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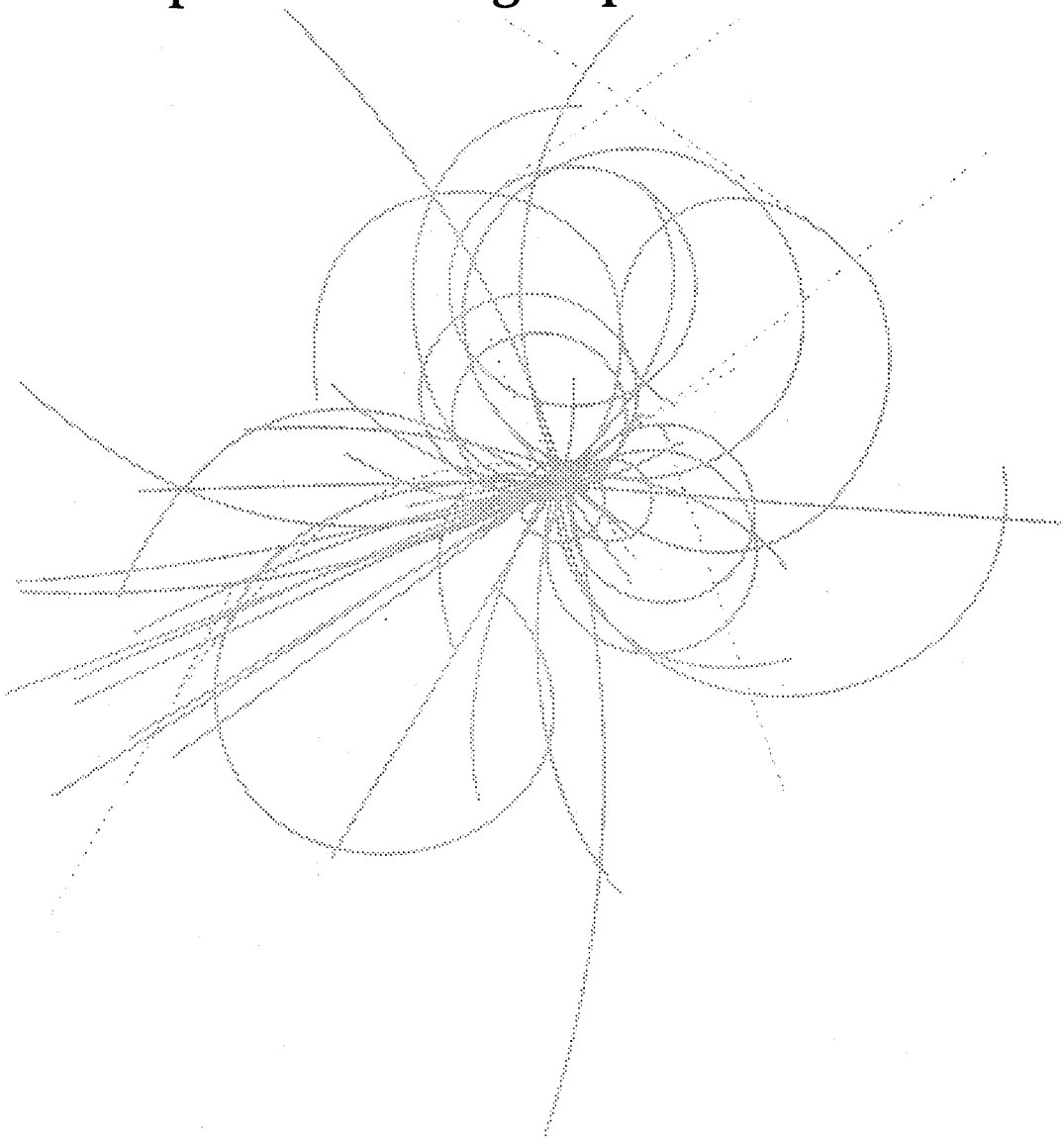
Superconducting Super Collider Laboratory



Study and Findings Concerning Egress Spacing and Life Safety

Working Group on Safety Codes
for
Underground Accelerator Operations

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— SUPERCONDUCTING SUPER COLLIDER —

WORKING GROUP ON SAFETY CODES
FOR
UNDERGROUND ACCELERATOR OPERATIONS

STUDY AND FINDINGS CONCERNING EGRESS SPACING AND LIFE SAFETY

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LIMITATIONS

Within the scope of the work reported here, the Working Group members warrant that they have exercised their best professional efforts in analyzing hazards, assessing risk, and formulating conclusions as reported herein. However, the Working Group members specifically disclaim any warranty, expressed or implied, that hazards or mishaps will be completely eliminated or that any particular standard or criterion of hazard or mishap elimination will be achieved if the information presented here is taken as guidance. The Working Group members do not, either individually or collectively, accept liability for any loss, damage, or injury resulting from the use of this information.

*Signatures indicate participation in the work reported here and verification that no significant technical errors have been found. Brief professional résumés are found in the Appendix.

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ABSTRACT

A Working Group of safety professionals has studied egress spacing for the main collider ring of the Superconducting Super Collider (SSC) accelerator tunnel with regard to life safety. The study, based on the SSC design concept, used three approaches: relying on applicable codes; extrapolating from a similarly configured representative facility having a statistically relevant injury history; and constructing a Preliminary Hazard Analysis. The Working Group found no codes dealing specifically with egress requirements for accelerator tunnel facilities. A safety standard dealing with underground mines prescribes egress requirements that are exceeded by the SSC. Egress-related risks for hazards to which SSC workers will be exposed were found to be less profound than those for the mining case. Thus it would be expected that the SSC egress-related injury rate should be less than that currently accepted in the mining industry. (The overall injury rate in mining is below the national average for industry at large.) The Fermi National Accelerator Laboratory was used as a model for injury rate studies. Fermilab, with an 18-year database, has an injury rate below the national average. Of all accelerator tunnel injuries over that period, there were none for which probability of occurrence or severity of outcome would have been affected had egress spacing been either reduced from the present 800 ft. or increased by several miles. If the injury history experienced at Fermilab is acceptable, there should be no reason to alter SSC egress spacing from the nominal five-mile intervals now planned. Should the Fermilab experience not represent an acceptable risk tolerance level, additional study would be necessary to formulate recommendations. However, it would first be necessary to select risk limits that would be tolerated. Finally, the Preliminary Hazard Analysis found no hazards apparent in the SSC conceptual design that exceed the *de minimis* level. That analysis provides an initial step in documenting a global inventory of hazards throughout system life.

1.0 PURPOSE

The Working Group on Safety Codes for Underground Accelerator Operations was commissioned in April 1989, by Dr. Roy Schwitters, Director, Superconducting Super Collider Laboratory. The goal of the Working Group was to carry out a mission contained within the Group's Charter:

> *"The Department of Energy has announced its intention to build the Superconducting Super Collider (SSC) Laboratory near Dallas, Texas. The principal feature of the Laboratory will be the main collider ring, 53 miles in circumference, situated in a tunnel with a diameter of approximately 10 feet at an average depth of 150 feet. Access to the tunnel is provided at intervals of 8 kilometers (5 miles), with ventilation shafts providing emergency egress midway between the access points. There are no safety codes specific to accelerator operations, although precedents exist at various laboratories.* **The mission of the Working Group is to evaluate, with respect to the accelerator tunnel and associated shafts, the risks involved in all anticipated phases of ultimate operational use, and to situate the operations within the framework of existing codes.** *If appropriate, the Working Group will formulate recommendations for modifying the Laboratory's proposed design and procedures for safety of personnel in the underground spaces during operations."*

In that portion of the Working Group's effort reported here, the concern was for adequacy of egress spacing with specific regard to life safety. In evaluating egress spacing, the Working Group relied exclusively on descriptions of the SSC configuration in its conceptual design state, as represented in Refs. 1 and 2. That evaluation is the subject of this report.

2.0 CHARACTERISTICS OF THE PROBLEM

The task of evaluating the egress-related risk to life safety for the SSC main collider tunnel poses an unusual challenge. Three chief factors contribute to this challenge:

2.1 Uniqueness

A number of underground particle accelerator facilities exist. Some have accumulated several decades of operating experience. Thus, many hazards to be anticipated in the SSC are identifiable based of experience elsewhere. Risk for many of these hazards can be assessed on the basis of that same experience. However, of the existing facilities, none are built to the large physical scale nor operated at the high energy levels planned for the SSC. As a result, for those egress-related hazards for which either the severity or the probability components of risk may be related to the size of the facility or to the energy level, risk assessment must be carried out with special care.

Safeguards will be in place to prevent occupancy of the main collider tunnel during accelerator operation (Refs. 1 and 2). Consequently, risk for egress-related hazards associated with the high energy level is deemed to be under appropriate control.

The planned spacing of means of egress is greater for the SSC than for any existing accelerator facility. It would be expected that life safety risk is related to the spacing between egress points. The Working Group recognized this relationship and was sensitive to the need to account for the influence of increased egress spacing on life safety in a facility of this unique kind. The questions raised by this consideration included determining the amount by which risk should be considered to be elevated by the increase in egress spacing over that found elsewhere, and the amount by which that increase might be offset by other features of the facility and its operating plan.

2.2 Codes Applicability

Safety codes prescribe measures that, if adopted, control levels of risk for hazards that may be anticipated in particular classes of facilities or operations. After the measures prescribed by the codes are imposed, the remaining residual risk is at a level deemed by the code-making body to be *de minimis,* a concept widely discussed in the current literature (e. g., Ref. 3). Codes can succeed at risk control only to the degree that the code-making body is able to anticipate the hazard peculiarities of the facilities and operations. The process can be relied on especially well to ensure the acceptability of residual risk in facilities of ordinary nature, well known to the code-making body, and having hazards that are well understood.

Alternatively, codes that are inflexibly drafted to deal in more general ways with broad ranges of facilities and operations suffer a substantial disadvantage. Because they cannot anticipate the individual hazard peculiarities of specialized cases, they may underprescribe countermeasures for some cases and overprescribe for others. For a novel facility, adherence to such a code may therefore result in unknowing acceptance of excessive residual risk in cases of the former kind, or in needless squandering of risk control resources without commensurate benefit in cases of the latter kind. This disadvantage becomes increasingly acute as the characteristics of the facility treated by the general code become increasingly novel.

As indicated above (Section 2.1), the SSC is unquestionably a novel facility, if owing only to its physical scale. Imposing a "generally applicable" code — i. e., forcing conformance to an unequivocal code drafted for a broad range of general cases — therefore introduces that potential disadvantage of the unknowing acceptance of excessive risk on the one hand, or of ineffectively deploying unnecessarily extravagant risk control resources on the other. Nonetheless, the practice is often attractive to the unenlightened facility proprietor. The steadfast adherence to "a code" does confer the appearance of earnest concern for the responsible management of risk. It may also provide the alluring appearance of reduced liability.

In approaching its work under its Charter, the Working Group remained mindful of the special challenge posed by this phenomenon. Although charged to " . . . situate the operations within the framework of existing codes," the Working Group was under no obligation to force applicability of any particular, generally drafted code upon the SSC accelerator tunnel. Instead, while recognizing the admonition contained within the Charter that ". . . there are no safety codes specific to accelerator operations," the Working Group accepted the challenge of finding codes for other underground activities — well known activities in which risk is deemed by code-makers to be under adequate control — and comparing egress-related risks in those activities to risks anticipated in the accelerator tunnel.

2.3 Multiple Countermeasures

For SSC hazards of some kinds, multiple layers of mitigation measures will be imposed to suppress risk, further complicating risk assessment. (Refs. 1 and 2 describe the measures.) These mitigation measures control both the severity and the probability components of risk to personnel. The multiple countermeasures include these examples:

- design to ensure the flammable burden within the tunnel will be low, and administrative controls to ensure it will remain low
- restricting electrical cable insulation to materials with low smoke properties and without halogenated hydrocarbons (Cable insulation is the major source of combustible material within most accelerator tunnels.)
- a system of redundant detectors to sense oxygen deficiency, temperature rise, smoke, and flooding

- emergency annunciation/evacuation alarms, both simultaneous and automatic (activated by the detection systems described above) at work locations and remote at control room and emergency response crew locations, to ensure rapid initiation of emergency responses

- full-time, instant, two-way communication between work crews and emergency response personnel to ensure ongoing emergency response coordination

- multi-skill emergency response crew makeup, including both trained, drilled firefighters and emergency medical technicians

- full-time, forced ventilation with greater-than-adequate throughput rate and with redundant, separately powered backup to operate during tunnel occupancy

- means for reversing forced ventilation flow, if necessary, to supply personnel undepleted, smoke-free air in the event of fire or a release of inert gas

- ventilation outage detection/alarm features to warn of failures and initiate evacuation procedures if backup systems fail

- screening employees who will work in the tunnel to ensure conformance to pre-established levels of physical fitness, and training and drills to ensure emergency preparedness

- limiting tunnel occupancy to two-man crews for two-day, fortnightly inspections and seven-man crews at widely spaced locations for major repairs, to limit exposure to a level less than that for which building egress codes are customarily drafted

- provisions to prevent energizing accelerator equipment during tunnel occupancy to preclude personnel exposures (Accelerator system equipment rests in a passive "storage state" during occupancy of the tunnel and remains so until personnel are evacuated.)

These risk reduction measures do provide reassurances. However, because many of them combine to control a single class of hazard — i. e., fire — they also complicate assessing the true level to which residual risk has been suppressed. And it is that combined effect of these numerous measures, acting together to reduce risk, that must be considered rather than the effect of individual measures acting singly.

This concept is expressed in NFPA 550 (Ref. 4): "Firesafety aspects such as construction features, combustibility of contents, protection devices, and characteristics of occupants have traditionally been considered independently of each other. This can lead to unnecessary duplication of protection." This declaration embraces the principle of equivalent safety by alternate means — i. e., risk reduction to the *de minimis* level, as achieved by pursuing specific measures prescribed by necessarily unequivocal codes, can also be achieved at that same *de minimis* level by adopting a suitable combination of multiple alternative countermeasures.

The Working Group's challenge was ensuring that the combined effects of the multiple countermeasures planned for the SSC were appropriately accounted for in the assessment of risk related to the adequacy of egress spacing.

3.0 APPROACHES

The Working Group adopted three independent approaches for reviewing the life safety provisions of egress spacing found within the conceptual design of the SSC accelerator tunnel and its associated shafts:

- Codes Search — A search was carried out for codes, standards, and regulations — within other domains of safety engineering practice — that might relate to identifying hazards and mitigating risks within the SSC.
- Use of a "Model" Facility — A "model" accelerator tunnel facility was sought and adopted as a reference standard from which to project evaluations of SSC risks.
- Preliminary Hazard Analysis — SSC hazards and their subjectively evaluated risks were inventoried using a Preliminary Hazard Analysis of the kind used in system safety practice.

The following sections describe the method employed and the results achieved for each of these three approaches.

3.1 Codes Search

3.1.1 Method

One mandate of the Working Group Charter (Section 1.0) is ". . . to situate the operations [of the accelerator tunnel and associated shafts] within the framework of existing codes." The Charter cautions, however, "there are no safety codes specific to accelerator operations. . ." Thus, the mandate is to identify those *non*-accelerator-specific codes that may exist for underground facilities having similar physical characteristics and employee activities, and to identify egress spacing requirements in those codes for cases in which parallels may be drawn with SSC hazards and their risks.

Accordingly, the Working Group mounted a search for appropriate codes. That search included:

- Codes cited in documentation provided to the Working Group — e. g., Refs. 1, 2, and 5
- The Codified Federal Register
- The Library of the Board of Certified Safety Professionals
- Codes and code-search methods separately available to the individual Working Group members

Among the codes found in the search, those listed in Table 1 were selected as warranting specific examination. In that examination, an attempt was made to apply comparison criteria to gage the extent of applicability in hazard and risk comparisons with the SSC. Chief among the comparison criteria were these:

1. Restricted Access — Access to the SSC accelerator tunnel will be limited to employees and to selected, individually escorted visitors. The public at large will not be admitted. (Thus, codes applicable to tunnels for public transport systems and private vehicle traffic can be useful in identifying hazards, but they have little value in addressing specific SSC risk considerations.)
2. Limited Occupancy — Work crew sizes will not be less than two nor more than seven individuals, at widely spaced locations.
3. Controlled Occupancy — SSC accelerator tunnel occupancy will be controlled to ensure that: only authorized crews are admitted; locations of all work crews are known at all times by Control Room monitors; each work crew has immediate communication contact with Control Room monitors.
4. Employee Training/Certification — Employees will be trained and certified in such areas as first aid, cardiopulmonary resuscitation, and emergency escape and rescue.
5. Occupant Equipment — Each SSC accelerator tunnel occupant will be outfitted with a monitoring device to warn of exposure to oxygen deficient atmospheres, and a supply of oxygen sufficient to permit egress.

6. Low Combustible Burden — SSC design, construction, and operating criteria will impose rigid strictures to limit the quantity of combustible materials within the accelerator tunnel.

3.1.2 Results

Table 1 summarizes the codes search results. The Working Group found no codes dealing specifically with egress spacing for accelerator tunnels. Thus, the codes search supported the position expressed by the Charter that none exist. Of the codes selected for specific examination as a result of the search (Table 1), two warranted detailed study when screened against the review criteria listed under **Method**, above:

- NFPA 101 — *The Life Safety Code* (Ref. 6) — This is a general code that seeks to prescribe countermeasures against risks that might be encountered in a wide spectrum of architectural configurations, and for broadly diverse occupancies and activities. Taken singly, many aspects of the SSC tunnel configuration and of the activities to be conducted within it were foreseen by the code-making body. However, certain of those aspects could not have been anticipated as existing in combination, within a single tunnel, containing only an assembly of equipment supporting the operation of a laboratory facility. Among those aspects are:

  - EQUIPMENT — A high-energy particle accelerator, to which there is access by personnel only during periods of no operation. All accelerator equipment is electrically de-energized during tunnel occupancy.
  - OCCUPANCY/ACTIVITY — Occupancy is discontinuous, infrequent, and at low density. There are no fixed work locations to which personnel are assigned.

- COMBUSTIBLE BURDEN — Combustible materials used in tunnel construction and installed within it are minimal. Electrical cable insulation constitutes the principal source of combustible material. That insulation is selected for low smoke properties, and it contains no halogenated hydrocarbons. All major electrical power circuits — the chief source of ignition — are de-energized during tunnel occupancy.

For the reason that this unusual combination of aspects could not have been foreseen by the code-making body, and for other reasons outlined in Table 1, the Working Group was confident that egress spacing provisions of this broadly general code should not be judged as specifically applicable to the SSC accelerator tunnel. Instead, an industry-specific code should be sought.

- CFR 30, Part 57 — *Mineral Resources / Safety and Health Standards — Underground Metal and Nonmetal Mines* (Ref. 7) — The Working Group studied this industry-specific code closely on the supposition that egress-related risks for personnel in an underground mine might be comparable to those to which SSC accelerator tunnel workers will be exposed. Summarized briefly, this code requires, within the noncoal mining industry to which it applies, that two unobstructed directions of egress to the surface must be available at all times to each worker within the facility and that exiting must be possible from any work location by normal means within one hour, unless an internal method of refuge is provided. It also requires that damage to one exit route must not lessen the effectiveness of others. A review of the SSC background documents (e. g., Refs. 1 and 2) shows the SSC conceptual design and planned operating procedures exceed these requirements. Consequently, a detailed comparison of the principal risks found in mines with those found in the SSC indeed becomes relevant.

Table 2 indicates differences between risks for the principal hazards found in the industry for which the Ref. 7 code is intended and those of the SSC. Entries in this table have been constructed according to the Preliminary Hazard Analysis approach to developing a system risk inventory. That approach is described in Ref. 8, and the adaptation used here is outlined in Section 3.3.1 and **Attachment 1**. Risk for each identified hazard is subjectively assessed in terms of the combined severity of the worst credible consequence of that hazard and the probability that the consequence will occur during the interval under consideration. In arriving at probability evaluations for Table 2, an exposure interval of 25 years was applied both to the mine and to the SSC cases. Risk for all hazards shown in Table 2 is deemed to be egress-related. For some (e. g., Fire), means of egress provide escape from the hazard. For others (e. g., Wall/Roof Collapse), means of egress serve to support rescue operations.

The entries in Table 2 have been grouped under rubrics selected to facilitate the risk comparison between facilities of the two kinds — mines and the SSC. The mine risk assessment, in terms of severity and probability for each hazard, was subjectively based on a population of more than 200 mines for which injury and fatality data have been examined over a period representing more than 1,500 mine-years of exposure. For the table entries, a representative noncoal mine was then subjectively postulated that would be comparable to the SSC accelerator tunnel, both in physical extent and in extent of personnel exposure.

The SSC risk assessment shown in Table 2 was based on two sources: study of a representative facility, scaled to represent the physical extent of the SSC and the personnel exposures anticipated in it (see **Section 3.2 — Use of Model Facility**); and a Preliminary Hazard Analysis (**Section 3.3**). The Table 2 comparison shows that risk for the ensemble of hazards found in the mining industry is more profound than that expected in the SSC. Of the 14 major hazard categories listed, all fall at the *de minimis* Risk Code 3 level for the SSC case. For the mine case, three fall at that level, 10 lie at the higher Risk Code 2 level, and one is at the 1 level.

Within the industry to which CFR 30 applies, the 1988 recordable injury rate is 7.4 cases per $2x10^5$ manhours (Ref. 9). (This is lower than the overall U. S. average rate of 7.9 cases per $2x10^5$ manhours for private sector industry at large, as also found in Ref. 9.) This rate may be taken as an index of the overall degree of risk prevalent within the mining industry. It cannot be determined to what degree the egress provision found in the code maintains the rate. Neither is it known to what degree contraventions of that provision may contribute to the rate. However, because the industry is a mature one, it may be assumed that the principle of homeostasis applies. That is, of each of the many mining-specific code requirements that have been in place for a substantial period, none is outstandingly more or less effective at controlling overall risk than is any other.

The injury rate of 7.4 cases per $2x10^5$ manhours may thus be said to characterize an industry having egress requirements that are satisfied by SSC conceptual design features. That is not to say that those egress requirements would be expected to produce the same injury rate in the SSC case. As the data in Table 2 have shown, differences between risks for the principal hazards in mining operations and in accelerator tunnel activities are substantial. The risks for hazards shown in that table are seen as being appreciably more profound for mining operations than for the SSC. To the degree that they are more profound, it should be expected that conformance of the SSC to the egress spacing requirements of the mine code would produce a lower injury rate for the SSC case than the rate now prevalent and accepted in the mature mining industry. This presumes, of course, that egress provisions do have an effect upon the rate in mining, and that they would also have an effect on SSC operations.

3.2 Use of "Model" Facility

3.2.1 Method

The Working Group sought an existing accelerator tunnel facility as a representative reference "model." Such a model would be useful in identifying potential SSC

hazards and in evaluating their risks. In seeking a facility to adopt as a model, the Working Group intended not to ascribe to it any claim of merit nor to imply that its hazards, risks, and injury experience should be viewed as acceptable. Instead, the purpose was to adopt a baseline standard from which to make extrapolations of risk to the SSC case. Ideally, the model facility would have these characteristics:

- Physical dimensions, equipment configuration, and employee activities similar in all major, risk-related features to those of the SSC
- Egress spacing similar to that of the SSC
- A statistically substantial, trustworthy, actuarial database representing injury/fatality history over a lengthy period of facility operation

The Working Group selected the Fermi National Accelerator Laboratory — Fermilab — to serve as the model facility. Fermilab satisfies the criteria listed above, with the obvious exception of egress spacing. Table 3 provides dimensional comparison data.

Fermilab employee injury data have been maintained in a way that makes it possible to examine the subset of data representing only those injuries experienced in accelerator tunnel work, as opposed to and not including support and operational work performed in all other locations of the facility. Manhour support has been similarly differentiated in the Fermilab database. Thus, accelerator tunnel injury rates that can be normalized to actual manhours of exposure can be computed. Moreover, the information has been gathered and maintained in a sufficiently descriptive way to enable determining — on a case-by-case basis — which injuries, if any, might have had either greater probability of occurrence/recurrence or more severe consequences had egress spacing been greater. Actual operating <u>risk</u> to personnel, in other words, can be related to egress spacing.

It is worth noting that not all accelerator facilities maintain injury rate data in the way described above. During the study reported here, the Working Group sought to develop an injury database representing several other accelerator facilities. Contacts were made with:

- Argonne National Laboratory
- Brookhaven National Laboratory
- Oak Ridge National Laboratory
- Stanford Linear Accelerator

Of these facilities, none were able to produce injury data and manhour exposure figures for accelerator tunnel operations alone, as distinct from other facility operations.

3.2.2 Results

Table 4 presents the Fermilab injury record for all accelerator tunnel operations from 1982 — when cryogenic technology was adopted — through June, 1989. All injuries for the period are shown there, both OSHA-recordable injuries and less severe cases. During that period, there were 26 injuries and no fatalities. Of those 26 cases, 6 qualified as OSHA-recordable, based on severity. None of the cases involved more than a single employee — that is, there were no multiple-injury mishaps. The Table 4 data and the manhour exposure figures for accelerator tunnel operations over the same period result in an OSHA-recordable injury rate of 7.1 per 2×10^5 manhours.

The Fermilab injury rate of 7.1 per 2×10^5 manhours is 11 percent below the recent-year nationwide, all-industry rate of 7.9 per 2×10^5 manhours (Ref. 9). It compares favorably with other modest-rate segments of industry — the aircraft and parts industry, for example, which has an injury rate of 7.0 per 2×10^5 manhours (Ref. 9). The population of only 6 instances of OSHA-recordable injuries on which the Fermilab rate is based appears to be too small for statistical relevance. However, that appearance is

a deceptive one; total exposure for the period during which the 26 injuries occurred approaches 100 manyears.

A case-by-case review of all injuries shown in Table 4 has shown none for the period 1982-present for which either probability of occurrence/recurrence or severity of outcome would have been influenced by changes in egress spacing. Even very substantial increases in spacing (i. e., to several miles) would have had no effect. Interviews with Fermilab emergency response personnel for cases over the 1971-1981 period produced the same conclusion, based on anecdotal recall. Thus, there have been no injury cases in which increased egress spacing would have altered the outcome during the 18-year Fermilab operating history — more than 500,000 manhours of accelerator tunnel work exposure. The Fermilab actuarial record persuasively shows relative independence of injury probability/severity from increases in egress spacing to distances of several miles.

Injury scenarios can indeed be postulated in which greater egress spacing could have an influence on the severity of outcome. However, the probability of such cases is envisioned as extraordinarily low. Current first aid and rescue philosophy bears on this. It was once the case that, in removing injury victims to remote emergency treatment facilities, haste was given priority over other considerations. Now, however, it is customary to stabilize the victim at the scene of the injury before attempting transportation. Thus, the length of the egress path has come to be less important.

3.3 Preliminary Hazard Analysis

3.3.1 Method

The Charter was interpreted also to commission the Working Group to initiate a Preliminary Hazard Analysis (PHA) that would support the work reported here and provide a hazards inventory useful in assessing risk in future SSC work. The method used for constructing the PHA is described in Ref. 8. This method follows the PHA

technique that has become widely accepted in system safety practice in the aerospace and the chemical processing industries.

In addition to inventorying hazards, the PHA assesses the risk of each hazard according to a method that, although subjective, is tightly disciplined. The severity and probability components of risk for each hazard item in the inventory are evaluated separately. For each hazard, the severity level for which risk is assessed is that of the worst credible consequence. The probability value expresses the likelihood of the consequence occurring, despite the presence of countermeasures. (The countermeasures are documented — e. g., in Ref. 1.) Because probability of occurrence cannot be judged unless a particular interval of exposure is presumed, a 25-year facility lifetime has been used for the SSC exposure interval in the analysis.

A widely used risk assessment matrix then guides the process of combining probability and severity evaluations to assess risk for each hazard. The matrix appears in **Attachment 1**. Although the matrix zone labeled "Code 3" represents risk at the acceptable *de minimis* level, only the system proprietor can decide at what level risk is to be accepted.

The technique of developing the PHA suffers the obvious limitation that not all hazards can be foreseen by the analyst. In an attempt to overcome this shortcoming, the Working Group used a variety of sources in identifying the hazards listed in the PHA:

- Prior documentation — e. g., Refs. 1, 5, and 10 through 18
- The OSHA Policy for Systems Safety Evaluations of Operations with Catastrophic Potential (Ref. 19)
- Consultations with operators of existing accelerator facilities and reviews of operating experiences
- Proprietary hazards checklists held by Working Group members
- Reliance on perceptive understanding of subtle hazards by the experienced, prudent, professional engineering mind

- Realistic scenario development — i. e., "what-iffing"

3.3.2 Results

The Preliminary Hazard Analysis appears as **Attachment 1**. It has been structured to place related hazards within salient groups. Only hazard exposures to employees have been considered in carrying out the PHA because the work reported here has dealt exclusively with life safety. Although other exposures have been neglected (e. g., downtime, equipment damage, the environment), hazards in these exposure areas can readily be added and analyzed as to the risks they pose.

Study of the PHA inventory of hazards indicates that three pose the greatest threats in terms of attention given to developing countermeasures in the conceptual design. Of those three, two are hazard groups that rely — in part — on means of egress as countermeasures: fire/explosion and oxygen deficiency. The third — exposure to the beam in the tunnel — is related to the control of occupancy, but less directly to means of egress. For these three and for many other hazards listed in the inventory, severity has been judged to fall at the highest level. However, for each, the probability component of risk is judged to be under appropriate control, based on the array of independent countermeasures adopted. No hazards were found in the PHA for which the residual risk — i. e., risk in the presence of documented countermeasures — was assessed to exceed the *de minimis* level.

This analysis outcome is not unusual. In "high-tech" industries and state-of-the-art, high-energy systems, PHA inventories often list many hazards for which severity components fall at the highest level. For such cases, it is also customary that system designers will have given great attention to the need for multiple, independent countermeasures to establish adequate control over the probability component of risk. Such system safety analysis methods as the PHA help provide assurances that risk control is indeed adequate.

This PHA must be viewed as a nucleus for a much larger, continually growing inventory of hazards. It has been based exclusively on the conceptual design information and on the countermeasures described in the references. As design proceeds, the PHA must be reviewed, revised, and extended to provide continuing assurance that the inventory of hazards remains complete, that countermeasures are appropriately effective, and that residual risks posed by the hazards have been properly assessed. A PHA must always be considered a "living" document. Additions and revisions must be made to it throughout facility life as experience is gained, as safety features are adopted or altered, as equipment is added or modified, and as mishaps are experienced.

4.0 CONCLUSIONS

Egress spacing planned for the SSC conforms to requirements imposed by an MSHA code for underground mining operations, where a more profound ensemble of risks to personnel exists. While other codes can be found that claim universal applicability to a broad range of facilities, their specific applicability to the specialized character of the SSC is questionable. Those codes could not have anticipated the unique configuration of the SSC nor the array of multiple countermeasures planned for the facility. Consequently, those codes stipulate egress spacing at very close intervals, as they must to ensure their applicability to the control of risk in other facilities posing greater threats to life safety.

The Fermilab accelerator tunnel serves as a reasonable hazard evaluation/risk assessment model for the SSC tunnel in all important risk-determining features except egress spacing. The Fermilab facility has a well-documented injury record and a statistically reasonable exposure interval. There have been no injuries of kinds for which either probability of occurrence or severity of outcome would have been worsened had egress locations been appreciably more widely spaced — e. g., by several miles. Scenarios can be postulated in which such cases might occur. The probability of such cases is envisioned to be extraordinarily low. The actual Fermilab injury rate is below the national average and is comparable to that of the aircraft and parts industry. If risk for SSC operations is deemed acceptable at these levels, then egress spacing planned in the conceptual design for the SSC accelerator tunnel should also be judged acceptable. If risk is deemed unacceptable at these levels, additional countermeasures should be considered. That should be done only after deciding the level of risk deemed tolerable.

The Working Group has sought to assess risk, i. e. to take its measure, not to address its acceptability. While the Working Group has sought to assess the level of SSC risk and to compare it to risks of other activities, it has specifically avoided addressing the acceptability of risk. In the effort reported here, the Working Group has considered

only matters of life safety, only as affected by egress spacing, and only during the post-construction period of facility use. However, the Preliminary Hazard Analysis begun as a part of this effort can now be used and extended to serve other SSC hazard identification and risk assessment purposes — e. g., risk to equipment, to the experimental data, and risk of damage to the environment.

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Table 1. Code Study of Egress Spacing Provisions and Facility Type with Comments on Code Applicability to Proposed SSC and Conformance of SSC Proposed Design

Number	Code Name/Number (Specific Example Application)	Type of Facility to which Code Applies Type of Occupant (P-public E- employees)	Occupant Requisites/ Provisions*	Major Egress Spacing Provisions Potentially Applicable to Proposed SSC (For Footnotes, see Addendum A to Table 1.)	Comments: Code Applicability to Proposed SSC	Comments: Conformance of SSC Proposed Design to Code
1	National Fire Protection Association NFPA 101/Life Safety Code and Handbook (1988) Chs. 1-7 and 31	Variable (These chapters contain general and background information.) P and E	Unc.	Ch 1. None (1a) (1b) Ch. 2. None (2a) (2b) (2c) Ch. 3. None (3a) Ch.4. None (4a) (4b) (4c) (4d) Ch. 5. (5a) (5b) (5c) (5d) (5e) Ch. 6. None (6a) Ch. 7. None (7a) Ch. 31. None	Ch. 1. NA Ch.2. NA Ch.3. NA Ch.4. NA Ch. 5. Indeterminate Ch.6. NA Ch.7. NA Ch.31. No provisions given for Special Purpose Industrial or Storage Occupancy or Special Structures	Ch. 1. NA Ch. 2. NA Ch. 3. NA Ch. 4. NA Ch. 5. Indeterminate Ch. 6. NA Ch. 7. NA Ch. 31. None necessary
1 (cont)	National Fire Protection Association NFPA 101/Life Safety Code and Handbook (1988) Chs. 8-27	Assembly, Educational, Health Care, Detention and Correctional, Hotels and Dormitories, Apartment Buildings, Lodging or Rooming, Residential Board and Care, 1- and 2-Family Dwellings, Mercantile, and Business Occupancies P and E	Mostly Unc.; Some 1, 2, 3	Egress spacing requirements are given for these facility/ occupancy types.	None	None necessary
1 (cont)	National Fire Protection Association NFPA 101/Life Safety Code and Handbook (1988) Ch. 28	Industrial Occupancy E predominantly	Mostly Unc.; Some 1,2,3	See Table A-5-6.1 and Section 28-2.6.3. Maximum travel distance to at least one exit is 300 feet	Unlikely. See Section 28-1.4.1(b). Special Purpose Industrial Occupancy. Certain concepts seem to fit SSC: e. g., "low hazard, building designed for only particular operations, low density of employee population, and much area occupied by equipment." First, far less than half the floor area will be occupied by equipment. More importantly, Ch. 28 applies to "factories making products of all kinds and properties used for operations such as processing, assembling, mixing, packaging, finishing or decorating, repairing, and similar operations." (See Section 28-1.1.) See also Footnote 5e, 2nd and 3rd comment. See also Formal Interpretation 81-7, Chapter 28, Question 3. See also explanatory paragraphs to Section 28-2.3.1. Although addressing "Capacity of Means of Egress," the underlying principles are applicable to the Egress Spacing Distance concept.	SSC design does not conform. This report deals with various aspects of the spacing issue and presents underlying issues and relevant information that uphold the adequacy of the proposed egress means and spacing.
1 (cont)	National Fire Protection Association NFPA 101/Life Safety Code and Handbook (1988) Ch. 29	Storage Occupancy E predominantly	Mostly Unc.; Some 1, 2, 3	Section 29-2.6.1, Exception 2. "No limitations on travel to exits for low hazard storage occupancy."	Possible. Although the SSC tunnel certainly does not function as a storage facility, descriptions given for activities and populations for Storage Occupancies fit it well. See Section 29-1.4, including Handbook text. NFPA recognizes the likelihood of an extremely low population;	SSC design conforms.

* For facilities in which requisites and conditions are imposed on occupants, these codes are used:

1. Controlled occupancy (locked entrance, entrance limited to "Authorized Personnel Only," sign-in procedure)
2. Employee training/certification
3. Occupant must carry communication equipment
4. Occupant must carry appropriate monitors (e.g. O_2 level, toxic gases, radioactivity)

Unc - Access is uncontrolled
Unk - This information is unknown or unavailable

Table 1. Code Study of Egress Spacing Provisions and Facility Type with Comments on Code Applicability to Proposed SSC and Conformance of SSC Proposed Design (continued)

Number	Code Name/Number (Specific Example Application)	Type of Facility to which Code Applies Type of Occupant (P-public E- employees)	Occupant Requisites/ Provisions*	Major Egress Spacing Provisions Potentially Applicable to Proposed SSC (For Footnotes, see Addendum A to Table 1.)	Comments: Code Applicability to Proposed SSC	Comments: Conformance of SSC Proposed Design to Code
1 (cont)	NFPA 101; Ch 29 (cont)				See Section 29-1.7. See also Sections 29-2.4.1, Exception 1 (and Handbook commentary), and 29-2.6 (and Handbook commentary). SSC design includes thorough and sophisticated alarm and backup alarm systems (See Section 29-3.4, especially 29-3.4.3. Handbook commentary). It is interesting to note no extinguishing requirements are included (See Section 29-3.5). It is not inconceivable to think of the SSC tunnel as a structure used primarily for storing or sheltering goods (i.e., superconducting magnets and the allied equipment). Personnel are permitted to enter only when equipment "in storage" is de-energized.	
1 (cont)	National Fire Protection Association NFPA 101/Life Safety Code and Handbook (1988) Ch. 30.	Special Structures (esp. underground and windowless) P and E	Mostly Unc.; Some 1,2	30-2.6. "Travel to exits . . . shall not exceed 100 feet."	It is conceivable that the SSC tunnel is a Special Purpose Industrial Occupancy (Ch. 28) or a Storage Occupancy (Ch. 29) in an underground and windowless structure. However, the underground location has no effect on hazards arising from conditions or activities within the tunnel. The effect of those hazards on life safety would be the same were the structure at grade level or elevated. Moreover, the risk posed by those hazards would be diminished inconsequentially by reducing egress spacing. (See text.) Probability of a mishap is unrelated to egress spacing. Severity of consequences is only rarely related to removal time, hence egress spacing. Current emergency response philosophy stresses the importance of stabilizing the victim on site, thereby making it unnecessary to respond with extreme haste to secure treatment.	SSC design does not conform. This report deals with various aspects of the spacing issue and presents underlying issues and relevant information that uphold the adequacy of the proposed egress means and spacing.
2	National Fire Protection Association NFPA 45/Standard on Fire Protection for Laboratories Using Chemicals (1986)	1-1.1 "Laboratory buildings, laboratory units, and laboratory work areas in which hazardous chemicals are handled or stored." E predominantly	1, 2, 4	3-3.Refers back to NFPA 101 3-4.1 and 3-4.1(f).Two interpretations: alternate routes to the same exit or two routes to any exit. 8-3 and 8-4.	1-1.1. None. No hazardous chemicals (See 1-4, definitions) in quantities posing threat to occupants will be used. 8-3 and 8-4. Short section on cryogenic fluids refers to 3-4 for means of egress.	None necessary to NFPA 45. SSC design complies with both interpretations of 3-4.1.

* For facilities in which requisites and conditions are imposed on occupants, these codes are used:

1. Controlled occupancy (locked entrance, entrance limited to "Authorized Personnel Only," sign-in procedure)
2. Employee training/certification
3. Occupant must carry communication equipment
4. Occupant must carry appropriate monitors (e.g. O_2 level, toxic gases, radioactivity)

Unc - Access is uncontrolled
Unk - This information is unknown or unavailable

Table 1. Code Study of Egress Spacing Provisions and Facility Type with Comments on Code Applicability to Proposed SSC and Conformance of SSC Proposed Design (continued)

Number	Code Name/Number (Specific Example Application)	Type of Facility to which Code Applies Type of Occupant (P-public E- employees)	Occupant Requisites/ Provisions*	Major Egress Spacing Provisions Potentially Applicable to Proposed SSC (For Footnotes, see Addendum A to Table 1.)	Comments: Code Applicability to Proposed SSC	Comments: Conformance of SSC Proposed Design to Code
3	National Fire Protection Association NFPA 130/Standard for Fixed Guideway Transit Systems (1988) (Seattle Transit Tunnel, 1.3 miles long) English Channel-Chunnel (31 miles long; 18 miles under water, each end emerges approx. 5 miles inland; ave. depth: 131 ft)	Public Railway Transit Sytems P and E (Bus transit) P and E Predominantly Rail Transit P and E	Unc. and 1, 2, 3, 4	2-5.3.2 - 300 feet from any point on the platform to the station (2-5.3.3-6 minutes) 2-5.1 - Refers to NFPA 101, Ch.8, "Assembly" 3-2.4.2 - The distance to an emergency exit stairway may not exceed 1,250 feet. (1,100 feet between exits) (3 parallel tunnels with horizontal crosspassage exits from main tunnel at 1,250 ft. intervals; continuous walkway)	Not applicable to SSC tunnel because of notable dissimilarities in use, hazards, and occupancy. (See 1-1. and 1-4 and definition of Fixed Guideway Transit System. 1-5.) (Ch. 2 refers to stations.)(Ch. 6 is devoted to Emergency Procedures, but makes no reference to egress spacing.)	Compliance not necessary.
4	National Fire Protection Association NFPA 502/ Recommended Practice on Fire Protection for Limited Access Highways, Tunnels. . ." (1988)	Limited Access highways, tunnels, bridges, elevated roadway, air right structures P and E	Unc.	See 3-7.1 - tunnels longer than 200 feet	None. 3-7 is limited to tunnels in which hazardous materials are transported. More basically, this refers to tunnels in the traditional sense (2 open ends, generally in a straight line), i.e. vehicular	Compliance not necessary.
5	National Fire Protection Association NFPA 801/Recommended Fire Protection Practice for Facilities Handling Radioactive Materials (1986)	Facilities handling radioactive materials E predominantly	1, 2, 3, 4	None. This is included only because Section 2-9 mentions Particle Accelerators specifically. The thrust of NFPA 801 is fire protection practices and peculiar hazards.	NA	NA
6	Uniform Building Code (1982)	All buildings and structures P and E	Unc.	Comments as for NFPA 101.	Comments as for NFPA 101.	Compliance not necessary.
7	BOCA - Basic Building Code (1987)	All buildings and structures P and E	Unc.	None	None	Compliance not necessary.
8	Southern Standard Building Code ca. 1983	All buildings and structures P and E	Unc.	Comments as for NFPA 101.	Comments as for NFPA 101.	Compliance not necessary.
9	NBFU National Building Code (1967)	All buildings and structures P and E	Unc.	Section 804.3 Underground Structure >2,500 sq. ft. must have 2 means of egress.	Applicable in principle.	SSC exceeds "2 means of egress" requirement: 10 means of egress and 10 means of escape.
10	Chicago Building Code (1985)	All buildings and structures P and E	Unc.	None	None	Compliance not necessary.
11	Los Angeles Metro Rail Transit Code	Public Transit System P and E	Unc.	None	Not applicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	Compliance not necessary.
12	California Administrative Code/Title 8, Chapter 4, Subchapter 17 (Mine Safety Orders/1981)	Underground Mines E	Unk.	2 separate exitways required from any point (spacing not specified). Recessed clearance space every 200 feet must be available if area for personnel activities between a wall and mechanical hauling equipment is <30 inches.	Not applicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	SSC meets 2 separate exitways requirements. Clearance is sufficient to preclude need for recesses.
13	California Administrative Code/Title 8 - Chapter 4, Subchapter 20	Mines and Tunnels - Construction Phase E	1, 2	No applicable provisions (construction phase)	None	The working Group Charter limits the scope of the examination to "ultimate operational use," not construction.

* For facilities in which requisites and conditions are imposed on occupants, these codes are used:

1. Controlled occupancy (locked entrance, entrance limited to "Authorized Personnel Only," sign-in procedure)
2. Employee training/certification
3. Occupant must carry communication equipment
4. Occupant must carry appropriate monitors (e.g. O_2 level, toxic gases, radioactivity)

Unc - Access is uncontrolled
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Table 1. Code Study of Egress Spacing Provisions and Facility Type with Comments on Code Applicability to Proposed SSC and Conformance of SSC Proposed Design (continued)

Number	Code Name/Number (Specific Example Application)	Type of Facility to which Code Applies Type of Occupant (P-public E- employees)	Occupant Requisites/ Provisions*	Major Egress Spacing Provisions Potentially Applicable to Proposed SSC (For Footnotes, see Addendum A to Table 1.)	Comments: Code Applicability to Proposed SSC	Comments: Conformance of SSC Proposed Design to Code
14	ANSI - Safety Requirements for Confined Spaces/2117-1988	Confined Spaces E	1, 2, 3	No applicable provisions	None	SSC meets requisites of code.
15	ANSI - National Electric Code / Section 39 (1984)	Installation in Tunnels P and E	Unc.	Sec. 391. A.5 Workspace must be at least 2 feet from vehicle travelway. 2 separate directions for egress required from any point. Egress spacing not specified. Workways must be unobstructed. Ventilation to provide safe environment required.	Applicable in principle.	Vehicle travelway and SSC internal hardware spaced adequately. 2 directions of egress possible from any point. Walkways will be unobstructed by internal hardware and transport vehicles. Adequate ventilation is provided.
16	OSHA Construction Safety Standards/29 CFR Part 1926 Subpart S (1986)	All buildings and structures, and all employers having more than 15 employees E predominantly	1, 2, 3, 4	Section 23 - Tunnels and Shafts, Construction Phase	None. The Working Group Charter excludes the construction phase.	Compliance during "ultimate operational use" not necessary.
17	OSHA Occupational Safety and Health Standards/29 CFR Part 1910	All buildings and structures, and employers having more than 15 employees. E predominantly	Unc. & 1, 2, 3, 4	None	Applicable in principle.	SSC will comply with all applicable OSHA (Part 1910) regulations.
18	Safety and Health Standards (MSHA) 30 CFR Part 57	Metal and Non-Metal Mines E	1, 2	Subpart J -Travelways and Escapeways. 2 or more escapeways. Escape to surface using normal exit methods must be possible within 1 hour unless an internal method of refuge reachable within 30 minutes is provided.	Potential applicability to SSC due to similar work locations and egress problems. SSC differs markedly in use, hazards, and occupancy.	SSC complies with required number of escapeways. The nearest exit shaft can be reached in 10 minutes using an electric transport vehicle. SSC exceeds requisites of code.
19	Safety and Health Standards (MSHA) 30 CFR Part 75	Coal Mines E	1, 2	Subpart P - Emergency Shelters. Refuge chambers required where necessary. Subpart R - Miscellaneous (Escapeways). 2 or more paths of egress (at least 1 ventilated) required from each working section. No exit distances nor time limits specified.	Potential applicability to SSC due to similar work locations and egress problems. SSC differs markedly in use, hazards, and occupancy.	SSC complies with egress requirements. Ventilation shafts usable for refuge. SSC exceeds requisites of code.
20	U. S. Army Corps of Engineers - Safety and Health Manual/Section 24 (1987)	Ventilation and Exhaust Systems E	1	Section 24 matches the provisions of OSHA (29 CFR Part 1926. 886) See Number 16.	None	SSC meets requisites of code.
21	U. S. Bureau of Reclamation - Construction Safety Standards/Section 23	Tunnels and Shafts E	1, 2	No applicable provisions	None	Compliance not necessary.
22	AASHTO, OSHA, and State of Virginia Department of Transportation Vehicle Safety Code Second Hampton Roads Tunnel (1.4 miles long)	Highway Tunnel P and E	Unc.	No applicable provisions	None	Compliance not necessary.
23	OSHA and Metro Sanitary District Sanitary Code Chicago TARP Tunnel (main tunnel 28 miles long; entire systems comprise 110 miles)	Flood and Sanitary Sewage/Operations Tunnel E	1, 2, 4	Egress spacing - 400 feet	Not applicable to SSC because of notable dissimilarities in use, hazards and occupancy.	Compliance not necessary.

* For facilities in which requisites and conditions are imposed on occupants, these codes are used:

1. Controlled occupancy (locked entrance, entrance limited to "Authorized Personnel Only," sign-in procedure)
2. Employee training/certification
3. Occupant must carry communication equipment
4. Occupant must carry appropriate monitors (e.g. O_2 level, toxic gases, radioactivity)

Unc - Access is uncontrolled
Unk - This information is unknown or unavailable

Table 1. Code Study of Egress Spacing Provisions and Facility Type with Comments on Code Applicability to Proposed SSC and Conformance of SSC Proposed Design (concluded)

Number	Code Name/Number (Specific Example Application)	Type of Facility to which Code Applies Type of Occupant (P-public E- employees)	Occupant Requisites/ Provisions*	Major Egress Spacing Provisions Potentially Applicable to Proposed SSC (For Footnotes, see Addendum A to Table 1.)	Comments: Code Applicability to Proposed SSC	Comments: Conformance of SSC Proposed Design to Code
24	OSHA (13) and U. S. Army Corps of Engineers Safety and Health Requirements (16) San Antonio Tunnels (4 miles long)	Flood water tunnel E	1, 2, 4	Egress spacing - 4,300 feet; ventilation provided by temporary fans during maintenance.	Not applicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	SSC plans call for forced ventilation before and during maintenance. Compliance not necessary.
25	WPCF - MP9 (Austin, Texas) Govalle Tunnel (8.1 miles long)	Sewer tunnel E	1, 2, 3	Maximum distance egress site - 2.5 miles	Not applicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	Maximum distance to means of egress in SSC is 2.5 miles. Maximum distance to means of egress or means of escape is 1.25 miles.
26	California OSHA Calaveras Tunnel (8 miles long)	Water transmission tunnel E	1, 2, 3	Maximum distance to egress site - 4.3 miles	Not appplicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	Maximum distance to means of egress in SSC is 2.5 miles. Maximum distance to means of egress or means of escape is 1.25 miles.
27	OSHA, AASHTO, Colorado OSHA Glenwood Canyon Tunnel, I-70 (.74 mile long)	Highway tunnel P	1, 2, 3	Crosspassage (to alternate direction lanes) every 650 feet	Not applicable to SSC because of notable dissimilarities in use, hazards, and occupancy.	Compliance not necessary.
28	Canadian and Province of British Columbia Standards Rogers Pass Tunnel (single track, 9.2 miles long)	Railway tunnel P and E (no gates, etc. keep public out; however, the tunnel is remote.)	Unc.	No applicable provisions	None	Compliance not necessary.

* For facilities in which requisites and conditions are imposed on occupants, these codes are used:

1. Controlled occupancy (locked entrance, entrance limited to "Authorized Personnel Only," sign-in procedure)
2. Employee training/certification
3. Occupant must carry communication equipment
4. Occupant must carry appropriate monitors (e.g. O_2 level, toxic gases, radioactivity)

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Addendum to Table 1*/**

1a. See 1-4.3 — "the *Code* cannot anticipate every type of building and occupancy configuration, and, therefore, the authority having jurisdiction is given the final power to determine whether life safety is or is not adequately provided."

1b. See 1-5.2 and 1-5.3 — "The specific requirements of this *Code* may be modified by the authority having jurisdiction to allow alternative arrangements that will secure as nearly equivalent safety to life from fire as practical."

2a. See 2-1 — "Every building or structure...designed for human occupancy..."

Comment: The SSC is designed primarily for equipment used to support particle physics research. Human occupancy is foreseen as infrequent (biweekly), strictly controlled in quality and quantity, and involved in activities that present low probability of fire and other emergencies.

"Reliance for safety to life in case of fire or other emergency will not depend solely on any single safeguard."

Comment: SSC does not rely on only one safeguard against fire and other emergencies. The layering and multiplicity of mitigating and preventing countermeasures are discussed in Section 2.3, and the PHA (**Attachment 1**) lists the countermeasures described in Ref. 1.

2b. See 2-3

Comment: These are essential considerations: character of the occupancy, number of persons exposed, fire protection available, height and type of structure.

2c. See 2-8

Comment: SSC design provides two means of egress and one means of escape from **any** location (Note Chapter 3 Definitions for the distinction). And there are no dead ends. SSC design eliminates the problem of a "Common

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* Not all notes and comments relate directly to egress spacing. However, their fundamental importance warrants their inclusion here.

** All quotations in this Addendum are taken from NFPA 101-1988 Life Safety Code Handbook with Complete Text.

Pathway Travel." (See Chapter 3/Definitions, 5-1.2.6, and 5-5.1.6.) From any location in the accelerator tunnel, there are two separate and distinct paths of travel to two exits. Notice also that the SSC design arranges the means of egress in a manner making it extraordinarily unlikely that a fire or other emergency at one egress site will affect egress at others.

3a. Chapter 3, Definitions - Occupiable Story

Comment: The SSC tunnel does not fit the definition for an Occupiable Story.

4a. Section 4-1 Preface

Comment: Classifying the Occupancy Type of the SSC tunnel and shafts presents a problem because of its unique design feature, proposed use, and low, infrequent, controlled, and equipped occupancy. Three occupancy classes that deserve additional attention are: Industrial (especially Special Purpose), Storage, and Special Structures.

4b. See 4-1.1

4c. See 4-1.9, 4-1.10, A-4-1.10, 4-1.11

Comment: None of these fit the SSC accurately. The SSC presents an unusual use of an unusual structure with unusual occupancy.

4d. See 4-2, especially 4-2.2.2

Comment: The Hazard of Contents classification for the SSC tunnel and shafts is deemed to be low. This is based on these factors:

- the principal combustible material in the tunnel will be cable insulation, chosen for its low flammability, low smoke, and low halogenated output
- there will be strict controls when flammable liquids are introduced
- welding will be done on nonflammable materials only
- open flames are allowed only when permit has been obtained from the Control Room and the Fire Department
- there will be no combustible materials or finishes on the walls, floors, or ceilings anywhere in the tunnel — exposed concrete or shotcrete only

- the potential for panic is controlled by permitting only trained, qualified, authorized personnel in the tunnel to perform work

5a. See 5-1.2 through 5-1.7 and 5-2.1 through 5-2.11

Comment: The "Exit Access" begins at **any** point in the tunnel and terminates at the doorway leading to the Exit Shaft. (No Common Paths of Travel [15-1.2.6] exist in the tunnel.) Each tunnel Exit Shaft constitutes exit. The Exit Discharge begins at the top of the Exit Shaft and opens above ground to a "safe place." SSC design plans provide for a "continuous and unobstructed way of exit travel from any point" to a "public way" or a "safe place."

All design features and components of the Means of Egress subparts (e.g. doors, stairs, alarms, regular and emergency lighting, exit signs, etc.) will comply with NFPA 101 requirements.

Comment on 5-2.1.1.3: The SSC is specially designed with locks/keys/interlocking security systems to exclude all but authorized personnel. Personnel will not be permitted within the tunnel when the accelerator equipment is energized. Personnel will be permitted only for periods of maintenance and/or repair. During these times, it is likely that more than 10 people will be scattered in clusters at various work sites in the tunnel. None of these groups will be without a ready means of egress or escape. And it is not credible that a mishap at one work site would impact life safety at another work site.

5b. See Section 5-3

Comment: Occupant Load Factors are given for several Occupancy Classifications. However, it is difficult to justify applying them to the SSC tunnel because of the tunnel's unique characteristics. The Occupant Load (and Density) is foreseen as being very low. And no Occupancy Classification seems applicable to the tunnel.

Foreseen maximum occupancy is known, as is the work area available. Therefore, an Occupant Density for the tunnel can be calculated. Reference 2 indicates that, out of a 14-day operating cycle, two days will be available for maintenance. Scheduled access will be possible only during these periods. The normal procedure during those periods will be to limit access to two teams of two each at each access point. During non-scheduled down times, estimated

to be on the order of 10 per year, a team of approximately 15 people will require access to the tunnel, of whom approximately seven would be in the tunnel at any given time during a six-shift work period. More people or teams will require the permission of the Accelerator Division Head. More than 50 people total in any given sector will require the permission of the Laboratory Director or his designee. Therefore, normally even during unscheduled down times, the limit to occupancy will be less than 15 per sector, which translates into less than 1 person per 10,000 square feet.

Depending on the starting point, every 8.83-mile portion contains one of these combinations:

- 2 Means of Egress (Exit Shafts) and 2 Means of Escape (Ventilation Shafts)
- 2 Means of Egress and 1 Means of Escape
- 1 Means of Egress and 2 Means of Escape

See Section 5-3.1.1

Comment: The text uses the term "occupied space." Chapter 3, Definitions, has no entry for "occupied space." It does, however, contain a definition for "Occupiable Story." See Footnote 3a, given earlier. The conclusion is that the SSC does not fit the definition for an "Occupiable Story."

5c. See Section 5-4.

Comment: The SSC tunnel meets and exceeds the minimum requirement of two exits from any position. Consider also that, according to 5-4.1.2, the number of means of egress from the SSC tunnel is sufficient to accommodate 1,000 people for every four Exit Shafts.

5d. See Section 5-5, especially 5-5.1.2, 5-5.1.3, 5-5.1.4

Comment: All exits are immediately accessible from an open floor area.

The very geometry of the SSC tunnel (a long, slender, elliptical tube) forces exit layout to be such that exits are remote from each other, thereby minimizing the likelihood that the same emergency condition renders two or more exits useless.

None of the examples given in 5-5.1.4 include a configuration like that of the SSC tunnel.

No dead-end pockets, etc. are included in the SSC tunnel design.

5e. 5-6 — Comment on opening/introductory text that describes factors on which the Committee on Safety to Life bases maximum travel distances:

1. "number, age, physical condition, rate at which occupant can move"

Persons will enter in teams of not less than two. It is expected they will be between 20 years old and 60 years old. They will have undergone rigorous physical screening to eliminate people having cardiac, pulmonary, circulatory, neurological, muscular, or skeletal deficiency or abnormality. Not only must they be free of such deficiencies, they must demonstrate better-than-average physical conditioning, stamina, and strength. It is not unreasonable to assume they can maintain an average rate on foot of 5-6 mph over long distances. (They will also have an Electric Transport Vehicle able to travel 15 mph as their normal means of transportation.) They will be well trained in evacuation procedures, and they will be well supplied with communication equipment, personal sensors, first aid training, fire extinguishers, breathing air escape packs, etc.

2. "obstructions"

The permanently mounted, necessary magnets and support equipment in the tunnel will not constitute obstructions. The equipment typically brought in to support repairs and maintenance will be hand transportable and arranged to allow free aisle space.

3. "number of people" and "distance from farthest point"

The maximum number of people found at any one time in each tunnel sector will be 14, grouped into two teams of 7 (Ref.2). Ordinarily, the teams will be working at sites remote from each other. Large groups and unprepared people will not be encountered in the tunnel.

The farthest a person anywhere in the tunnel must travel to reach a Means of Egress is 2.5 miles; the farthest a person must travel to reach a Means of Egress or a Means of Escape is 1.25 miles. To traverse 2.5 miles in an

Electric Transport Vehicle traveling at 15 mph requires 10 minutes, and on foot moving at 5 mph requires 30 minutes. To traverse 1.25 miles requires half that: 5 minutes by Electric Transport Vehicle and 15 minutes by foot.

4. "amount and nature of combustibles"

The Classification of Hazard Contents for the tunnel is deemed as low. (See Footnote 4d.)

5. "rapidity of fire speed"

This, too, is deemed as low. Tests at other facilities indicate very low spread velocities. Also, automatic fire, smoke, temperature rise, and oxygen deficiency sensors and alarms will be installed.

Comment: Section 5-6.1 also mentions "occupied space." See the comment for Section 5-3.1.1. in Footnote 5b.

Comment: No Occupancy Type has been established for the SSC tunnel.

See 5-6.5. Refer to Footnote and Comments for Chapters 28, 29, and 30.

6a. See Chapter 6.

Comment: SSC design will comply with applicable provisions of this chapter.

7a. See Chapter 7.

Comment: SSC design will comply with applicable provisions of this chapter.

Table 2. COMPARISON OF MAJOR RISKS
SSC and Representative Underground Noncoal Mine

	SUPERCONDUCTING SUPER COLLIDER ACCELERATOR TUNNEL				COMPARABLE UNDERGROUND NONCOAL MINE			
Source*	Probability **	Severity	Risk Code***		Probability **	Severity	Risk Code***	
FIRE ****	E	I	3		D	I	2	
Electrical				•				•
Welding/Brazing				•				•
Solvent Misuse				•				•
Engine Heat				–				•
Spontaneous Combustion				–				•
Friction				–	D			•
Explosion				•				•
WALL/ROOF COLLAPSE	E	I	3	•		I	2	•
O_2 DEFICIENCY	E	I	3		D	I	2	
Gas From Tunnel Walls				–				•
LN_2 Leak				•				–
LHe Leak				•				–
Fire Combustion Products				•				•
Other (e.g., solvent, refrigerant, etc)				•				•
EXPLOSIVE BLAST	E	I	3		D	I	2	
Thermal				•				•
Shock Wave				•				•
Projectiles				•				•
FLOODING	E	I	3		D	I	2	
Water From Surface				–				•
Inflow From Tunnel Walls				–				•
SLIP/TRIP/FALL	E	I	3		D	I	2	
Liquid On Floor				•				•
Trip Hazard On Floor				•				•
Stairs/Climb Structures & Devices				•				•
Open Shaft				–				•
Panic Flight/Obscured Vision				•				•
CRYOGEN INJURY	E	I	3	•	F	I	3	–
RADIATION	E	I	3		E	I	3	
Exposure To Beam In Tunnel				•				–
Residual Radiation				•				–
Uranium/Radon, etc				–				•
PERSONNEL TRANSPORT	E	I	3		D	I	2	
Vehicle Collision With Person				•				•
Elevator/Manlift Mishap				•				•
AIRBORNE DUST	F	I	3	–	D	I	2	•
MATERIAL HANDLING	E	I	3		C	I	1	
Lifting Objects				•				•
Falling Objects				•				•
Moving Objects (Caught Between)				•				•
Sharp Tools				•				•
Powered Haulage				•				•
ELECTRICAL	E	I	3		D	I	2	
110 Volt				•				•
High Voltage				•				•
High Current				•				•
UTILITY OUTAGE	E	I	3		E	I	3	
Ventilation Failure				•				•
Transport Failure				•				•
Sump Pump Failure				•				•
MACHINERY (Other than used for **Material Handling**: e.g., drills, compressors, winches, pumps, etc)	E	III	3	•	D	I	2	•

* Aspect within which risk arises (e.g., hazard, energy source, or activity)
** Probability Interval: 25 years of operational service
*** • indicates that hazard exists for item shown/contributes to risk for that category
– indicates that hazard is not present
**** Includes death directly by burns only. Other fire complications are considered under the O_2 DEFICIENCY and SLIP/TRIP/FALL categories.

See Risk Assessment Matrix (Addendum to Table 2, next page) for definitions and explanations of the values used in the Probability, Severity, and Risk Code columns.

Addendum to Table 2
Risk Assessment Matrix*

Severity of Consequences	Probability of Mishap: F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
I Catastrophic					1	
II Critical				2		
III Marginal			3			
IV Negligible						

Category	Descriptive Word	Severity of Consequences: Personnel Illness/ Injury	Equipment Loss($)	Test Unit Downtime	Data Compromise	Environmental Effect
I	Catastrophic	Death	>500K	>4 months	Data never recoverable or primary program objectives lost	Long-term (5 yrs or greater) environmental damage or requiring $500K or more to correct and/or in penalties
II	Critical	Severe injury or severe occupational illness	100K to 500K	2 weeks to 4 months	Repeat of test program	Medium-term (1-5 yrs) environmental damage or requiring $100K-$500K to correct and/or in penalties
III	Marginal	Minor injury or minor occupational illness	1K to 100K	1 day to 2 weeks	Repeat of test period	Short-term (less than 1 yr) environmental damage or requiring $1K-100K to correct and/or in penalties
IV	Negligible	No injury or illness	<1K	<1 day	Repeat data point or data requires minor manipulation or computer rerun	Minor environmental damage that readily can be repaired or requiring less than $1K to correct and/or in penalties

Probability of Mishap

Level	Descriptive Word	Definition
A	Frequent	Likely to occur repeatedly during life cycle of system
B	Probable	Likely to occur several times in life cycle of system
C	Occasional	Likely to occur sometime in life cycle of system
D	Remote	Not likely to occur in life cycle of system, but possible
E	Improbable	Probability of occurrence cannot be distinguished from zero
F	Impossible	Physically impossible to occur

Risk Zones

Code	Action
1	Imperative to suppress risk to lower level
2	Operation requires written, time-limited waiver endorsed by Management
3	Operation permissible

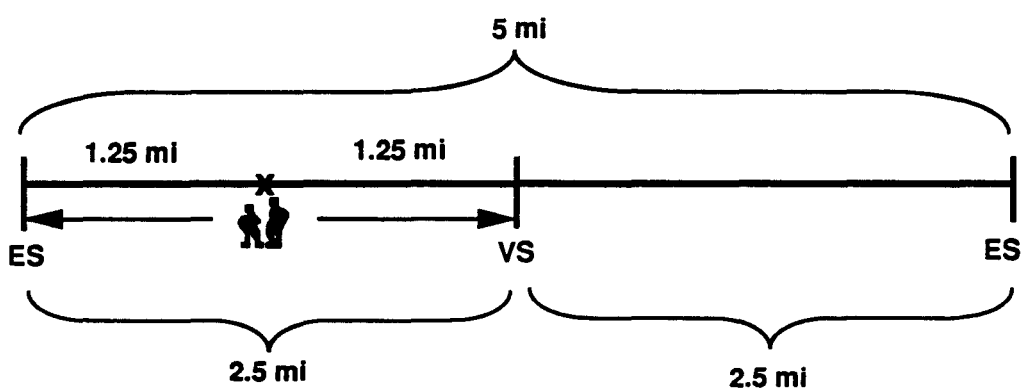
Note: PERSONNEL must not be exposed to hazards in Risk Zones 1 and 2

* Adapted from MIL-STD-882B

Table 3
ACCELERATOR TUNNEL DIMENSIONAL COMPARISON

DIMENSION	FNAL	SSC
Tunnel Diameter	10 ft (3 m)	12 ft (3.6 m)
Ring Circumference	3.9 mi (6,283 m)	53 mi (84,000 m)
Free Aisle Width	5.3 ft (1.6 m)	6.0 ft (1.8 m)
Distance Between Exit Shafts	800 ft (240 m)	5 mi (8,000 m)
Maximum Travel Distance To Nearest Exit Shaft	400 ft (120 m)	2.5 mi (4,000 m) See drawing*
Maximum Travel Distance To Nearest Egress Point	400 ft (120 m)	1.25 mi (2,000 m) See drawing*

* Ventilation Shafts (VS), usable for egress, are interposed at 5-mile intervals, approximately equidistantly spaced (i. e., midway) between the Exit Shafts (ES).



Distance from an ES to next ES, passing by the interposed VS, = 5 mi
Distance from an ES to nearest egress point (a VS) = 2.5 mi
MAXIMUM travel distance (assumes being midway between an ES and a VS) = 1.25 mi

Table 4
FERMILAB INJURY HISTORY*

DATE	WORK DAYS LOST	WORKDAYS RESTRICTED DUTY	INJURY DESCRIPTION	INJURY SOURCE/ACTIVITY
11 Nov 82**	1	2	General contusions	Employee hurrying, fell down stairs.
31 Jan 83**	1	3	Contusion - leg	Employee moving cart by hand, leg caught in pinch point.
10 Jan 84	0	0	Laceration - hand	Employee grasping piece of metal in drill press.
29 Feb 84	0	0	Muscle strain - side	Employee pulling and lifting cables.
01 May 84	0	0	Contusion - ribs	Employee injured when spool fixture slipped.
17 Jul 84	0	0	Sliver - hand	Employee picked up wooden block, which slipped.
23 Jul 84	0	0	Burn - hand	Employee burned by hot torch.
26 Jul 84	0	0	Laceration - hand	Employee removing insulation from cryostat.
04 Oct 84	0	0	Contusion - hand	Employee's hand caught in leak detector.
14 Nov 84	0	0	Contusion - head	Employee using scrubbing machine, struck head on protruding pipe.
29 Nov 84	0	0	Contusion/laceration - head	Employee vacuuming, bumped head.
29 Nov 84	0	0	Abrasion - leg Laceration - hand	Employee emptying vacuum cleaner, which slipped.
13 Dec 84	0	0	Contusion - head	Employee bumped head while bending down sweeping.

* Reporting Period: 01 Jan 82 to 07 Jul 89 (7 1/2 years). Cryogenic era began 01 Jan 82.
All injuries listed here occurred inside the accelerator tunnel.

** OSHA-Recordable

Table 4
FERMILAB INJURY HISTORY*
(continued)

DATE	WORK DAYS LOST	WORKDAYS RESTRICTED DUTY	INJURY DESCRIPTION	INJURY SOURCE/ACTIVITY
12 Feb 85	0	0	Laceration - scalp	Employee struck head on safety box.
05 May 85	0	0	Pain - elbow	Employee joined coaxial connectors, noticed pain.
15 Oct 85	0	0	Contusion - foot	Employee's foot run over by lift truck.
23 Oct 85	0	0	Strained muscle - lower abdomen	Employee lifting pipe, lost balance.
02 Dec 85	0	0	Sprain - ankle	Employee stepped on bag of garbage.
20 Dec 85	0	0	Abrasion - eye	Employee grinding; steel chip flew under goggles.
05 May 86	0	0	Foreign object - eye	Employee putting up control wires.
16 Jun 86	0	0	Contusion - finger	Employee installing tubes.
29 Jul 86**	3	0	Infected laceration - finger	Employee cut finger on electrical lead.
09 Oct 86**	1	0	Burn - hand	Employee brazing magnet.
25 Apr 86**	89	116	Tendonitis - shoulder	Employee working in tight quarters, felt pain.
25 Apr 88	0	0	Foreign object - eye	Employee pulling cables.
26 Apr 88**	0	5	Contusion - knee	Employee riding cart, bumped knee passing scaffolding.

* Reporting Period: 01 Jan 82 to 07 Jul 89 (7 1/2 years). Cryogenic era began 01 Jan 82.
All injuries listed here occurred inside the accelerator tunnel.

** OSHA-Recordable

Addendum to Table 4

OBSERVATIONS ON FERMILAB INJURY RECORD

Information gathered from review of injury data and interviews with personnel

- No significant cryogen releases have occurred in the accelerator tunnel during personnel occupancy. (Intentional releases have been made to support tests.)
- In no instances has it been necessary to use personal "escape packs" as protection against oxygen deficient atmosphere.
- Outside the accelerator tunnel (i. e., the Main Ring), there have been two instances of oxygen deficiency — one occurred in a sump pit, and the other in a welding tent.
- There has been one accelerator tunnel fire: welding slag contacted a protective polyethylene film. Damage was minimal.
- There have been no mishaps in which either egress path length or response time by emergency crews was a factor in determining the short- or long-term outcome of injury.

Appendix

Resumes of the Working Group on Safety Codes for Underground Accelerator Operations

Pat L. Clemens, P.E., C.S.P. **Chairman**

Thirty years of experience in system engineering design and safety analysis. Holds national board certification in four areas of safety discipline and is experienced in the development, application, and direction of system safety analytical techniques and program management. Has performed system safety analyses and developed training programs for complex, energy-intense industries and processes. Certified by the Department of Energy as an accident/incident investigator. Awards include IEEE Centennial Medal (1984) and Educator of the Year Award, System Safety Society (1988).

Dr. Larry Coulson **Accelerator Facility Safety**

Seventeen years of experience in the area of accelerator facility safety. Currently serves as Manager for the Fermi National Accelerator Laboratory's Environment, Safety, and Health Program. Holds PhD in Medium Energy Particle Physics from the University of Virginia.

Robert E. DeHart, P.E., C.S.P. **Probabilistic Risk Assessment**

Senior Risk Analysis Engineer with 15 years of experience in the areas of risk review, hazards analysis, and accident investigation. Professional Engineer and Certified Safety Professional. Active in the American Institute of Chemical Engineers, Center for Chemical Process Safety and the American Society of Safety Engineers. 1989 President of the Joint Council for Health and Safety in Education and Accreditation and 1989 Chairman for the Joint Committee of American Board of Industrial Hygiene and BCSP. Past President of the Board of Safety Professionals and former Director of the Board of CSP.

Dr. Charles P. Lazzara **Mine Fire/Explosion Prevention**

Holds PhD in Physical Chemistry from Loyola University and awarded postdoctoral fellowship from the Institute of Gas Technology - Chicago for combustion kinetics research. Joined Bureau of Mines, Pittsburgh Research Center, in 1971 to contribute to mine fire and explosion prevention studies. Currently serving as supervisory Research Chemist investigating preventive measures for mine fires. Author of several publications on flammable materials, fire prevention and suppression, and general explosions in underground mine operations.

Marshall E. Peterson, P.E., C.S.P. **Fire Safety Engineering**

Professional Engineer with 38 years of experience in the field of safety and fire protection engineering. Certified Safety Professional, Certified Fire Investigator, and currently serves on the Board of Directors for CSP. Actively participates as a member or an officer with many standard or code making groups, such as the National Fire Protection Association and the National Safety Council. Diplomate Member of the National Academy of Forensic Engineers. Elected Fellow of the Society of Fire Protection Engineers.

Robert J. Powers, P. E. **Cryogenics Safety Engineering**

Registered Professional Engineer with more than 30 years of experience in superconductivity, cryogenics, and high vacuum technology. Career has included contributions to the Princeton Plasma Physics Laboratory fusion reactor and the Fermi National Accelerator Laboratory cryostats and superconductivity coils as well work on a wide range of cryogenics systems for power generation, airborne, and space applications.

Dr. Ralph J. Vernon, C.I.H., C.S.P. **Industrial Hygiene and Occupational Safety**

Certified Safety Professional with PhD in Preventive Medicine and Environmental Health. Certified Industrial Hygienist and Certified Manufacturing Engineer. Currently provides consulting services to industry and federal agencies. Professor Emeritus, Texas A&M University, following 20 years as Professor of Industrial Engineering at that institute.

ATTACHMENT 1

PRELIMINARY HAZARD ANALYSIS

— SUPERCONDUCTING SUPER COLLIDER —

WORKING GROUP ON SAFETY CODES
FOR
UNDERGROUND ACCELERATOR OPERATIONS

PRELIMINARY HAZARD ANALYSIS

PURPOSE / BACKGROUND: The Preliminary Hazard Analysis (PHA) comprises an inventory of system hazards together with a subjective risk assessment for each hazard. Risk is defined as the probability-severity doublet familiar to system safety practitioners, and these two risk components — probability and severity — are evaluated separately for each hazard. These separately evaluated components are then combined to produce a risk assessment. Any of several chart-like aids prevalent in the literature may be used to combine the separate risk components. These aids also customarily display one or more iso-risk contours to indicate at what combined severity-probability levels risk may be considered acceptable and at what levels remedial actions are necessary to bring risk into acceptable bounds. Establishing and/or adopting limits of risk acceptance is an obligation borne by the system proprietor rather than by the risk analyst, of course. Ideally, the PHA inventory of hazards and the assessment of their risks is begun while developing the system design concept or shortly thereafter, as has been the case here. The PHA is then further developed and refined on a continuing basis as the system design matures, and it is revised throughout system life.

INFORMATION SOURCES: In developing the PHA inventory of hazards and the risk assessments presented here, these chief sources were used:

- Prior documentation — e. g., the references cited in: "Study and Findings Concerning Egress Spacing and Life Safety"* — The Working Group on Safety Codes for Underground Accelerator Operations; 1989
- Observations during Working Group site visit: The Fermi National Accelerator Laboratory; July, 1989
- OSHA "Policy for Systems Safety Evaluations of Operations with Catastrophic Potential" (Ref. 19 in the Baseline Document)
- Consultations with operators of existing accelerator facilities and reviews of operating experiences
- Proprietary hazards checklists held by Working Group members
- Reliance on personal experience and knowledge of members of The Working Group on Safety Codes for Underground Accelerator Operations
- Realistic scenario development — i. e., "what-iffing"

SCOPE: This PHA deals exclusively with post-construction hazards to personnel. Hazards for exposure categories other than personnel have not been addressed here (e. g.: Equipment Loss, Downtime, Data Compromise, Environmental Effect). System hazards and risk assessments for these other exposure categories can be added to the PHA, should this become desirable. Additionally, hazards to personnel have been treated only for the SSC accelerator tunnel and its associated shafts, in keeping with the scope of the Working Group assignment expressed in the Charter found in the Baseline Document.

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*This paper is hereafter referred to as the "Baseline Document."

RISK ASSESSMENTS: Once system hazards to personnel were identified using the **INFORMATION SOURCES** listed above, severity and probability levels were assigned to each hazard. The Risk Assessment Matrix, found at the end of this PHA, guided this process. This matrix is a widely used adaptation drawn from MIL-STD-882B ("System Safety Program Requirements" — 1984). Severity levels I-IV are as defined in the matrix. The severity level assigned to each hazard from the matrix represents the worst credible mishap consequence for that hazard. Probability judgment, also based on the matrix, represents the likelihood of occurrence of that worst credible consequence, for each hazard, over the exposure interval of interest. Factor-of-ten increments are presumed to separate adjacent steps in the A-E probability scale of the matrix, and, for this PHA, probability was based on the presumption that exposures will continue over a 25-year facility lifetime. The probability judgment also presumes the documented countermeasures, which are listed, have been implemented and will be effective at levels that are usual for countermeasures of like kind, elsewhere, in comparable settings. Thus, the assessed risk represents, in fact, the residual risk that remains to each hazard in the presence of system countermeasures.

Subjective probability declarations are more difficult to formulate than are evaluations of worst-case severity. The "Descriptive Word/Definition" guidance given in the MIL-STD for mishap probability is duplicated as a part of the Risk Assessment Matrix used here. That guidance is intended to facilitate probability evaluations. However, it is recognized as having only limited value for realistic application to long-mission system lifetimes. To overcome this shortcoming, a frequently used "calibration point" was employed in the work reported here: round-trip commuting on a controlled, well-maintained, codeworthy, 15-mile-long, 2-lane access highway, over a working lifetime, was postulated to encompass a hazard ensemble having a severity level of I, a probability of E, and a risk level of 3 for the individual employee. (The Code-3 zone of the risk assessment matrix is taken to represent the *de minimis* level.) Such hazard ensembles are well known to members of the Working Group, and this concept

provides an element of realistic uniformity in the risk assessment work.

RESULTS: Hazards within the PHA inventory are grouped into 11 major rubrics in the worksheets that follow. The hazard identifications and the risk assessments within those rubrics are largely self-explanatory. Hazards of Fire/Explosion (PHA 2.0), Oxygen Deficiency (PHA 6.0), and Radiation/Exposure to Beam in Tunnel (PHA 8.a) pose the greatest perceived threats in terms of attention given to developing countermeasures in the conceptual design. Hazards posing least apparent threat are those of Flooding (PHA 3.0), Radiation/Radon Emissions (PHA 8.c), and Wall/Roof Collapse (PHA 11.0). For all hazards identified, the assessments show that the residual risk in the presence of the indicated countermeasures falls within the *de minimis* region.

LIMITATIONS: As noted under **SCOPE**, above, this PHA has treated only hazards to personnel during the period of facility service following SSC construction and only within the accelerator tunnel and its associated shafts. Additionally, it has been assumed that the Code-3 zone portrayed in the risk assessment matrix used here is acceptable to the system proprietor as representing *de minimis* risk. Beyond these bounds, which apply to this particular PHA in its present form, the PHA, as an analytical technique, has these limitations:

- Not all hazards to be encountered within the system can be foreseen either by this or by any other technique. Reliance on multiple hazard identification methods can help ensure against oversight, as can involving several analysts. (Both of these methods have been used in developing the PHA presented here.) However, although thoroughness may be great, there can never be assurance that it is exhaustive.

- Risk is assessed for hazards in the PHA on an item-by-item basis. Therefore, if risk for each of the individual hazard items in the inventory appears to be acceptable, the impression may be given that overall system risk is acceptable. True system risk, however, may approach the sum of the risks for the individual hazard items.
- The PHA must be based on a complete description of the system and its operation. Also, the PHA hazards inventory must be begun early for a system undergoing design if hazards are to be recognized and suitable countermeasures are to be established before design changes become exorbitant in cost. (The "early start" has been used for the present PHA.) These two requirements, for completeness and for early analysis, are in obvious conflict. Early system information serving as the basis for an initial PHA is inevitably less than complete. The information will increase in volume and will change in character as the design evolves, and the original analysis will be outdated. Additionally, new hazards not initially foreseen and entered into the inventory may come into evidence as design work progresses. (An important example in the SSC case relates to mechanically manipulating major accelerator components within the tunnel. Because the methods for handling these components have not yet been specifically identified, this potential hazard category has not been included in the PHA at this point.) Consequently, the PHA must be updated periodically as the system design matures. This updating is necessary to ensure that hazards becoming newly recognized during design development will be entered into the inventory and that already-recognized risks, initially seen as falling at the acceptable *de minimis* level, will continue to do so.

Finally, to serve its ultimate function, the PHA must be treated as an "open file" document throughout system life. PHA reviews and revisions should be made:

- As operating experience is gained
- When the system, its safety features, or its method of operation is modified in ways that might alter risk
- When mishaps are experienced
- When improved insight into hazard recognition is gained through newly acquired knowledge — e. g.: information concerning experience at other accelerator facilities

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PHA 1.0
Electrical Energy

Index	Hazard Electrical Shock/Fibrillation/Burns	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
1.a.	High voltage (distribution, operation, maintenance)	Armored cable (2.2.3.3-p.8). Safety reviews (5.3.2-p.45). Inspection and observation (5.4.1-p.46). Others as for 1.b/1.c, below.	I	E	3
1.b.	High current	Physical barriers (8.3.4.1-p.78).	I	E	3
1.c.	Low voltage (<480 v.)	De-energized circuits (8.3.4.1-p.78). Lockout procedures (8.3.4.1-p.78). Disconnects/breakers (8.3.4.2-p.79). Tag-out procedures (8.3.4.2-p.79). SSC Supervisor authorization (8.3.4.2-p.79). Consultation with expert (8.3.4.2-p.79). Supervisory inspection (8.3.4.2-p. 79).	I	E	3
1.d.	Ungrounded equipment	Normal industrial practices (2.2.3.3-p.8). Inspection and observation (5.4.1-p.46).	I	E	3

* An inventory of hazards foreseen in ultimate operational service for the accelerator tunnel and associated shafts. The construction period is excluded, and experimental halls are not considered here. An exposure interval of 25 years is assumed.

** Toohig, T.E. – "The Superconducting Super Collider / SSC Safety Review Document" – SSC-SR-1037, November 1988

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PHA 2.0
Fire/Explosion

Index	Hazard Thermal/Blast Overpressure	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
2.a.	Asphyxiants	Alarm systems (2.2.3.1-p.7) (8.3.1.1.2-p.60) (8.3.1.3-p.62). Employee physical fitness requirements (2.2.3.1.3-p.7). Fresh air supply (2.2.3.1-p7), (8.3.1-p.58). Safety equipment (2.2.3-p.6), (8.3.1-p.58). Evacuation (8.3.1.1.2-p.60). Sensors (8.3.1.3-p.62). Personnel isolation zones (8.3.1.1.2-p.60).	I	E	3
2.b.	Electrical apparatus	Inspection, observation, instruction (5.4.1-p.46).	II	D	3
2.c.	Electrical insulation	Electric cable selection (8.3.1.1.2-p.60).	II	D	3
2.d.	Failure of monitoring systems	Routine monitoring of system status (2.2.3.1.3-p.7). Redundancy (2.2.3.1.3-p.7). Central monitoring (2.2.3.1.3-p.7). Monitor testing (5.4.2-p.46), (8.5.2-p.84).	I	E	3
2.e.	Gases, fumes, vapors	Sensors (8.3.1.3-p.62). Alarms (8.3.1.3-p.62).	I	E	3
2.f.	Liquids, solvents	Sensors (8.3.1.3-p.62). Alarms (8.3.1.3-p.62).	I	E	3

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PHA 2.0 (Sheet 2)
Fire/Explosion

Index	Hazard Thermal/Blast Overpressure	Countermeasure(s)/ Where Documented**	Residual Risk		
			Severity	Probability	Risk
2.g.	Overheated equipment	Supervisory inspection (8.3.4.2-p.79).	II	E	3
2.h.	Tunnel blockage	Alternate escape routes (8.3.1.2-p.61). Evacuation alarm (8.3.1.2.2-p.61). Trained personnel (8.3.1.2.2-p.61).	II	E	3
2.i.	Tunnel "people movers"; motors, battery packs	Guidance provided by experiences of LEP project at CERN and golf carts at Fermilab (2.2.3.2-p.8).	II	E	3

* An inventory of hazards foreseen in ultimate operational service for the accelerator tunnel and associated shafts. The construction period is excluded, and experimental halls are not considered here. An exposure interval of 25 years is assumed.

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PHA 3.0
Flooding

Index	Hazard Drowning	Countermeasure(s)/ Where Documented**	Residual Risk		
			Severity	Probability	Risk
3.a.	Water in tunnel	Monitoring systems (2.2.3.6-p.9). Sump pumps (2.2.3.6-p.9). Alarms (8.3.1.3-p.62).	I	E	3

* An inventory of hazards foreseen in ultimate operational service for the accelerator tunnel and associated shafts. The construction period is excluded, and experimental halls are not considered here. An exposure interval of 25 years is assumed.

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PHA 4.0
Materials Handling

Index	Hazard Mechanical Injuries	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
4.a.	Cranes, hoists, etc.	Safety reviews (5.3.2-p.45). Inspection observation (5.4.1-p.46). Regulations (8.3.1-p.57).	I	E	3
4.b.	Elevators	Design features (p.v). Safety organization (p.v).	I	E	3
4.c.	Equipment transporters	Design features (p.v). Inspection, observation (5.4.1-p.46). Safety audits (5.3.1-p.45). Safety awareness training (6.4-p.52). Safety organization (p.v).	I	E	3
4.d.	Manual handling (lifting, moving, positioning)	Inspection, observation (5.4.1-p.46). Safety audits (5.3.1-p.45). Safety awareness training (6.4-p.52). Safety organization (p.v).	II	D	3

* An inventory of hazards foreseen in ultimate operational service for the accelerator tunnel and associated shafts. The construction period is excluded, and experimental halls are not considered here. An exposure interval of 25 years is assumed.

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PHA 5.0
Mechanical Systems

Index	Hazard Mechanical Injuries	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
5.a.	Mechanical power transmission	Mechanical devices safety subcommittee (5.3.2-p.45). Safety reviews (5.3.2-p.45). Inspection, observation, instruction (5.4.1-p.46).	II	D	3
5.b.	Point-of-operation (machine tools)	Mechanical devices safety subcommittee (5.3.2-p.45). Safety reviews (5.3.2-p.45). Inspection, observation, instruction (5.4.1-p.46).	III	D	3
5.c.	Compressor noise	Enclosures (8.3.3.5.2-p.78). Hearing protection (8.3.3.5.2-p.78).	III	D	3

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PHA 6.0
Oxygen Deficiency

Index	Hazard Asphyxia	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
6.a.	Loss of ventilation power	Alternate grid (8.3.1.1.1-p.60). Remote transfer switches (8.3.1.1.1-p.60). Emergency generators (8.3.1.1.1-p.60).	I	E	3
6.b.	Failure of ventilation systems (other than 6.a.)	Evacuation (8.3.1.1.2-p.60). Alarms (8.3.1.3-p.62). Back-up systems (8.3.3-p.72). Exclusion of personnel (8.3.3.4-p.75).	II	E	3
6.c.	Blockage of ventilation	Evacuation alarm (8.3.1.2.2-p.61). Trained personnel (8.3.1.2.2-p.61). Others as for 6.b., above.	II	E	3
6.d.	Leakage of cryogens	Evacuation of personnel (8.3.1.1.2-p.60). Exclusion of personnel (8.3.3.4-p.75). Sensors (8.3.3.2-p.72), (8.3.3.3-p.74). Monitors (8.3.3.2-p.72). Alarms (8.3.3.4-p.75). Personnel training (8.3.3.4-p.75), (8.3.3.5-p.76). Education, training, supervision (8.3.3.5-p.75). Safety analyses and reviews (5.3.2-p.45) (8.3.3.5-p.75). Posted warning signs (8.3.3.5-p.76). Personal oxygen monitors (8.3.1-p.58), (8.3.3.5-p.76).			

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PHA 6.0 (Sheet 2)
Oxygen Deficiency

Index	Hazard Asphyxia	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
6.d. continued	Leakage of cryogens (continued)	Medical approval (8.3.3.5-p.76). Multiple personnel communications (8.3.3.5-p.76). Unexposed observer communication (8.3.3.5-p.76).	I	E	3
6.e.	Failure of cryogenic equipment (other than 6.d.)	Alarms (8.3.3.5.1-p.77). Flow detection (8.3.3.5.1-p.77). Safety analyses and reviews (8.3.3.4-p.75). System design (8.3.3.5-p.75).	I	E	3
6.f.	Fire/Smoke	Evacuation warning system (8.3.1.1.2-p.60). Personnel isolation zones (8.3.1.1.2-p.60). Alarm system (8.3.1.3-p.62).	I	E	3

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PHA 7.0
Personnel Transport

Index	Hazard Mechanical Injury	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
7.a.	Elevator failure	Design feature (p.v). Life safety codes (4.2-p.21). Safety reviews (5.3.2-p.45).	I	E	3
7.b.	Horizontal transport/collisions vehicle-vehicle vehicle-person vehicle-fixed equipment passengers-fixed equipment	Design features (p.v). Inspection, observation (5.4.1-p.46). Safety audits (5.3.1-p.45). Safety awareness (6.4-p.52). Safety organization (p.5).	I	E	3

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PHA 8.0
Radiation

Index	Hazard Health Impairment	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
8.a.	Exposure to beam in tunnel	Shielding (8.3.2.1-p.63) (8.3.2.1-p.65) (8.3.2.2-p.66) (8.3.2.3-p.66) (8.3.2.3-p.67) (8.3.2.4-p.68). Exclusion of personnel (8.3.2.1-p.63) (8.3.2.1-p.64). Access control (8.3.2.1-p.64) (8.3.2.1-p.65). Interlocks (8.3.2.1-p.64) (8.3.2.1-p.65). Monitoring (5.4.2-p.46) (8.3.2.1-p.63) (8.3.2.1-p.65) (8.3.2.4-p.67). Education and certification (8.3.2.1-p.66). Worker I. D. and health clearance (8.3.2.1-p.64). Redundant critical device protection (8.3.2.3-p.66).	I	E	3
8.b.	Residual radiation	Shielding (8.3.2.5-p.70) (8.3.2.5-p.71). Absorbers (8.3.2.5-p.70). Scrapers (8.3.2.9-p.69).	II	E	3
8.c.	Radon emissions	Personnel monitors (5.4.2-p.46).	I	F	3

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PHA 9.0
Toxic Materials

Index	Hazard Acute Health Impairment	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
9.a.	Gases, vapors, fumes, mists, smoke, etc.	Alarms (8.5.1-p.83) (8.3.1.3-p.62). Evacuation (8.3.1.3.2-p.60). Detectors (8.3.1.1.2-p.60), (8.5.2-p.83). Sensors (8.3.3.2-p.75).	I	E	3
9.b.	Blockage of ventilation	Evacuation alarm (8.3.1.2.2-p.61). Trained personnel (8.3.1.2.2-p.61).	I	E	3
9.c.	Failure of monitoring system	Environmental sensors (5.4.2-p.46-47).	I	E	3
9.d.	Failure of ventilation system	Countermeasures as for 6.a/6.b/6.c.	I	E	3

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PHA 10.0
Walking/Working Surfaces

Index	Hazard Falls/Mechanical Injury	Countermeasure(s)/ Where Documented**	Residual Risk Severity	Probability	Risk
10.a.	Slippery floors	Inspection, observation, instruction (5.4.1-p.46).	III	C	3
10.b.	Wet floors	Inspection, observation, instruction (5.4.1-p.46).	III	D	3
10.c.	Stairs	Original design (1.3-p.2). Inspection, observation, instruction (5.4.1-p.46).	III	C	3
10.d.	One/two riser steps	Original design (1.3-p.2). Inspection, observation, instruction (5.4.1-p.46).	III	C	3

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PHA 11.0
Wall/Roof Collapse

Index	Hazard Mechanical Injury	Countermeasure(s)/ Where Documented**	Residual Risk		
			Severity	Probability	Risk
11.a.	Structural failure (overload/seismic disturbance)	Use of standard, high-quality, tunnel construction designs/materials/assembly methods. (Private communication: Dr. Larry Coulson, 20 October 1989)	I	E	3

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Preliminary Hazard Analysis Risk Assessment Matrix*

Severity of Consequences	Probability of Mishap: F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
I Catastrophic					1	
II Critical				2		
III Marginal			3			
IV Negligible						

Severity of Consequences

Category	Descriptive Word	Personnel Illness/ Injury	Equipment Loss($)	Test Unit Downtime	Data Compromise	Environmental Effect
I	Catastrophic	Death	>500K	>4 months	Data never recoverable or primary program objectives lost	Long-term (5 yrs or greater) environmental damage or requiring $500K or more to correct and/or in penalties
II	Critical	Severe injury or severe occupational illness	100K to 500K	2 weeks to 4 months	Repeat of test program	Medium-term (1-5 yrs) environmental damage or requiring $100K-$500K to correct and/or in penalties
III	Marginal	Minor injury or minor occupational illness	1K to 100K	1 day to 2 weeks	Repeat of test period	Short-term (less than 1 yr) environmental damage or requiring $1K-100K to correct and/or in penalties
IV	Negligible	No injury or illness	<1K	<1 day	Repeat data point or data requires minor manipulation or computer rerun	Minor environmental damage that readily can be repaired or requiring less than $1K to correct and/or in penalties

Probability of Mishap

Level	Descriptive Word	Definition
A	Frequent	Likely to occur repeatedly during life cycle of system
B	Probable	Likely to occur several times in life cycle of system
C	Occasional	Likely to occur sometime in life cycle of system
D	Remote	Not likely to occur in life cycle of system, but possible
E	Improbable	Probability of occurrence cannot be distinguished from zero
F	Impossible	Physically impossible to occur

Risk Zones

Code	Action
1	Imperative to suppress risk to lower level
2	Operation requires written, time-limited waiver endorsed by Management
3	Operation permissible

Note: PERSONNEL must not be exposed to hazards in Risk Zones 1 and 2

* Adapted from MIL-STD-882B