ATTACHMENT I

AUXILIARY BOILER FEED PUMP
TURBINE MISSILE ANALYSIS SUMMARY

POWER AUTHORITY OF THE STATE OF NEW YORK
INDIAN POINT 3 NUCLEAR POWER PLANT
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INTRODUCTION

As a result of a Nuclear Regulatory Commission inquiry, an evaluation of the possibility of internally generated missiles from the Auxiliary Boiler Feed Pump Turbine (ABFP Turbine) was performed. Among the questions sought to be answered by the evaluation were the following:

1. Can a turbine disk fragment penetrate the ABFP Turbine's casing

2. If a fragment does penetrate, can the missile damage anything of vital importance in the ABFP Room.

3. If the answers to the above questions were unsatisfactory, investigate a means of mitigating an incident.

The evaluation findings were that missiles generated at "destructive overspeed" could penetrate the turbine casing. It also indicated that there are possible targets that would require protection from such a missile. Because there were unacceptable targets, a shield aound the turbine was designed.

The following sections briefly describe the methodology and design philosophies used in the evaluation and subsequent design of a missile shield.

TARGET IDENTIFICATION

The method used to identify essential targets involved superimposing a 50° angle of revolution (per Reg. Guide 1.15) about the turbine midplane on applicable piping, instrument, and electrical layout drawings. After a target was identified, the failure of the equipment was assumed and it's impact on the ability to safely shut down the plant after any FSAR Chapter 14 event was analyzed. The decision to protect any piece of equipment was dependent on this analysis.

MISSILE CHARACTERISTICS

Two types of disk failure that can occur in a turbine disk were considered in the evaluation. The first is failure by the propagation of a crack due to stress corrosion or fatigue. This disk failure would most probably occur at operating speed but has been considered to occur at a speed up to rated design overspeed. The second mode of failure is due to gross ductile yielding of the disk under its own centrifugal forces. Ductile failure will only occur at extremely high burst speeds, called "destructive overspeed".

Regardless of the mode of failure, the failure planes would be oriented radially outward from the center of the disk. For this reason, the missiles considered in the analysis assume a "pie" shape.

The velocity, energy and momentum of the "pie" shaped missile depend upon the speed at which the disk actually fails. The rated speed of the auxiliary feed pump turbines is 3570 RPM. Rated design overspeed is somewhat in excess of 3927 RPM, which is the speed at which the inlet steam valve is set to trip following a governor failure. The reason the design overspeed can exceed the trip speed when a sudden load loss occurs is because there is stored energy in the steam between the valve and the turbine which can further accelerate the turbine disk. How much further acceleration occurs is a function of the rotor time constant and the valve closure time. To accurately calculate maximum design overspeed these values must be known.

Values for the rotor time constant and the valve closure time were not known. The following, however, will yield a rough approximation for rated design overspeed. Assuming a rotor time constant of 2 seconds and a reasonably fast valve closure time (less than one second), the design overspeed would be in the vicinity of 125-150 percent of trip speed or around 4909 to 5891 RPM.

The overspeed protection system for the auxiliary feed pump turbine is not treated as safety grade and credit is not taken for its functionability following a load loss accident. For this reason, an evaluation of missile generation must consider destructive overspeed, which produces the highest energy missiles.

The speed at which the disk would burst under its own centrifugal forces was determined to be the speed at which the average centrifugal stress along a diametral plane equalled the ultimate stress of the disk material. This can be written

$$S_u = \frac{8N^2 \int t r^2 dr}{\text{Area}}$$

where,

- N - thousands of RPM
- t = thickness of disk
- r = radius
- Area = profile radius from center out

Solution of this equation for the disk present in the ABFP Turbine gives a destructive overspeed of 14047 RPM.

Another factor that determines the missile's velocity, energy and momentum is the angular size of the missile. The missile size that would have the maximum translational kinetic energy would be a 134 degree missile. This missile would weigh approximately 50 pounds and would have a center of gravity located 6.67 inches radially outward from the center of the shaft. Kinetic energy would be approximately 495,250 ft-lbs at destructive overspeed.

In turbine missile analysis, conventional practice has been to consider design segment sizes of either 134°, 120°, or 90°. The choice of these sizes is based partly on consideration of failure at keyways (e.g., in the past Westinghouse has used four keys in their designs and consequently considered only quarter disk segments as missiles) and partly because these size missiles will have greater kinetic energies than smaller sizes. This analysis investigated the effects of all possible sizes in the analysis and discovered that for the missiles speeds considered here, segment sizes around 30° would require greater shield thicknesses to contain. These smaller missiles have less kinetic energy but also have lesser impact areas resisting perforation.

CONTAINMENT AND PERFORATION CRITERIA

The containment of a disk fragment is a sequential two-stage process as indicated by Hagg and Sankey (reference 1) and Recht and Ipson (reference 2). During the initial stage, momentum is transferred to the target surface and if the local shear and compression energy is not sufficient to absorb the portion of the kinetic energy associated with this process, puncture will occur. If perforation does not occur the impact enters a second stage in which the gross ductile tensile yielding of the shield must absorb the energy remaining from Stage 1.

During Stage 1, momentum is transferred to an effective mass around the impact area. Test measurements indicate that for a velocity range of 700 to 900 feet per second the effective mass extends a distance of three times the shield thickness from the impact area. The missile velocities considered in this analysis are in or near this velocity range and thus similar effective masses were assumed. The magnitude of effective mass will determine how much energy must be absorbed in each stage. The criteria for stage 1 non-perforation is:

$$E_s + E_c > \Delta E_1$$

where,

E_s = The energy required to shear the contact area

E_c = The energy required to compress the contact area

ΔE_1 = The amount of kinetic energy that must be absorbed in Stage 1.

The above criteria are based on a combination of analytical and empirical results which were developed by Westinghouse for use on large turbines. The equations presented are substantiated with test results. The testing was performed on models whose diameters were scaled down from main turbine low pressure disks, but which also represent almost exactly the diameters of the auxiliary feed pump turbines. Thus the correlation is even more appropriate for the missiles in question.

TURBINE CASE FAILURE

Utilizing the theory discussed above, an analysis was performed to see if any missiles generated from destructive overspeed could escape the auxiliary feed pump turbine case. The analysis did not take any credit for the casing ribs because their effect is negligible. The analysis also assumed full circumferential contact (no sharp points). This assumption is acceptable because of the small distance within the turbine casing in which the disk segment can rotate. As is common practice, rotation energy was assumed to be dissipated by friction forces and thus impact calculations were based only on translational energies.

The casing material is A-216 GR WCB and has an ultimate strength of 70 ksi. During dynamic applications the ultimate strength of carbon steel increases. For the analysis, the ultimate strength was increased 25 percent in accordance with numerous reports and test results on strain-rate effects. Similarly, because the casing is carbon steel, the plastic strain was decreased 50% to account for strain-rate effects.

Calculations have shown that missiles generated at burst speeds of 14047 RPM can easily fail the case by stage 1 perforation

SHIELD DESIGN

The results of the previous section and of the target analysis showed that added missile protection is needed for safety related equipment in the auxiliary feed pump room. A shield that can surround the turbine and absorb destructive overspeed missiles is the ideal solution since the best place to shield missiles is at the source. Missiles produced by failure at lesser speeds will also be stopped by such a design.

The material selected for the shield must be ductile to prevent stage 2 failure and strong to prevent stage 1 failure. The material selected for this purpose is SA240 type 302 or 304, Chromium-nickel stainless steel plate.

As appropriate for stainless steels, strain rate effects were accounted for by raising the tensile strength by 10% and assuming no reduction in elongation values.

A factor of safety of 2 was used in the calculation of shield thickness. This is consistent with safety margins endorsed by the NRC for pipe rupture restraints, which also are designed for impact loadings. A factor of safety of 2 means that there is twice as much available strain energy in the shield as there is kinetic energy in the missile. A schematic sketch of the shield is presented in Figures 1 and 2. Loss of energy during case perforation was considered. A parametric study was made which analysed missiles of different segment sizes and different failure speeds. This study showed that the worst case missile was a 30° segment produced at the 14047 RPM burst speed. The thickness required to stop this missile would be 1.70 inches if no factors of safety were applied. Using the recommended safety factor of 2, the minimum shield thickness would be approximately 3 inches.

The shield will be anchored with the use of Williams Form Engineering Corporation's rock bolts. Holes will be core drilled into the turbine pedestal in which the rock bolts will be anchored and the holes filled with grout.

REFERENCES

1. "The Containment of Disk Burst Fragments by Cylindrical Sheels" by A.C. Hagg and G.O. Sankey W LABS, April 1974, Journal of Engineering for Power.

2. "Ballistics Perforation Dynamics" by R.F. Recht and T.W. Ipson, DRI, Journal of Applied Mechanics, Trans ASME, Vol. 85, 1963.

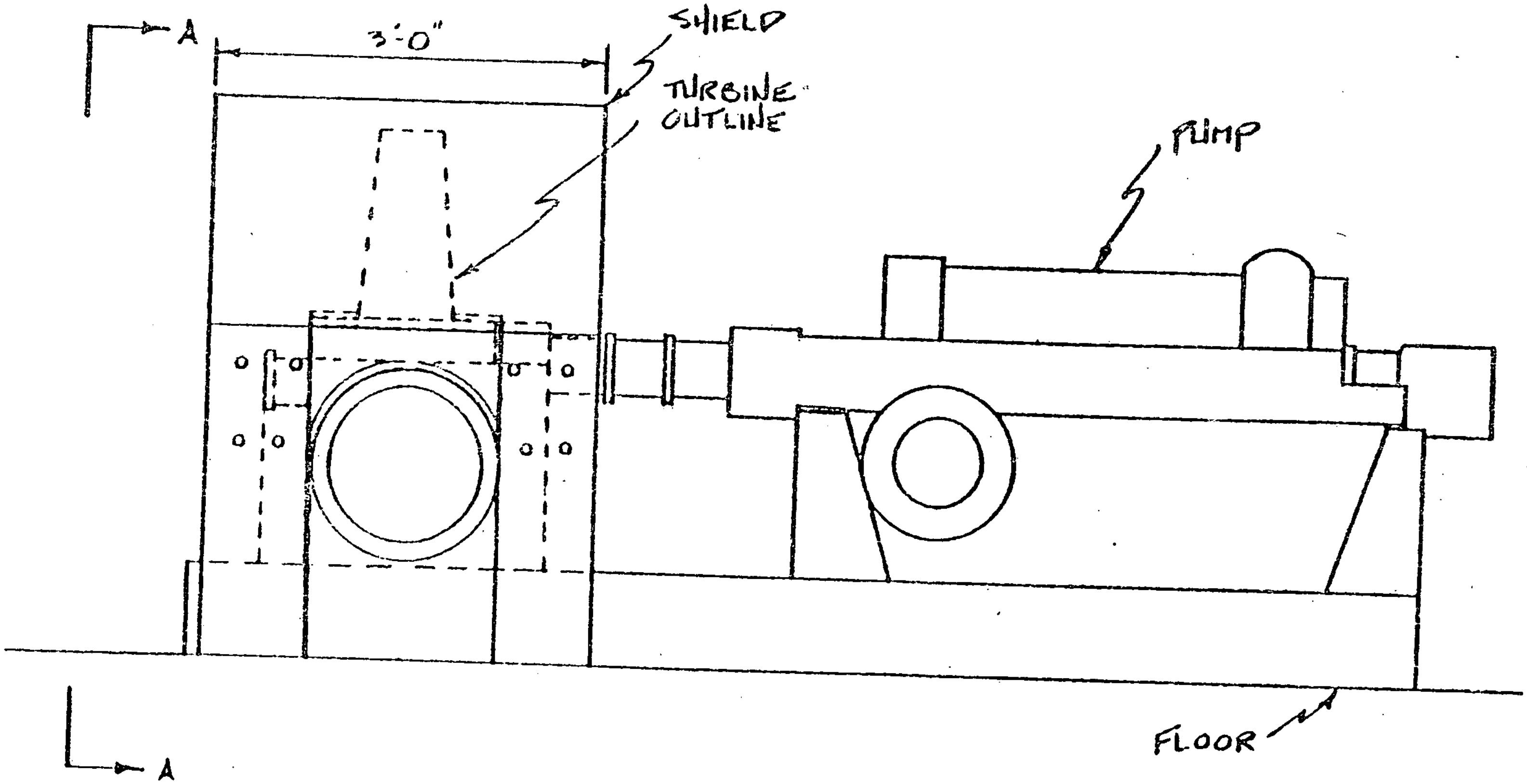

FIGURE 1

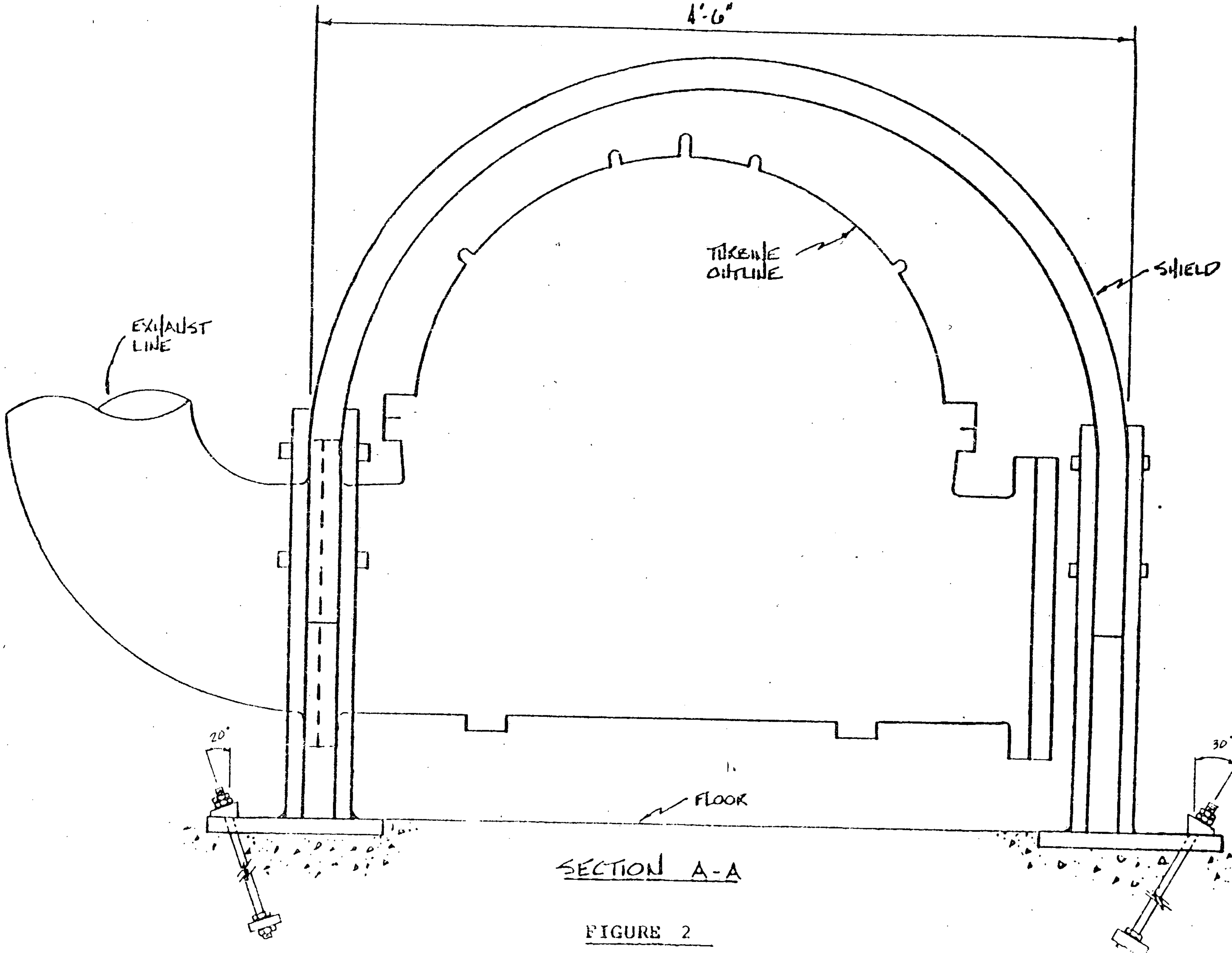
4'-6"
TURBINE OUTLINE
SHIELD
EXHAUST LINE
20°
30°
FLOOR
SECTION A-A

FIGURE 2