not completely covered by oil. The absence of oil allowed the gas in the expansion cap to permeate the exposed paper layers. Once gas permeates the paper region the busings are degraded electrically and long time periods are required to completely reimpregnate the paper with oil. Such degraded bushings are susceptible to corona discharges on overvoltage conditions such as those experienced by these bushings before their ultimate failures.

Corona discharges are usually extinguished when the voltage returns to normal; however, the dielectric quality of the bushing is reduced each time a corona discharge occurs. As a result, new corona discharges will occur at lower voltage levels than those of the previous discharges. This process is cumulative and can continue until the corona extinction voltage level is less than the normal operating level, in which case disruptive failures will occur. Unlike previous disruptive events at North Anna, the transformer failure of July 3 generated such great internal forces that the transformer box and one oil pump discharge pipe ruptured. The oil that erupted from these two breaks ignited, and the resultant fire shorted out the overhead bus bars from a three-phase reserve station service (RSS) transformer. The affected RSS transformer is one of three transformers that supply Unit 1 and 2 with offsite power(startup power) whenever a unit generater is not available. These transformers are also the preferred sources of power for the Class 1E loads whenever a unit generator is not available. Underground cables serve the 4160-V emergency buses from these RSS transformers, and the overhead bus bars and cables serve the normal service station buses; however, there are no isolation breakers near the RSS transformer for the overhead bus bars.

3. Fourth Failure: On July 25, 1981, while being backfed from the 500-kV switchyard for preoperational testing, Phase C transformer of the North Anna Unit 2 main transformer bank failed. The failure was a high voltage to ground fault which ruptured the tank and resulted in the loss of cooling oil. No fire ensued. Factors which contributed to this failure include:

   - This transformer was purchased by another utility in 1968 and placed in service in 1970; its two companion transformers failed in 1976. It was then shipped to the Westinghouse factory in Muncie for retest, where it was subjected to its basic insulation level test. The unit was shipped from Muncie to the other utility and in June of 1981 it was shipped to North Anna.

   - On July 3, 1981 it was exposed to the failure experienced by Phase B transformer.

It appears that the low-voltage coil edge of the transformer experienced an incipient failure as a result of the high-voltage to low-voltage failure of Phase B transformer on July 3, 1981. Evidence leading to the assumption includes:

The inside of the tank top above the end frames was coated with carbon. The corner nearest the failed points was darker than other walls.

The original oil level was clearly defined by a dark carbon ring encircling the inside of the tank, indicating that the carbon ring was probably generated during the July 3 failure of Phase B transformer (e.g., the ruptured tank associated with the July 25 failure depleted the oil too quickly for a carbon ring to form).

4. Fifth Failure: On August 22, 1982, Phase B transformer of the North Anna Unit 2 main transformer bank experienced an electrical insulator bushing failure. This failure caused a turbine trip and reactor trip from 30 percent power; as a result hot transformer oil was sprayed around the failed unit and the fire protection water deluge system was activated. Although no fire ensued, the oil emanating from the bushing also sprayed the bus bars of RSS Transformer C. After the plant was brought to a static condition and to ensure that no fire would occur from the sprayed oil, RSS Transformer C was taken out of service until the oil was removed.

   Offsite power to most of the plant auxiliary loads remained available via RSS Transformers A and B; however, the Class 1E buses normally served from RSS Transformer C required the running of the onsite emergency diesel generator dedicated to said buses. While in the process of restoring RSS Transformer C to service, an unrelated event occurred. Load on the diesel generator was being increased while syschronizing the generator with the grid in order to restore RSS Transformer C to service. During this period oil leaked on the hot exhaust system of the diesel generator and a fire ensued. The fire was quickly extinguished and no damage was done to the diesel generator.

5. Sixth Failure: On November 16, 1982, while Unit 1 was being heated up following a refueling outage, the Phase C Transformer of the main transformer failed. Since the Unit was not generating power at the time of the failure, the main transformer was being used to provide power to the auxiliary loads from the grid. Although this is the sixth main transformer failure experienced at the North Anna nuclear facility, it is the first failure of a Unit 1 main transformer.

   As a result of this failure, a small hole was blown in the transformer's case, causing oil to be sprayed into the adjacent area. The oil was contained in the concrete basin surrounding the transformer and no fire ensued.

   Subsequent to this failure, Westinghouse recommended that the North Anna Unit transformers be modified. Shortly thereafter the licensee modified the Unit 1 transformers as recommended by Westinghouse. The recommendations included incorporating a constant oil pressure system (COPS) that separates the nitrogen gas from the transformer oil by use of a diaphragm. The intent of this modification was to eliminate the previously described adverse affect of dissolved nitrogen gas in the oil.

6. Seventh Failure: On December 5, 1982, with Unit 1 operating at 30 percent power, its Phase B main transformer failed. The transformer failure caused an automatic trip of the turbine and the reactor. Prior to the trip, but not related to the transformer failure, two steam flow instruments had been tripped because of erratic indications. Subsequent to the trip, the reactor coolant temperature (Tave) reached a low setpoint which initiated emergency safeguards functions, including safety injection which was terminated after seven minutes.

   The forces associated with this failure caused the transformer's case to rupture; however, since the rupture occurred in the upper part of the transformer, the oil discharged was limited to approximately 1,500 gallons. The oil was contained within the transformer's concrete basin.

   The effects of the failure were not confined to the immediate area of the transformer. Rather, the effects were propagated to the main unit generator and its accessories which suffered significant damages. The damage due to this event included:

   - Phase B Transformer: Tank ruptured in several places; COPS remained intact, but the connection line from the tank to top of the transformer ruptured. Cooling fans and enclosures were blown off and fell against the fire lines breaking the lower ring of the deluge system; low-voltage bushings were both broken; low-voltage connection box split; high-voltage flexible cable to the bushing had failed and had gone to ground and to the secondary winding.

   - Isolated Phase Bus and Ducting: Oil found on the B Phase duct; breaker G-12 was coated with aluminum dust and its access cover on Phase A was bowed out; Phase A and B duct and bus work at the elbow on the generator side of Breaker G-12 and six standoff insulators for the bus were damaged sufficiently to require replacement.

- Main Unit Generator: Neutral grounding transformer, feeder cable and enclosure destroyed; generator neutral enclosure was damaged and the north side was blown out (a fire was created in the enclosure but only minimal damage resulted); hydrogen lines to the generator around the neutral enclosure were badly damaged, but no leaks occurred (had a leak occurred or had the line ruptured, the health and safety of plant personnel could have been endangered); Phase C in the neutral enclosure bushing was cracked and others received splatter; stator damaged and copper found in the lead box; air handler ducting damaged.

The licensee estimates that repair or replacement of the damaged parts will be completed by April of 1983.

The licensee is investigating the main transformer failures at the North Anna nuclear facility. The licensee plans to replace the Unit 1 transformers prior to restart and the Unit 2 transformers during the next refueling outage with different make transformers.

We have been informed that about 300 similar transformers were placed in service between 1965 and 1976. To date, twenty-one failures have been experienced by these transformers, seven of which have occurred at the North Anna facility and six at a Georgia Power Company fossil fuel plant. These failures have been characterized as being winding or bushing failures similar to those described in this Notice.

If you have any questions regarding this matter, please contact the Regional Administrator of the appropriate NRC Regional Office or this office.

/S/

Edward L. Jordan, Director
Division of Engineering and
Quality Assurance
Office of Inspection and Enforcement

Technical Contact: I. Villalva, IE
(301) 492-9635

Attachments:
1. Figure 1, "Outline - High Voltage Bushing"
2. List of Recently Issued IE Information Notices

*SEE PREVIOUS CONCURRENCES

WPU:JD	*EAB:DEQA:IE	*C:DEQA:IE	*D:DEQA:IE
12/17/82	I VILLALVA	WR MILLS	EL JORDAN
5520	12/ /82	12/ /82	12/ /82

The licensee is investigating the main transformer failures at the North Anna nuclear facility. ~~The NRC resident inspector and specialists from the Region II Office are monitoring the progress of the licensee's investigation and will review the adequacy of the corrective actions.~~ The licensee plans to replace the Unit 1 transformers prior to restart and the Unit 2 transformers during the next refueling outage, with different make transformers.

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I.V.	GF for	
EAB:DEQA:IE	C:DEQA:IE	D:DEQA:IE
I VILLALVA	WR MILLS	EL JORDAN
12/16/82	12/16/82	12/ /82

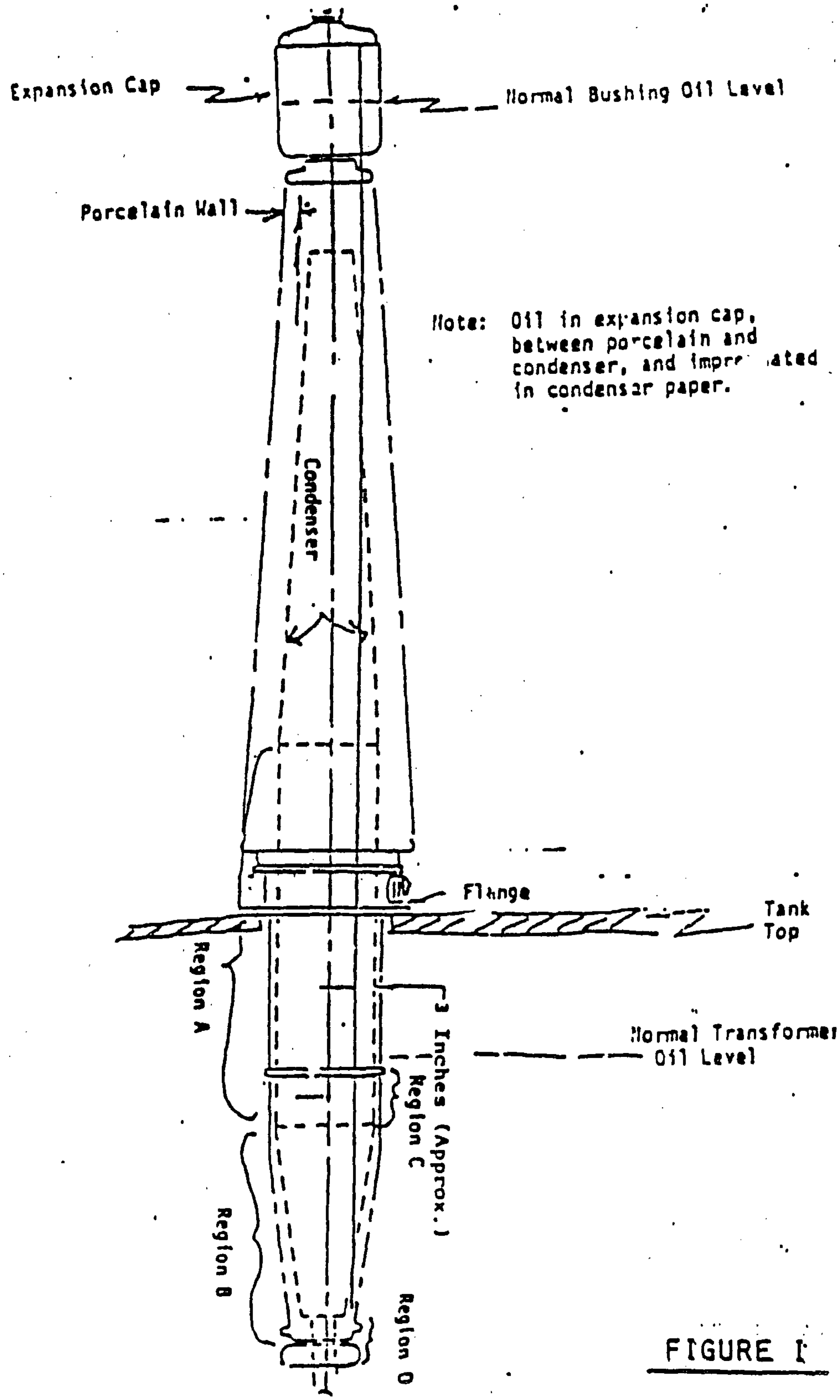
Expansion Cap
Normal Bushing Oil Level
Porcelain Wall
Note: Oil in expansion cap, between porcelain and condenser, and impregnated in condenser paper.
Condenser
Flange
Tank Top
Region A
3 Inches (Approx.)
Normal Transformer Oil Level
Region C
Region B
Region D

FIGURE I

Attachment 2
IN 82-53
December 22, 1982

LIST OF RECENTLY ISSUED IE INFORMATION NOTICES

Information Notice No.	Subject	Date of Issue	Issued to
82-52	Equipment Environmental Qualification Testing Experience - Updating of Test Summaries Previously Published in IN 81-29	12/21/82	All power reactor facilities holding an OL or CP
82-51	Overexposure in PWR Cavities	12/21/82	All holders of a Senior Reactor Operator license; all power reactor facilities holding an OL or CP
82-50	Modification of Solid State AC Undervoltage Relays Type ITE-27	12/20/82	All power reactor facilities holding an OL or CP
82-49	Correction for Sample Conditions for Air and Gas Monitoring	12/16/82	All power reactor facilities holding an OL or CP; research and test reactors; fuel facilities; Priority I materials
82-43	Failures of Agastat CR 0095 Relay Sockets	12/3/82	All power reactor facilities holding an OL or CP
82-47	Transporation of Type A Quantities of Non-Fissile Radioactive Material	11/30/82	All NRC licensees
82-46	Defective and Obsolete Combination padlocks	11/26/82	All facilities pursuant to 10 CFR Parts 50 and 70 and Part 95 applicable facilities
82-45	PWR Low Temperature Overpressure Protection	11/19/82	All PWR facilities holding an OL or CP
82-44	Clarification of Emergency Plan Exercise Requirements	11/18/82	All power reactor facilities holding an OL or CP

OL = Operating License
CP = Construction Permit

~~Lori~~

Please see that the attached labels are filmed for all of these FE Notices

Thanks Cathy

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FL2 exG1-3

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GROUP # 01 TYPE LABELS - 3 99999	SELECTION - 000000 SETS - 01	WO# 006596 WO DATE - 010383	# LABELS 2,535 DATE COMPLETED - 01/03/83 TIME COMPLETED - 0929
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