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PROTECTION OF NUCLEAR POWER PLANT CONTROL ROOM OPERATORS AGAINST AN ACCIDENTAL CHLORINE RELEASE

A. INTRODUCTION

Criterion 4, "Environmental and missile design bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that structures, systems, and components important to safety be designed to accommodate the effects of and to be compatible with the environmental conditions associated with operation, maintenance, testing, and postulated accidents. Criterion 19, "Control room," requires that a control room be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions.

The release of chlorine could potentially result in the control room operators becoming incapacitated. This guide describes design features and procedures that are acceptable to the NRC staff for the protection of nuclear plant control room operators against an accidental chlorine release. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

Many nuclear power plants use chlorine for water treatment in the circulating water system and in other auxiliary systems. Chlorine is normally stored on the site as liquified gas in one-ton tanks or large railroad cars (typically 16 to 55 tons).

Regulatory Guide 1.78, "Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release," identifies chlorine as a hazardous chemical which, if present in the control room atmosphere in sufficient quantity, could result in the control room becoming uninhabitable. It is the purpose of this guide to describe specific design features and procedures that are acceptable to mitigate hazards to control room operators from an accidental chlorine release. Although this guide was developed to provide protection from an onsite chlorine release, the protection provisions described here are also expected to be sufficient for an offsite chlorine release. The positions stated in this guide are based on the specific physical properties and physiological effects of chlorine.

Two basic accident types can be postulated: a long-term, low-leakage-rate release and a short-term puff release. The majority of chlorine releases experienced to date have been of the first type, involving leakage from valves or fittings and resulting in a long-term release with a leakage rate from near zero to less than one pound of chlorine per second. Given warning, only breathing apparatus is necessary to protect the control room operator from this kind of release. However, because such a release might continue unabated for many hours, self-contained breathing apparatus, a tank source of air with manifold outlets, or equivalent protection capable of operation for an extended period of time should be available.

A less probable but more severe accident would be the failure of a manhole cover on the chlorine container or the outright failure of the container itself.

* Lines indicate substantive changes from previous issue.

Such failure could occur during the transportation of a container as a result of a handling mishap or could be due to naturally or accidently produced environments such as earthquakes, flooding, fire, explosive overpressure, or missiles. A failure of this type could result in a puff release of about 25% of the chlorine. The balance of the chlorine would be vaporized and released over an extended period of time. As a result of the cloud formed by the release from such an accident, the chlorine concentration inside the control room might increase rapidly. In the absence of special design measures to limit the buildup within the control room, the operators might be incapacitated before they are able to don breathing apparatus.

Adequate protection of the control room operators against the types of accidental chlorine release discussed above will be achieved if features are included in the plant design to (1) automatically isolate the control room if there is a release, (2) make the control room sufficiently leak tight, and (3) provide equipment and procedures for ensuring the use of breathing apparatus by the control room operators. Protection provisions adequate for the large instantaneous release will also provide protection against the low-leakage-rate release. Staff analysis of control room designs and the degree of protection afforded by each design has resulted in criteria for acceptance, as will be discussed in the next section. These criteria are based on the limitation (given in Regulatory Guide 1.78) that the chlorine concentration within the control room should not exceed 15 ppm by volume (45 mg/m^3) within two minutes after the operators are made aware of the presence of chlorine.[1] This concentration, the toxicity limit, is the maximum concentration that can be tolerated for two minutes without physical incapacitation of an average human (i.e., severe coughing, eye burn, or severe skin irritation).

Table 1 gives the maximum allowable weight of a single container of chlorine as a function of distance from the control room for various control room types. It is based on an instantaneous release of 25% of the contents of the chlorine container and an allowable chlorine concentration in the control room of 45 mg/m^3, the toxicity limit, for two minutes. The initial cloud dimensions assume expansion of the chlorine gas into a spherical cloud having a Gaussian concentration gradient. Dispersion of the cloud was calculated using the instantaneous release diffusion model appearing in Appendix B of Regulatory Guide 1.78. For those cases where the control room was located a short distance from the release point and the amount of chlorine release was small, the model was adjusted to allow for additional dispersion in the vertical direction by assuming uniform mixing between the ground and the elevation of the fresh air inlet (a 15-meter elevation from ground level was used). The maximum allowable chlorine weights were determined by using worst case conditions for calculating the control room concentrations (significant parameters being wind speed, cloud dimensions, normal air exchange rate, time to isolate, and isolated air exchange rate). For certain control room characteristics and high wind speed, the maximum operator exposure occurs before isolation. For other cases with other control room characteristics and low wind speed, the maximum operator exposure occurs two minutes after isolation and is primarily due to infiltration. The six control room types listed in the table span the expected range of protections required for most plants. Other combinations of the significant parameters are possible, but those listed in the table should provide sufficient guidance for most cases.

This guide does not address the protection of individuals either outside the control room or within the control room but not directly involved in reactor operations. Breathing apparatus should be provided and be readily accessible throughout the plant in order to eliminate the need for personnel to seek shelter in the control room during a chlorine release.

The features and procedures described in this guide apply to plants having conventional ventilation systems. Any different methods of protection proposed will be evaluated on a case-by-case basis.

C. REGULATORY POSITION

Control room operators should be protected against the effects of an accidental chlorine release as described below.

1. Liquified chlorine should not be stored within 100 meters of a control room[2] or its fresh air inlets. (Small quantities for laboratory use, 20 lbs or less, are exempt.)

2. If a chlorine container having an inventory of 150 lbs or less is stored more than 100 meters from the control room or its fresh air inlets, the capability for manual isolation of the control room should be provided.

3. For single container quantities exceeding 150 lb, the maximum allowable chlorine inventory in a single container stored at specified distances from the control room or its fresh air inlet is given in Table 1 for control room Types I through VI (described below). For each control room type, the maximum allowable chlorine inventory in a single container is given as a function of distance from the control room. If there are several chlorine containers, only the failure of the largest container is normally considered unless the

[1] Two minutes is considered sufficient time for a trained operator to put a self-contained breathing apparatus into operation, if these are to be used.

[2] Control room is defined to include all zones serviced by the emergency ventilation system.

TABLE 1

MAXIMUM ALLOWABLE CHLORINE INVENTORY IN A SINGLE CONTAINER

Control Room Type	Control Room Characteristics					Maximum Weight (1000 lb) of Chlorine as a Function of Distance from Control Room[a]				
	Local Detectors	Remote Detectors	Isolation Time (sec)	Air Exchange Rate – Normal (hr^{-1})	Air Exchange Rate – Isolated (hr^{-1})	100 m (330 ft)	200 m (660 ft)	300 m (980 ft)	500 m (1640 ft)	2000 m (6560 ft)
I	Yes	No	10	1	0.06	0.5	2	4	10	1200
II	Yes	No	4	1	0.06	1	5	12	40	3400
III	Yes	No	10	0.3	0.06	2	6	14	36	2700
IV	Yes	No	4	0.3	0.015	6	20	60	230	32000
V	Yes	Yes[b]	10[c]	1	0.06	8	20	50	120	5000
VI	Yes	Yes[b]	10[c]	1	0.015	70	180	380	1300	60000

[a] To determine allowable chlorine inventories for distances between those given in this table, log-log interpolation is acceptable.

[b] See Regulatory Position 3.e for an alternative to remote detectors.

[c] The isolation time of 10 seconds refers to detection by local detectors. If detection is by remote detectors, isolation time is effectively zero since detection and isolation will be accomplished before the chlorine reaches the control room isolation dampers.

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containers are interconnected in such a manner that failure of a single container could cause a chlorine release from several containers.

a. Type I control rooms should include the following protective features:

(1) Quick-response chlorine detectors located in the fresh air inlets. Within 10 seconds[1] after arrival of the chlorine, detection should initiate complete closure of isolation dampers to the control room.

(2) A normal fresh air makeup rate of less than one air change per hour. The fresh air inlet should be at least 15 meters above grade.

(3) Low-leakage construction with an equivalent air exchange rate of less than 0.06 hr^{-1} when all penetrations are exposed to a 1/8-inch water gage pressure differential. Construction details should be provided to show that this limit is met.

(4) Low-leakage dampers or valves installed on the upstream side of recirculation fans or other locations where negative systems pressure exists and where inleakage from chlorine-contaminated outside air is possible.

b. Type II control rooms should include the protective features of paragraph a except that the isolation time should be 4 seconds or less rather than 10 seconds or less.

c. Type III control rooms should include the protective features of paragraph a except that the normal fresh air makeup rate should be limited to 0.3 air change per hour or less.

d. Type IV control rooms should include the protective features of paragraph a except that the isolation time and the normal air exchange rate should be equal to or less than 4 seconds and 0.3 air change per hour, respectively. In addition, the control room isolated air exchange rate should be reduced to 0.015 air change per hour or less (see description of required leak rate verification test in Regulatory Position 5).

e. Type V control rooms should include the protective features of paragraph a with the addition of remote chlorine detectors located at the chlorine storage and unloading location. These additional detectors should be placed and the detector trip points adjusted so as to ensure detection of either a leak or a container rupture. A detector trip signal should accomplish automatic isolation of the control room dampers. The detector trip signal should also set off an alarm and provide a readout in the control room. An alternative to the installation of remote detectors would be to provide an isolation system using local detectors but having an isolation time of effectively zero. This can be accomplished by ensuring that the time required for chlorine to travel from the chlorine detector to the isolation damper, within the inlet ducting, is equal to or greater than the time required to detect the chlorine and close the isolation damper.

f. Type VI control rooms should include the protective features in paragraph e except that the control room isolated air exchange rate should be reduced to 0.015 air change per hour or less. For isolated exchange rates between 0.015 hr^{-1} and 0.06 hr^{-1}, linear interpolation of the weights given for control room Types V and VI in Table 1 can be made. Verification testing is required within this range of exchange rates (see Regulatory Position 5).

4. The following should be applied to all control room types (I through VI):

a. Immediately after control room isolation, the emergency recirculating charcoal filter or equivalent equipment designed to remove or otherwise limit the accumulation of chlorine within the control room should be started up and operated.

b. Steps should be taken to ensure that the isolated exchange rate is not inadvertently increased by design or operating error. For instance, the following should be considered:

(1) An administrative procedure should require that all doors leading to the control room be kept closed when not in use.

(2) Ventilation equipment for the control room and for the adjacent zones should be reviewed to ensure that enhanced air exchange between the isolated control room and the outside will not occur (e.g., if there is a chlorine release, exhaust fans should be stopped and/or isolated from the control room ventilation zone by low-leakage dampers or valves).

(3) A control room exit leading directly to the outside of the building should have two low-leakage doors in series.

c. The use of full-face self-contained pressure-demand-type breathing apparatus (or the equivalent) and the use of protective clothing should be considered in the development of a chlorine release emergency plan. Because calculations indicate that chlorine concentrations may increase rapidly, emergency plan provisions and rehearsal of these provisions are necessary to ensure donning of breathing apparatus on detection of high chlorine

[1] This is the time interval between the time the chlorine concentration exceeds 5 ppm at the isolation dampers and the time the dampers are completely closed. Note that if the chlorine detectors are upstream from the isolation dampers, credit will be allowed for the travel time between the detectors and the dampers.

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concentrations. Storage provisions for breathing apparatus and procedures for their use should be such that operators can begin using the apparatus within two minutes after an alarm. Adequate air capacity for the breathing apparatus (at least six hours) should be readily available onsite to ensure that sufficient time is available to transport additional bottled air from offsite locations. This offsite supply should be capable of delivering several hundred hours of bottled air to members of the emergency crew. A minimum emergency crew should consist of those personnel required to maintain the plant in a safe condition, including orderly shutdown or scram of the reactor. As a guideline, a minimum of five units of breathing apparatus should be provided for the emergency crew.

d. The air supply apparatus should meet the single failure criterion and be designated Seismic Category I. (In the case of self-contained breathing apparatus, the single failure criterion may be met by supplying one extra unit for every three units required.)

The isolation system components should be of a quality that ensures high reliability and availability. One method to meet these goals is to provide a system that meets the requirements of IEEE-279, "Criteria for Protection Systems for Nuclear Power Generating Stations." In all cases, the isolation system, recirculating filter system, and air conditioning system should meet IEEE-279 since they are required to maintain a habitable environment in the control room during design basis radiological events.

Specific acceptance criteria for the chlorine detection system and allied actuating electronics are as follows:

(1) *Chlorine Concentration Level.* Detectors should be able to detect and signal a chlorine concentration of 5 ppm.

(2) *System Response Time.* The system response time, which incorporates the detector response time, the valve closure time, and associated instrument delays, should be less than or equal to the required isolation time.

(3) *Single Failure Criteria.* The chlorine detection system should be redundant and physically separate to accomplish decoupling of the effects of unsafe environmental factors, electric transients, physical accidents, and component failure.

Local detectors should consist of two physically separate channels for each fresh air inlet. Each channel should consist of a separate power supply, detector, actuating electronics, and interconnecting cabling. Remote detectors should also consist of two separate channels having detectors located at the chlorine unloading facility.

(4) *Seismic Qualification.* The chlorine detection system should be designated as Seismic Category I and be qualified as such.

(5) *Environmental Qualification.* The detection system should be qualified for all expected environments and for severe environments that could clearly lead to or be a result of a chlorine release. The installation of the detectors should ensure that they are protected from adverse temperature effects.

(6) *Maintenance, Testing, and Calibration.* The manufacturer's maintenance recommendations are acceptable provided they follow sound engineering practice and are compatible with the proposed application. A routine operational check should be conducted at one-week intervals.

Verification testing and calibration of the chlorine detectors and verification testing of the system response time should be conducted at six-month intervals.

5. The gross leakage characteristic of the control room should be determined by pressurizing the control room to 1/8-inch water gage and determining the pressurization flow rate. (The use of a higher pressure differential is acceptable provided the flow rate is conservatively adjusted to correspond to 1/8-inch water gage.) For air exchange rates of less than 0.06 hr^{-1}, periodic verification testing should be performed. An acceptable method for periodic testing would be the use of a permanently installed calibrated pressurization fan. The system would have a known pressure-versus-flow characteristic so that the leak rate could be determined by measuring the control room pressure differential. Testing should be conducted at least every six months and after any major alteration that may affect the control room leakage.

6. Emergency procedures to be initiated in the event of a chlorine release should be provided. Methods of detecting the event by station personnel, both during normal workday operation and during minimum staffing periods (late night and weekend shift staffing), should be discussed. Instrumentation that has been provided for the detection of chlorine should be described including sensitivity; action initiated by detecting instrument and level at which this action is initiated; technical specification limitations on instrument availability; and instructions for maintenance, calibration, and testing. Criteria should be defined for the isolation of the control room, for the use of protective breathing apparatus and other protective measures, and for maintenance of the plant in a safe condition including the capability for orderly shutdown or scram of the reactor. Criteria and procedures for evacuating nonessential personnel from the station should also be defined.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plans for using this regulatory guide.

This guide reflects current NRC staff practice. Therefore, except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein is being and will continue to be used in the evaluation of submittals for construction permit applications until this guide is revised as a result of suggestions from the public or additional staff review.

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