MASTER

SAFETY ASPECTS OF GROUND TESTING
FOR LARGE NUCLEAR ROCKETS

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In the last year, the Rover program has enjoyed successes in four reactor tests; the KIWI's B4-D and B4-E and the NERVA NRX A2 and A3. These successes have pointed the way toward the development, with increased confidence, of larger nuclear engines with the assured capability of powering the interplanetary flights now in the early planning stages.

It is perhaps somewhat anomalous that perhaps the major public safety problems associated with engines intended for deep space use could be those introduced by the ground testing programs (similar to chemical engine static tests) required to assure their operability. Since these large nuclear engines will not operate in a flight mode until they have been boosted well out of the earth's atmosphere, the retention of the fission products generated within the fuel, although perhaps desirable, is not an essential specification at this time. In the ground test phase however, the loss of fission products from the core becomes an embarrassment which can lead to restrictions on test capability at the present test site for the higher-power, longer running reactor tests of the future.

Substantial improvements have been made in the design and fabrication of fuel elements for the present uranium-graphite core concept of the NERVA

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program. The fuel has markedly improved from the early KIWI reactors in both structural integrity and fission product retentivity. However, designers are understandably pressing this improved fuel to provide higher power density and thrust; the more severe temperature and flow conditions then tend to cancel the improved fission product retention capability of the advanced fuels.

Other advanced reactor concepts do not seem to offer much advantage in this area. Based on a reasonable extension of present technology, the gaseous core reactors would, if anything, have a higher fission product release rate than the solid fuel units. It seems inevitable that high efficiency nuclear rocket reactors will have relatively poor fission product retention characteristics. The question then arises as to the problems that must be faced in the maintenance of public safety during the conduct of ground tests at the present Nuclear Rocket Development Station in Nevada.

Sources

Present reactors under test in Nevada are operated at nominal power levels of 1000 Mw. It does not seem unreasonable in the future to anticipate reactors with power levels in the range up to 5,000 Mw for space applications. Similarly, present operating time requirements are less than

an hour, and maximum testing time requirements of 1 hour do not seem to be an unreasonable extrapolation.

The frequency of testing plays a highly significant role in evaluating the impact of releases on the environment, and will be determined in large measure by the development schedule. Over the past year, tests of four reactors have been conducted. As the program continues, engine tests and static stage tests will also be required. It does not seem unreasonable to project a future schedule of 8-12 tests per year on reactors, engines and stages at various levels of development.

As described earlier, the release of fission products from reactors strongly depends on both fuel design and operating temperatures. As the design improves however, full advantage will (and should) be taken to improve engine efficiency and specific impulse. Fission product release rates can then be expected to remain at or perhaps even above present rates. For the purposes of this analysis, a normal release of 5% of the gaseous and volatile fission product elements has been arbitrarily assumed. The problems created however, will be directly proportional to the release fraction which will almost certainly not be the same for all isotopes.

As a development program, it can be expected that there may be accidents which result in some uncontrolled releases. Although these

accidents are examined for each system to be tested, this cannot be done now for the future systems being considered here; instead, an arbitrary assumption is made of a 50% release of the full run inventory as the worst accident, or MCA.

Transport and Dose Models

Many models have been used for the prediction of downwind transport of airborne contaminants. The Sutton model is used with reasonable success by the USWB in Nevada:

$$\frac{TIE}{Q} = \frac{2}{\pi \bar{u} C^2 X^{2-n}} \exp - \frac{h^2}{C^2 X^{2-n}}$$

where TIE = total integrated exposure on plume centerline, curie-sec/m³

Q = total source release, curies.

$\bar{u}$ = mean wind speed, meters/sec

C^2 = isotropic diffusion coefficient, metersⁿ

n = stability parameter

X = downwind distance, meters

h = initial height of cloud, meters

For the usual test conditions at NRDS, values of $C^2 = 0.1$, $n = 0.25$ and a cloud height of 1200 m have been used, and an average wind speed of

5 m/sec is common. For these higher power tests, a cloud height of 1500 - 2000 meters might be anticipated.

The major effects which must be examined are those associated with iodine inhalation and ingestion via milk, and the external gamma dose during cloud passage. Assuming a constant release fraction for all iodine isotopes, an adult infinite thyroid dose from inhalation of iodines is calculated to be about $100 \frac{\text{TIE}}{\text{Q}} f \frac{\text{rad}}{\text{Mw-sec}}$, where f is the fraction released. This is valid over about the first 8 hours after which the coefficient decreases. For ingestion via milk, a value of about $500 \frac{\text{TIE}}{\text{Q}} f \frac{\text{rad}}{\text{Mw-sec}}$, is obtained for infinite thyroid dose from I-131 to an infant consuming 1 liter per day of milk contaminated by a single event.

The cloud gamma dose is estimated using the infinite cloud approximation, $0.25 (\text{TIE})E \text{ rad per curie-sec/m}^3$, and an average gamma decay energy (E) of 0.7 Mev per disintegration. The cloud activity is assumed to decay according to a $t^{-1.2}$ relationship.

It is recognized that these relationships are approximations, and in fact a computer program, NURSE-1 (Nuclear Rocket Safety Evaluation) has been written at NUS for SNPO to perform more sophisticated analyses of specific systems. However, for the present case, the relationships given are entirely adequate.

Calculated Test Effects

Using the source term, transport and dose models for the system under consideration, the dose projections for a normal run are presented in Figure 1 for initial cloud rises of 1500 and 2000 meters. Gamma doses on the cloud centerline would peak at values of about 0.6 r and 0.25 r at distances of 8 and 10 miles, respectively, for the two release heights used. Adult thyroid doses from iodine inhalation would peak at 2 rad or 1 rad, at distances of 10 and 14 miles for 1500 and 2000 meters, respectively, decreasing to 0.5 rad at about 35 miles. Infant thyroid doses from milk ingestion would exceed 0.5 rad for distances closer than about 95 miles.

For the accident release, an initial source height of 300 meters was assumed to result from the postulated loss-of-coolant type accident following a full power run. The calculated doses are shown in Figure 2. Plume centerline cloud gamma doses would exceed LD_{50} values at distances closer than about 3 miles, would exceed 25 r at distances less than about 8 miles, and would be less than 0.5 r at distances greater than 30 miles. Inhalation of radioiodines would lead to thyroid doses greater than 300 rad at distances less than 2.5 miles, and less than 0.5 rad at distances greater than 140 miles. Contaminated milk would exceed 10 rad to infants at distances less than about 65 miles.

Discussion

Normal Run

The dose values calculated under the assumptions made in this example tax the capability of the present test facility environment. Although it is probable that actual doses would be lower than those predicted here (perhaps by a factor of five) due to wind direction variation over the test duration, this cannot be assured for each test. A reduction in the release is obviously required to meet reasonable requirements for a single test - more so in the event of multiple testing. Two areas must be considered: the off-site resident population, and the site workers.

With respect to the off-site areas, the nearest town is about 15 miles SSW of NRDS; depending on direction, other towns can be found between 35-100 miles away. Based only on off-site considerations, a reduction factor of 2-3 would be required to meet a 0.5 rad thyroid inhalation dose from a single test at the closest (15 mile) distance. A reduction factor of 15 would be required to reduce the infant ingestion dose to this same value, or milk would have to be controlled out to a distance of about 95 miles. In this regard it should be noted that the inhalation thyroid dose to a child is on the same order as the dose received via the milk route. Therefore, a release reduction by a factor of about 15 in a single test would be

required to meet inhalation dose restrictions for children at the closest off-site town even if milk supplies were controlled. The required reduction in dose could be achieved for a single test if maximum advantage were taken of on-site distance before reaching the nearest town.

The on-site problem is not negligible in this context either. Peak doses in a single test, both from iodine inhalation and external gamma radiation, are in the order of 10% of permissible annual doses for radiation workers. It would therefore suggest evacuating all unprotected site personnel in the downwind sector out to distances of perhaps 20 miles.

If nuclear rocket engines having the capabilities stipulated here are deemed to be necessary to this country's space effort, it is apparent that development must begin at an early date of advanced facilities which will permit the ground testing of such units. It is not reasonable to expect such reactors to be tested in the present type of facility simply extrapolated in size. To take maximum advantage of the solid fuels from a temperature viewpoint, thought is being given to the incorporation of some sort of decontamination facility for the exhaust gases prior to their release. Although this will require an extensive development process, it is not technically impossible, and the development costs would probably be a small part of the engine development costs.

Depending upon the reduction in release from a single test, other restrictions might also be necessary. Some restriction on wind direction might be required to assure that the effluent either does not repeatedly expose the same population, or takes maximum advantage of distance before reaching uncontrolled populations. Also, an expanded program of environmental monitoring and population control will be required to assure compliance with appropriate AEC regulations. Perhaps the greatest care will have to be devoted to the monitoring of milk as a concentrator of radioiodines of particular importance to children.

Accident Case

From an examination of the dose predictions in Figure 2, it is obvious that an accident of this character could not be tolerated, either on- or off-site. In this case the on-site effects would tend to be more catastrophic, with lethal external gamma doses delivered out to distances of 3 miles on the cloud centerline, and 300 rad adult thyroid doses out to 2.5 miles. Milk would have to be confiscated at distances less than 65 miles to avoid exceeding the 10 rad PAG (Protective Action Guide) of the FRC, and control of milk would be desirable out to distances on the order of 350 miles. Similarly, inhalation doses to children would exceed 5 rad at distances less than about 95 miles.

Here again, the accident situation indicates that advance consideration in both reactor and test facility designs are required to make ground testing of these units feasible . Two reactor accident types are usually considered in safeguard analyses: inadvertant criticality, and a loss-of-coolant. For specific engine designs the maximum release for an excursion can be limited in magnitude by design control. For the loss-of-coolant type of accident to be eliminated, a redundancy of coolant supply must be provided which can meet any postulated accident circumstance. These preventative measures, coupled with the normal run effluent decontamination facility should permit operations to be conducted at the present site.

Although these restrictions may not be popular with reactor and facility designers and operators, they may be the only alternative to the establishment of test facilities at a site enjoying the isolation of the Pacific proving area for nuclear weapons, or in an underground cavern which can be isolated, or in space.

Summary

It has been shown that the normal testing of large nuclear rocket engines at NRDS could impose some restrictions on the fuel performance which would not otherwise be required by space flight operation. The only apparent alternative would require a capability for decontaminating

effluent gases prior to release to the atmosphere. In addition to the source restrictions, tests will almost certainly be controlled by wind and atmospheric stability conditions, and the requirements for monitoring and control of off-site exposures will be much more stringent than those presently in force.

An analysis of maximum accidents indicates that projections of present credible occurrences cannot be tolerated in larger engine tests. The apparent alternatives to a significant (order of magnitude or better) reduction in credible accident consequences, are the establishment of an underground test facility, a facility in an area equivalent to the Pacific weapons proving ground, or in space.

FIGURE 1
NORMAL RUN EFFLUENT DOSES

FIGURE 2
MAXIMUM ACCIDENT EFFLUENT DOSES