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NUCLEAR REGULATORY COMMISSION
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NOTE FOR: George Mazuzan

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SUBJECT: WASH-3, APPENDIX A: RADIATION HAZARD FROM CLOUD CONTAINING ALL OF A REACTOR'S FISSION PRODUCTS

The model (circa 1948) used to develop the siting formula ($0.01\sqrt{P}$ = exclusion radius in miles, where P is the reactor thermal power level in kilowatts) is very conservative and, for reactors now operating, very unrealistic.

The reactor is assumed to be in normal operation at a fixed power level. For one of several reasons discussed in the main body of the report, the reactor experiences a severe reactivity excursion and the power level increases on a 0.1-sec period (power increasing by factor 2.718 each tenth-second) until the chain reaction is stopped by core disruption or negative temperature effect or other mechanism. Fission products are released and, because there is no containment, 50 percent of the total fission-product activity is assumed to be in a cloud that spreads out as it leaves the reactor. The cloud is assumed to be 1,500 ft in vertical dimension ("thickness" as noted in the write-up) and its width (horizontal dimension) increasing to one-seventh the distance it travels from the reactor, e.g. at one mile from the reactor the cloud is one-seventh mile or about 750 ft wide.

The total fission-product content of the cloud is 50 percent of the pre-accident reactor inventory (fission products generated during the reactivity excursion can be neglected) and is decreasing with time according to the well-known approximation $1/t^{1.2}$, where t is in seconds. The rate of emission of radiation within the cloud is assumed to be decreasing as $0.1/t^{0.2}$, i.e. at t = 1 second the emission rate is down to 10 percent of its initial rate, at 60 seconds it is about 4.4 percent of its initial rate, and at 3 hours about 1.6 percent. The initial rate of emission of energy by all the fission products is assumed to be equal to the thermal power level at which the reactor had been operating. (This is a reasonable and slightly conservative approximation.) The "power level" in kilowatts of the cloud is thus 50 percent X $(0.1/t^{0.2})$ X reactor thermal power level in kilowatts, or $(0.05/t^{0.2})$ X P (kilowatts), where t is in seconds.

As the cloud spreads out the fission-product content of the cloud is diluted by a factor 1/volume of cloud. The volume of the cloud is assumed to be height X width X length of cloud. The width or spread of the cloud is assumed to increase with distance from reactor according to the formula d/7. The "length" depends on how long the cloud has been emitted and what its velocity is, i.e. cloud length = time X wind velocity. Thus the cloud volume is h X (d/7) X time X wind velocity, and the dilution factor is 1/h(d/7)tw, where w is the wind velocity.

An individual at a distance d from the reactor is exposed to the cloud for the time t during which the cloud passes over his position. The radiation dose is then the product of the "power level" of the cloud, the cloud dilution factor, and the time

$$[0.05t^{-0.2}P]\,[1/h(d/7)tw]t =$$

$$0.05 \times 7t^{-0.2}P/hwd \text{ kilowatt-sec/cm}^3$$

where P is in kilowatts, t in seconds, d and h in cm and w in cm/sec. This is converted to roentgens by multiplying by the factor 10^{11} roentgens per (kW-sec/cm^3). Roentgen is exposure dose in air and one roentgen is equal to the radiation that creates ion pairs in 1 cubic centimeter of air with 1 electrostatic unit of charge or 3 X 10^9 coulombs. Creation of each ion pair requires about 30 electron-volts energy.

The exposure dose calculation is based on the assumptions that all the radioactive energy released by the cloud is used up in generating ion pairs -- a fair but conservative approximation -- and that the receptor of the radiation (the individual at distance d from the reactor) is immersed in the cloud. Since the receptor is on the ground and not fully immersed, a factor of 0.6 is introduced. This is generally conservative although it neglects radiation from fall-out, that is, fission products deposited on the ground and not traveling on past the receptor. The final result is

$$\text{Roentgens exposures at distance } d = 2 \times 10^{10}P/d^{1.2}w^{0.8}h$$

where t has been eliminated by noting that t is the time for the cloud moving with velocity w to travel a distance d (t = d/w). Note that d and h are in cm and w in cm/sec.

The wind velocity (w) and the cloud height (h) have to be assumed. If the wind velocity is assumed to be very small, then an individual at any reasonable distance d would probably be warned before the cloud arrives so the exposure would be reduced. If the wind velocity is assumed to be too great then the cloud would pass over the individual so rapidly that the total exposure would be small. The conservative assumption is made that the wind velocity is such that the cloud would reach an individual at distance d in just 3 hours, i.e. w = d/3 hr. If w is expressed in miles per hour, d in miles and h in feet, the exposure in roentgens at distance d becomes (after some tedious arithmetic)

$$\text{Roentgens} = \frac{43\ P}{d^2 h}$$

where P is in kilowatts. (The w has been eliminated by substituting w = d/3 hr = d/10,800 sec.)

The exclusion distance -- defined as the distance where the calculated exposure would be "dangerous" -- is determined by solving for the distance where the individual dose would be 300 roentgens (an extremely severe dose corresponding to about 15 percent early fatalities).

$$300 \text{ roentgens} = \frac{43\ P}{d^2 h}$$

$$d = \sqrt{43\ P/300h} = \sqrt{0.144P/h},$$

where d is in miles, P is in kilowatts, h in feet.

Finally, the height of the cloud is assumed to be 1,500 ft based on observations at Hanford (the typical site which apparently was not identified until WASH-3 was declassified). This reduces the formula to

$$d\ (\text{miles}) = 0.01\sqrt{P\ (\text{kilowatts})}$$

According to this model a 10-megawatt (thermal power) reactor would need an exclusion distance of 1 mile, a 1,000-megawatt (thermal) a 10-mile exclusion distance, or a 1,000-megawatt (electrical) a 17-mile exclusion distance. As the WASH-3 authors conclude, "... in our present state of knowledge we cannot possibly recommend settlement of population closer to a pile than this distance."