A study of underground rescue chambers as alternative to several egress paths -

A case study of new underground facilities at CERN

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Titel
En undersökning av räddningskammare i underjordiska anläggningar som alternativ till flera utrymningsvägar – En fallstudie av nya underjordiska anläggningar hos CERN

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Abstract

This study has investigated the usage of rescue chambers as an alternative to additional egress paths. The new underground facilities at CERN that are planned as a part of the HL-LHC project have two proposed designs with rescue chambers or additional egress paths. This report consists of two parts, a case study of the proposed designs for CERN and a literature review on rescue chambers. The results of the case study found that the design with rescue chambers created dead end passages where personnel could be trapped by a fire. This could be avoided by using the alternative design adding additional egress path in proposed locations. The literature review brought forward a problem with different usage of terms and definitions when researching rescue chamber and refuge alternatives. It showed that the majority of research has been conducted for rescue chambers within mines and underground construction sites and rescue chambers are more likely to be an acceptable alternative to self-rescue in these environments.

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Summary

Refuge alternatives have become an ordinary feature in mines and in underground construction sites. In this type of environments, it is often difficult to create new egress paths as the layout changes when the working fronts are moving. Refuge alternatives are tools to create safe areas for respite or shelter for workers not able to evacuate safely. Rescue chambers are a type of refuge alternative.

CERN has several underground areas and in the HL-LHC project two new underground facilities are planned. For the first time CERN has proposed installation of rescue chambers as a permanent safety feature and as an alternative to self-rescue. Due to uncertainty of the safety of the proposed configuration, a second configuration has been presented where rescue chambers are replaced by additional egress paths. This second configuration will however require a more extensive excavation process.

A collaboration between CERN and the Division of Fire Safety Engineering at Lund University was initiated to evaluate the fire safety of the new facilities. This report is written as a bachelor thesis and it is focused on the evacuation and the use of rescue chambers in comparison with additional egress paths. This report presents a case study with evacuation simulations and analysis of the two proposed configurations for the new facilities and a literature review on rescue chambers. Within the collaboration framework, there is also a master thesis concerning risk analysis, as well as fire simulations are conducted for a set of chosen scenarios. The three parts of the collaboration are performed by different students but will share results and information.

Conclusions drawn by the literature review show an inconsistency in the use of terms and definitions when researching rescue chambers and other refuge alternatives. It also shows several environments where refuge alternatives are important for safe evacuation but their effectiveness is associated with different issues such as training, placement, maintenance etc. It also shows an increased dependability on fire brigades capacity and experience for safe evacuation. Most important that self-rescue is preferable when possible.

The simulations and analysis of the CERN facilities shows a clear advantage for the alternative configuration where additional egress paths were used instead of rescue chambers. In the basic configuration with rescue chambers there were several long dead ends where personnel could become trapped. The alternative configuration eliminates the long dead end and reduces the chance of personnel not being able to evacuate.

From the perspective of the fire brigade, the alternative configuration is also preferred as it provides them with more access paths. As there are no rescue chambers in the alternative configuration, the fire brigade does not have to expand their capabilities to be able to handle rescue chambers.

Sammanfattning

Tillflykts alternativ har blivit ett vanligt inslag i gruvor och underjordiska byggarbetsplatser. I denna typ av miljöer är det ofta svårt att skapa nya utrymningsvägar när utformningen förändras när arbetsfronten rör sig. Räddningskammare är till för att skapa säkra områden där personal kan pausa under utrymning eller ta skydd tills de kan bli evakuerade av räddningstjänsten.

CERN har flera underjordiska anläggningar och i HL-LHC-projektet planeras två nya underjordiska anläggningar. För första gången har CERN föreslagit användandet av räddningskammare som en permanent säkerhetsåtgärd och som ett alternativ till egen utrymning. På grund av osäkerheten om den föreslagna konfigurationen har en andra konfiguration presenterats där räddningskammare ersätts med ytterligare utrymningsvägar. Denna andra konfiguration kommer dock att kräva en mer omfattande utgrävningsprocess.

Ett samarbete mellan CERN och Avdelningen för Brandteknik vid Lunds universitet startades för att utvärdera brandsäkerheten i de nya anläggningarna. Denna rapport är ett examensarbete och är inriktad på evakueringen och användningen av räddningskammare i jämförelse med att införa ytterligare utrymningsvägar. Denna rapport presenterar en fallstudie med utrymningssimuleringar och analys av de två föreslagna konfigurationerna för de nya underjordiska anläggningarna och en litteraturstudie om räddningskammare. I samarbetet finns också ett examensarbete om riskanalys och i en tredje del av samarbetet görs brandsimulering för valda scenarier. De tre delarna av samarbetet görs av olika elever men de kommer att dela resultat och information inom samarbetet.

Litteraturstudien visar på en inkonsekvent användning av begrepp och definitioner i studier om räddningskammare och andra tillflykts alternativ. Den visar också på att det finns flera miljöer där tillflyktsalternativ är viktiga för att en säker evakuering ska kunna göras. Men vid användning av räddningskammare tillkommer flera behov såsom utbildning, praktik, underhåll etc. Det visar också ett ökat behov räddningstjänstens kapacitet och erfarenhet för säker utrymning. Möjlighet att personer kan evakuera utan assistans är att föredra när det är möjligt.

De simuleringar och den analys av CERNs anläggningar som utförts visar en klar fördel för den alternativa konfigurationen där ytterligare utrymningsvägar installerades istället för räddningskammare. I grundkonfigurationen med räddningskammare fanns flera långa återvändsgränder där personalen kan bli instängd. Den alternativa konfigurationen eliminerar långa återvändsgränder och minskar risken för personalen blir instängd.

Ur räddningstjänstens perspektiv är den alternativa konfigurationen också att föredra eftersom det bland annat ger räddningstjänsten fler insatsvägar. Eftersom det inte finns några räddningskammare i den alternativa konfigurationen behöver inte räddningstjänsten utöka sin kapacitet för att kunna hantera räddningskammare.
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Abbreviations

CERN	Conseil Européen pour la Recherche Nucléaire, European Organization for Nuclear Research
HL	High Luminosity
LHC	Large Hadron Collider
FDS	Fire dynamics simulator (software)
FDS+EVAC	Fire dynamics simulator + Evacuation (software)
PM	Shaft to the surface
US	Cavern for cryogenic equipment
UW	Cavern for ventilation and water
UR	Tunnel parallel to LHC containing transformers and power converters
UA	Transversal gallery for radio frequency equipment
UL	Transversal gallery for cryogenic ducts

1 Introduction

This thesis is part of a larger project between CERN and the Division of Fire Safety Engineering at Lund University. In the High-luminosity project at CERN, two new underground facilities will be constructed in connection to the Large Hardon Collider. The joint project concerns the fire safety of these two new facilities. The project was divided into three separate thesis topics covering three areas.

The focus of this thesis is evacuation of the two new underground facilities and their proposed designs. CERN has narrowed it down to two designs which will be evaluated in this report. One of these proposed designs uses rescue chambers as an alternative to self-rescue, while the other suggests the use of connections to the LHC as additional egress paths. CERN has no experience using rescue chambers for this purpose in this kind of environment and therefore a literature review on the usage of rescue chamber is also a part of this report.

1.1 Overall objective

The objective with this thesis is to review evacuation strategies from underground facilities. CERN facilities will be used as a case study for this purpose.

Other goals of this thesis are:

- A literature review on rescue chamber overall usage underground.
- To evaluate the proposed usage of rescue chamber in chosen CERN facilities as an alternative to self-rescue.
- To compare and evaluate the proposed configurations of selected CERN facilities from an evacuation perspective.

1.2 Methodology

This bachelor thesis focused on evacuation is part of a larger project together with a master thesis and FDS simulations.

The project started with a visit to CERN and the common goals of the cooperation were decided together with CERN . The work was split in three sections, one for each thesis.

This thesis consists of two major parts, analysis of the case study and a literature review. The case study is dependent on results from the two other parts, which are a part of the joint project, while the literature review is independent. The three parts have the following areas:

- *Comparative study of risk analysis methods from a fire safety perspective* – Risk analysis
- *A study of underground rescue chambers as alternative to several egress paths* – Evacuation
- Fire simulations

The chosen strategy for this was to split the work into four phases. The first phase is to compile the information gathered during the CERN visit and to determine evacuation scenarios and simulations. These are provided to other parts of the project.

The second phase is the literature review on rescue chambers. This phase is completely independent from the other theses. The literature review is a tool to later be used to analyse and evaluate the proposed usage of rescue chambers in the CERN facilities, but also to review the current use of rescue chamber as an alternative to additional emergency routes.

The third phase is to combine results from fire dynamic simulations and evacuation simulations to analyse and evaluate the case study. The fire dynamic simulations are conducted within another part of the joint project.

In the fourth and final phase, the conclusions from the analysis and the literature review are used to do an overall review on the case study and to come to conclusions on the thesis.

Modelling Program

To able be able to simulate different evacuation scenarios in the not yet built facility, evacuation modelling programs can be used. Such models (as many other engineering models) are not intended to be a perfect replication of a real scenario, but they are used to obtain insights into the evacuation process.

FDS+EVAC

The software used is a FDS subroutine for evacuation developed by VTT Technical Research Centre of Finland, which in combination is called FDS+EVAC (Korhonen, T. 2015). This section presents a description of the main characteristics of the model based on the documentation provided by the model developer. FDS+EVAC combines a computational fluid dynamics model for fluid flow and an agent-based egress calculation model. The movement sub-model makes use of a continuous approach. In the joint project, fire simulations of a set of scenarios are modelled in FDS. FDS+EVAC can be used to model egress using the FDS fire simulations as an input for the fire/smoke conditions. FDS+EVAC is able to run fire simulations and evacuation simulations simultaneously and is therefore able to use information from the fire simulation to affect the evacuation model.

In FDS+EVAC each evacuee is treated as an individual agent. FDS+EVAC creates a 2-dimensional flow field to guide agents through the geometry and to the exits. One 2-dimensional flow field is created for each part of the geometry. The movement model is based on the social force model by Helbing. This is briefly described in the FDS+EVAC technical guide but see Helbing’s et al. work (1995,2000,2002,2003) for more extensive information. Each agent is affected by contact, psychological and motive forces associated with the interactions with other agents and the environment. The model accounts for a distribution of movement speeds and body diameters. The human body is represented as an approximated ellipsis made by one circle with two smaller circles on each side, representing body and arms. Each agent accelerates to its individual walking speed towards chosen exit. The agent follows the 2-dimensional flow field but its movement is affected by forces accounting for the presence of other agents and obstacles.

Agents chose an exit depending on two main factors, namely exit familiarity and smoke. Agents will prefer familiar exits as long as they are smoke-free. If there is smoke, an agent will prefer a smoke-free exit even if it is unfamiliar and there is a familiar option if this is not visible because of smoke. FDS+EVAC allows modelling of behaviours such as group interactions but in this thesis herding behaviours have not been explicitly taken into consideration. A conservative assumption has been used, that considers a conservative agent that choses its exit using familiarity and smoke as criteria. If there is more than one exit that is “best”, the agent choses the one that gives the shortest evacuation time. If the conservative agent discovers another more preferable exit, it may change its choice and pursue the new exit.

When a detection time is not set, the function TDET_SMOKE_DENS can be used to allow agents to initiate evacuating. TDET_SMOKE_DENS allows agents to detect the smoke and start the evacuation when the mass concentration reaches a set value at a set height where the agents are located.

An agent walking speed can be impeded by reduced visibility, irritant and asphyxiating gases. The reduction in walking speed is based by default on the experiments by Frantzich and Nilsson (2003). Agents cannot reduce their speed to the point that they will stop but instead they have a minimum movement speed at which they will move until the environment improves or they are incapacitated. Agents are simulated as incapacitated when the fractional effective dose accumulated by the agent from toxic smoke has reached a set value.

FDS+EVAC automatically calculates the fractional effective dose each agent is exposed to. For scenarios where fire simulations are not simulated simultaneously this method cannot be used. For those scenarios, the fractional effective dose will be calculated using the following method.

The fractional effective dose is calculated by FDS+EVAC by the following equation.

$$FED_{tot} = \left(FED_{CO} + FED_{CN} + FED_{NO_2} + FLD_{irr}\right) * \; HV_{CO_2} + FED_{O_2} \qquad (1)$$

The calculation of each parameter can be seen in FDS+EVAC technical guide and it is based on Purser’s fractional effective dose concept (2003).

In FDS+EVAC the building geometry is fitted to the underlying rectilinear mesh, in this case the one used in the fire simulations. The geometry from the fire simulation will be included in the evacuation simulation if not told otherwise but modifications can be made to control the movement of the evacuees, which would only affect evacuation modelling. Due to the complex FDS geometry, consisting of equipment, much of it was not used in the evacuation geometry to avoid unnatural behaviour from the simulated agents. Modifications in the evacuation simulations were made to make sure the evacuees follow the egress paths.

The software is able to simulate inclines, but the since geometry is based on the fire simulations geometry, where there is no incline, they are not modelled in the present work.

FDS+EVAC cannot simulate delayed movement when occupants open doors. What can be done is to implicitly modify flows through doors. This has not been done and the factor is assumed to have very little impact on the results because of the facility size, few doors and low occupant loads.

FDS+EVAC includes a very simple model for elevators. However, as the pressurized safe-area at the bottom of the shaft can be considered as a safe location agents entering this area will therefore leave the simulation. Therefore, the usage of the elevator sub-model is not needed. This can be done since the safe-areas capacity of at least 150 people, a much larger number than proposed occupancy of the facility.

The CO toxicity in FDS is based on user’s input and this represents a potential source of error. The CO toxicity will not be determined in this report but in one of the other parts of the joint project.

FDS+EVAC was mainly chosen for its ability to affect the behaviour of the evacuees directly based on a simultaneous fire simulation. However, FDS+EVAC is still a relatively new module to FDS and is still primarily a research tool and not fully validated.

Simplified calculations

The travel time for evacuation is also calculated using a simple movement speed calculation along the egress path. The results are compared with the travel times from the simulations. The comparisons are presented in Appendix B.

Evacuation Simulations

The evacuation simulations are done in FDS+EVAC to easily incorporate the effect of fire and smoke on the evacuees. The fire simulations will be created and simulated in another part of the joint project and the results from the fire simulations will be used to run several FDS+EVAC iterations. The results from the fire simulations and evacuation simulations will then be used to evaluate the configurations during the different scenarios.

The input parameters into the evacuation simulation software will change depending on the scenarios which will be simulated. Table 1 presents the parameters for the different scenarios that have been chosen in the joint project as the ones needing further analysis. Some parameters will be kept constant throughout all simulations.

Table 1 Input parameters

Parameter	**Value**	**Comment**
Walking speed	1,3±0,1 (m/s) Uniform distribution	The walking speed is set to be within the values for adults in FDS+EVAC. (Korhonen, T. 2015)
Reaction time	30-80 (s) Uniform distribution	Reaction time is based on results of experiments in *Evacuation in complex environments – an analysis of evacuation conditions in a nuclear power plant and a tunnel construction site* (Frantzich, H. 2009)

The reaction time was based on an evacuation drill at a nuclear power plant by Håkan Frantzich and Daniel Nilsson (2009). The reason this reaction time was chosen is that it is a complex environment and it has safety measurements for leaving, such as airlocks. It is also a complex environment where radiation is a present hazard. The reaction time for personnel working on the reactor lid were not used as they wore protective suit and were unwilling to leave. Instead the reaction time was used for personnel doing maintenance or other tasks. The reaction times for these workers varied between 30- and 84 seconds. Another experiment with a tunnel construction site were also studied and gave much lower reaction times, 4- to 30 seconds. This was not used as the CERN facility will not be a construction site and will be more similar to the nuclear power plant experiment.

Fraser-Mitchell and Charters (2005) have written a paper on *Human Behaviour in Tunnel Fire Incidents.* In this paper they state that evacuees during an emergency will almost certainly be moving away from the fire. Personnel which is not in UA53 in scenario 3, 4, 5 and 6 is assumed to be able to evacuate safely and therefore not a part of the simulations for these scenarios.

FDS+EVAC automatically place randomly agents within the chosen location, and the preparation time is also randomly assigned from distributions. The reason is to account for the difference between evacuation simulations within the same scenario given the possible variability of human behaviour (so called behavioural uncertainty) (E. Ronchi, P. A. Reneke, R.D. Peacock (2014)).

Five repeated simulations of each evacuation scenario have been run and average results have been obtained. Preferably, a more sophisticated method should have been used to choose the number of runs and more iterations should have been simulated but only five iterations were conducted for each scenario due to time constraints of the project. The uncertainty given with five iterations is presented in Appendix A.

Tenability criteria for safe evacuation will account for three different aspects, temperature, toxicity, and visibility. The criteria can be seen in Table 2. Tenability criteria for visibility and temperature are from the standard ISO/TS13571:2002(E). All tenability criteria are measured at 1,8 meters.

Table 2 Tenability criteria

Parameter	Value	Comments
Toxicity	FED = 0.3	For fractional effective dose (FED) the threshold 0.3 can be used for most general evacuees in most reasonable fire scenarios.
Visibility	15 m	ISO standard set distances between 5 and 15 meters. To have a single value 15 meters were chosen to be conservative.
Temperature	60 °C	This value is the air temperature when convective heat for is considerably painful for unprotected skin.

Regarding the temperature tenability criteria, burns in the respiratory tract from inhaled air has a threshold of 60°C if the air inhaled has a water volume higher than 10%. However, if the water volume is than 10% lower burns in the respiratory tract usually occur after burns on bared skin. Since the water volume in the air is unknown, it is assumed to be more than 10% to be conservative.

1.3 Disposition

Chapter 1 Introduction. The thesis objective and methodology are presented together with the limitations and boundaries.

Chapter 2 Background. The base of the thesis is presented. The concerned projects, facilities and other details are described here.

Chapter 3 Analysis. Evacuation analysis is presented together with scenarios and simulations.

Chapter 4 Literature review: Rescue chambers. The literature review on rescue chambers in underground environments made for this thesis is presented.

Chapter 5 Discussion. Conclusions from the analysis and the literature review are presented and discussed.

Chapter 6 Conclusions. Conclusions which can be drawn from this thesis are presented.

Chapter 7 Future studies. Possible future studies and research on this thesis are presented.

1.4 Limitations

This project has been conducted in an early phase in development of the facilities and many features have not been finalised or decided yet. This will of course affect the project and future implementations of results and solutions as things may change in ways not foreseen in this report. Since the facilities have not been built yet, there is no data on fire drills or evacuation drills and this report will therefore rely on models, simulations and analysis of the suggested designs.

Scenarios and fire simulations are provided to this thesis from other sources and it is within this thesis assumed that these are accurately done. The deliverance of them becomes a limitation as the evacuation simulations and analysis cannot be done without. This also limits the number of repeated iterations which can be done of the same evacuation scenarios due to time constraint. Decreasing the number of iterations will increase the uncertainty of the evacuation simulation results since a more accurate assessment of behavioural uncertainty could have been obtained. In addition, the accuracy of the results produced are limited by the functions of the software and scenario.

1.5 Boundaries

Due to the limitations in time for this bachelor thesis, the focus will be on short stops in the operational phase (short technical stop) and technical shut down (long technical stop). The reasons why these were chosen are specified in 2.5.

The design given by CERN shows the rescue chambers as the moveable rigid steel container variant. Only this type of chambers will be evaluated and not any inflatable type or others incorporated into a separate excavation. The two facilities on Site 1 and Site 5 will have the same layout which makes it redundant to evaluate both facilities. The facility at Site 5 will be the one evaluated since it is the furthest from the CERN Fire brigade. The travel time to this facility is much longer than the one at Site 1. Because the facilities are identical what is safe for the facility at Site 5 is assumed to be safe for the facility at Site 1.

2 Background

2.1 CERN and High Luminosity

The European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire) or CERN for short was founded in 1952 to establish an organization in Europe to research fundamental physics. Today CERN's main area of research is particle physics. At CERN there are several particle accelerators including the world's largest accelerator, the Large Hadron Collider or LHC for short. The LHC is 27-kilometers in circumference and allows the collision of high-energy beams near the speed of light. (CERN, 2015b)

The High luminosity project (HL) aims to upgrade the LHC's rate of collision by a factor of 10, from the original design value of 300 to 3000 fb-1. To make it possible, several upgrades and changes need to be done. This upgrade will take longer than a decade to complete and it is planned to be finished in 2026. As a part of the HL-LHC project, two new underground facilities have to be built and CERN has decided to do an extensive safety research for these. This report is a part of a joint project to do this research. (CERN, 2015c)

The sites for the new facilities are Site 1 at the ATLAS and Site 5 at the CMS site, their respective location can be seen in Figure 1. Site 1 is located at the main CERN area while Site 5 is located at the opposite side of the LHC at the furthest most area.

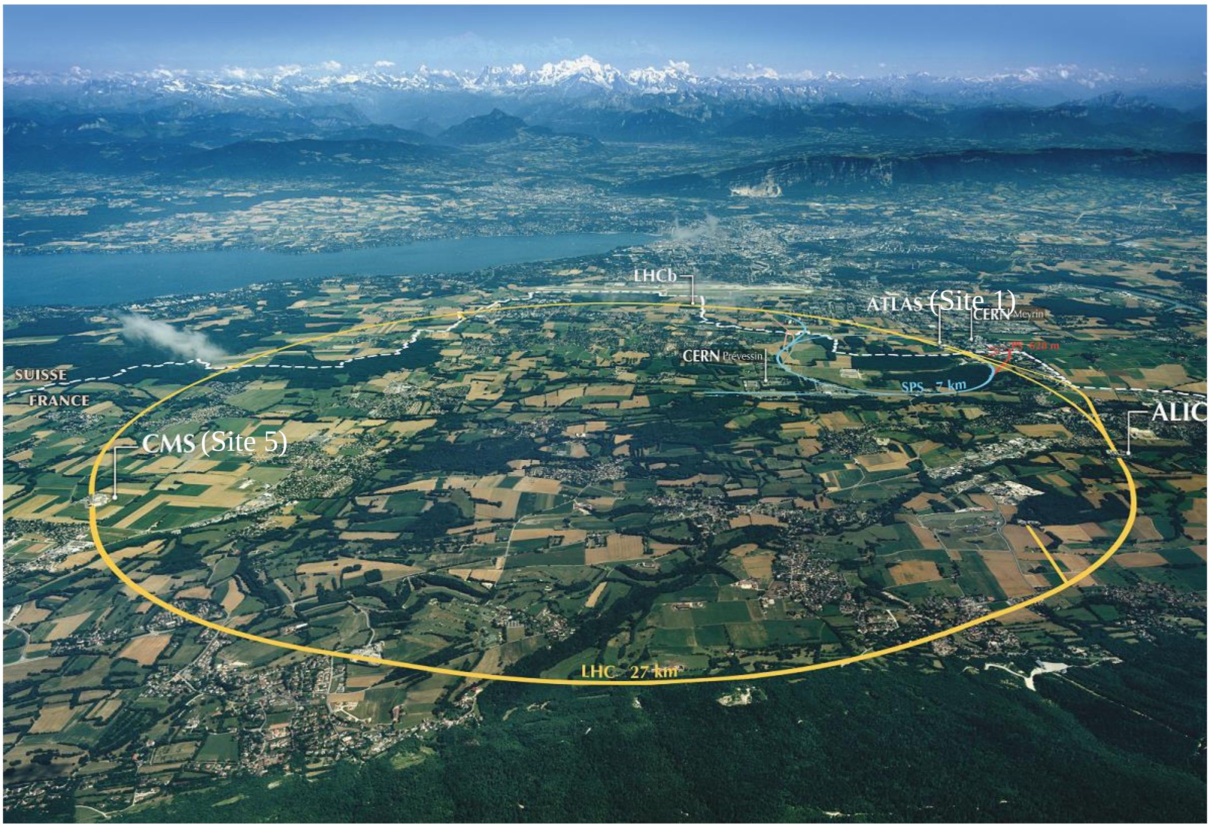

Figure 1 Aerial view (CERNa, 2015)

2.2 Joint Safety Project

In cooperation with the Division of Fire Safety Engineering at Lund University CERN started a project to evaluate the fire safety of the new underground facilities which are to be built in the High Luminosity project. The beginning of the project consists of three reports by fire engineering students at Lund University to evaluate and propose changes to the fire safety design of the new facilities, as part of their exam theses.

The reports cover design fires, scenarios, risk assessment, fire simulations and evacuation. This report focuses on evacuation but it also analyses the use of rescue chambers as a permanent safety feature in the facilities. The different reports are part of the joint project and share results when analysing and evaluating each reports' subject.

2.3 Evacuation

Underground environments often result in problematic evacuation procedures. Ventilation, limited number of access and egress points, lighting and the effect on human behaviour are some of the problems that can arise in underground emergency situations. Underground operations pose problems for the rescue services due to the environment. This combined with potential fire hazards makes it important to analyse the evacuation process as emergencies can result in loss of human lives. Since changes to the new facilities will be more complicated and expensive after the construction is finished it is important to analyse the design and make necessary changes before the construction begins. Evacuation is a primary safety concern of the joint project and will be the focus of this report.

2.4 Rescue Chambers

In the proposed designs for the new underground facilities, rescue chambers could be installed as a permanent safety feature. Rescue chambers are safe-areas placed as an alternative to self-rescue to protect evacuees from an untenable environment. Here evacuees can make a stop before continuing or wait for rescue. This report includes a literature review on rescue chambers which are proposed to be used within the new facilities. This type of safe-areas is mainly used in mines and underground construction site but CERN wants to use a rescue chamber type as a permanent part of the safety design.

2.5 Facilities

The two new facilities which will be built as a part of the HL-LHC project will have their surface entrances at Site 1 and Site 5 and will be connected to the LHC. The facilities will be located at a depth of 70-100 meters with a shaft connecting to the surface. The facilities are built to support new equipment for the HL-project.

The underground area of the facility will be used during several phases from the start to the end of its lifespan. The phases, which have been laid forth in this project, are as follows:

- Excavation and construction
- Installation
- Commissioning
- Operation
- Technical stop

This report will only focus on the last two phases, operation and technical stop, since the facility will spend the majority of its lifespan in these phases. During the operation phase there will be few to no personnel in the facility. Therefore, a short stop during the operation phases is examined in this project as it is similar to normal operation but has an increased number of personnel within the facility at a single time. Personnel entering the facility need to obey the "rule of two". The "rule of two" is according to La Mendola, S. (Personal communication, 24 November, 2015) a CERN rule that any work in this type of facility should always be done by at least two people. Work in the facility by single person will only be done under special circumstances and with additional safety measures. This is very rarely done.

Operation phase - Short technical stop

In this phase, the facility works without any major malfunctions which would cause problems with the operation of the LHC. During this period there will be personnel only occasionally inside the facility. The only occupants during normal operation will be personnel from the radio frequency group who would do equipment checks and adjustments. These will be doing work in the UA57/53 where the radio frequency equipment is located, see Figure 2.

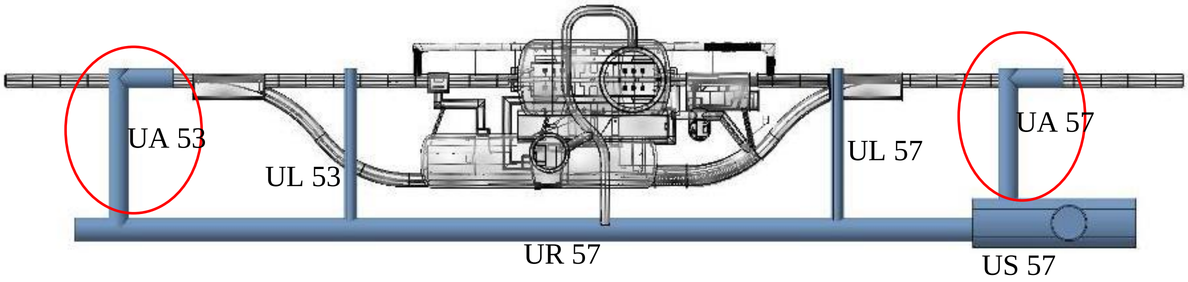

Figure 2 Baseline layout, marked areas worked by the RF group. Used with permission from CERN.

A short technical stop occurs when the LHC stops normal operation in order to do some repairs or adjustments. These could be something as small as a fuse that needs to be changed. During these short technical stops, it is common for other groups involved to do quick fixes and adjustments on their equipment within the facilities. There are currently five different groups with equipment in the facility and, in accordance of the rule of two, there would be ten people inside the facility at the same time if every group sends one team, however there could be more people sent into the facility. The personnel would be spread out inside the entirety of the facility, working where their equipment is located. As the short technical stop is during the operation phase these stops are short, rarely longer than twenty-four hours. Due to the short time span of the short technical stop the equipment inside the facility will be kept operational. This means the primary fire risk is an electrical fire in the equipment throughout the facilities. During the short technical stop personnel can be expected to be in any area of the facilities, excluding the two traversal galleries indicated in Figure 3. It is unlikely all occupants will be in a single area as they originate from different groups with equipment in different parts of the facilities.

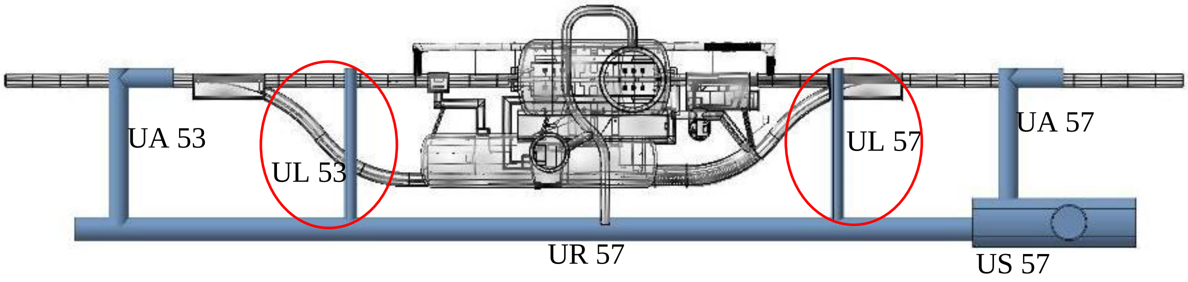

Figure 3 Baseline layout with empty sections marked. Used with permission from CERN.

Technical shutdown – Long technical stop

The technical shutdown is a planned stop in the operation for maintenance and upgrades. These are often during longer periods of time and there could be major work done inside the facility. During a long technical stop a majority of the equipment in the facilities will be shut down. This changes the primary fire risk from an electrical risk to that of hot work or other sources related to the upgrades and maintenance. There is also a possibility of the usage of small vehicles to move heavy equipment which is another possible source for transient fires. The focus when it is a long technical stop is transient fires. As in the case of the short stop, there could be personnel in any part of the facilities working.

2.6 Basic configuration

The facility is located 70-100 meters underground, 5 meters above the LHC and it is connected to the surface through a single shaft, PM57. The shaft is equipped with a vertical transport, maintenance stairs a personnel elevator, and emergency stairs, and is connected to a cavern. The personnel elevator and the stairs are pressurized and they connect to a safe-zone at the bottom of the shaft. The large cavern consists of two parts, US57 and UW57. The shaft connects to the US57 part of the large cavern, where the cryogenic equipment is located. US57 has a mezzanine above the bottom floor. UW57 is separated from US57 by a wall and contains cooling and air treatment equipment. UW57 is separated into two floors. US57 connects to the main gallery and one of the transversal galleries. The main gallery, named UR57 runs alongside the LHC. UR57 contains mainly transformers, power converters, electrical cabinets and cable trays. UR57 is around 350 meters long from one end to the other, the walkway in UR57 is about 1.6 meters' wide. (Otto, T. 20015)

The facility contains four transversal galleries, the UAs and ULs, which are connected to LHC. The ULs transfer cryogenics to the LHC through a single cryogenic line each and the UAs contains mainly RF-equipment for the crab cavities. The transversal galleries connect to LHC through vertical tunnels. These tunnels are only for equipment and not accessible for personnel, therefore passage to the LHC for personnel is not possible. The entire facility has a slight slope of 4% along UR57.

This configuration poses possible problems concerning safety and evacuation. In Figure 4 the placement of smoke curtains and fire doors is shown. In UR57 there are no fire compartments only smoke curtains, which means that the UR57 can be considered an around 350 meters long fire compartment. The transversal galleries are 40 to 60 meters long and only have one access point and no rescue chambers (Otto, T. 20015). This turns the transversal galleries into dead end tunnels. Having only one access/egress path in the facility severely hampers the ability to evacuate the entire facility in case of a fire, and it is possible that personnel find themselves trapped in a dead–end tunnel with no available egress path.

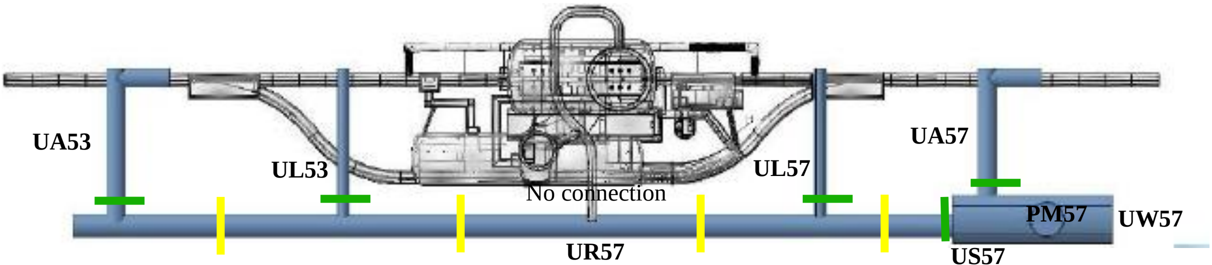

Figure 4 Top view, Yellow-smoke curtains, Green - Fire doors. Used with permission from CERN.

Besides the fire compartmentalization and fire curtains shown in Figure 4 there will also be a smoke extraction system in the entire underground area, a sampling smoke detection system and possibilities to extinguish fires with CO_2 extinguishers, portable compressed air foam system (CAFS) and dry riser. There will also be installed two rescue chambers in UR57. Rescue chamber 2 in the far end and rescue chamber 1 in the middle. The rescue chambers can be used as safe areas to protect occupants from smoke but cannot withstand a direct fire or a certain amount of heat.

2.7 Alternative configuration

The second configuration was chosen from a number of configurations made to address the evacuation problem. Figure 5 shows the proposed configuration and it differs from the basic configuration by having emergency exits connecting the transversal galleries to the LHC with staircases or ladders, stairs or ladders are not yet determined. This solution would eliminate the long dead end tunnels in the basic configuration. The new connections to the LHC remove or shorten dead ends to acceptable lengths. (Otto, T. 2015)

There will be two fire doors placed between the transversal galleries and the LHC in the emergency exits to prevent fire and smoke propagation from one to the other. Otherwise the configuration will be the same as the basic configuration. (Otto, 2015)

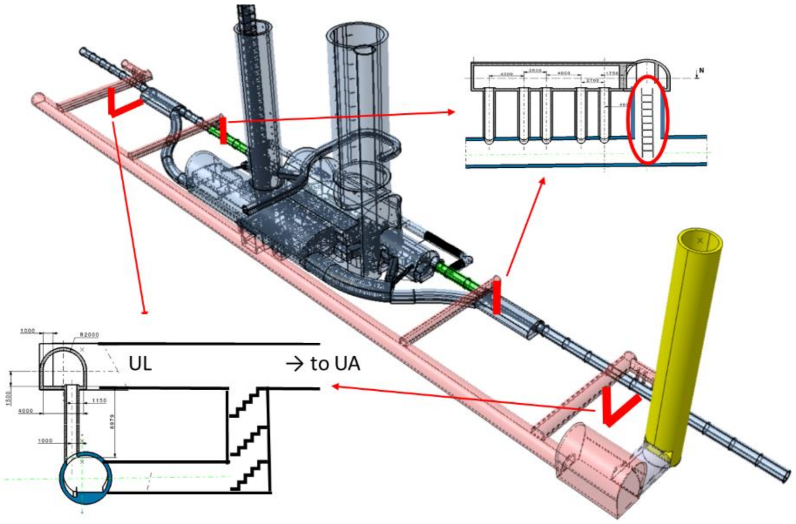

Figure 5: Proposed alternative, baseline connected to the LHC. Used with permission from CERN.

2.8 CERN Fire brigade

CERN has its own fire brigade which operates from the main area. The fire brigade has several vehicles and other equipment but only those that can be used inside the facility will be taken into consideration in this report. This part will focus on the capabilities and strategies of the fire brigade. The input from the fire brigade about the current project will also be summarized.

Capacity

The CERN fire brigade consists of one on-duty crew of nine people and one call-in crew of the same size. Additionally, they can also call on the host countries fire and rescue services. However, the response time of the host countries is at least 30 minutes and in some cases even longer.

The on-duty team consist of 1 fire officer, 1 crew commander, 4 firefighters, 2 emergency medical services firefighters and 1 operator. During a fire emergency the on-duty crew can form 3 teams of two for fire intervention under the crew commander, the operator and fire officer will probably lead from the operation centre. (Amalich, A. 2015)

Strategy Underground

The preferred strategy when doing a fire intervention in an underground facility is to have two attack/retreat points to ensure the possibilities to evacuate personnel and to ensure the safety of the fire and rescue crews.

When fighting fires underground the fire brigade will deploy from a safe point. A safe point is a compartment that the firefighters can occupy without the need of respiratory equipment and has a fresh air supply. Preferably, there should be a compartment not yet compromised by the fire between a compromised fire compartment and the safe point as to not compromise the firefighters' safety in case of a compartment breach.

In an underground facility, the firefighting capacity is wholly dependent on what kind of equipment they are able to bring with them and/or what is already present in the facility. The CERN fire brigade has done an evaluation of their capabilities and strategies for different fuel loads summarized below.

Offensive:

- Fire attack. Extinguishers, <25kg fuel load.
- Fire attack. Portable CAFS, HRR<5MW + direct attack possible.
- Fire attack. Water dry riser, HRR<20MW + direct attack possible.

Defensive:

- Door protection. Water dry riser, HRR>20MW or direct attack not possible.

The CERN fire brigade is a first responder with limited capabilities. This limits the length of the initial intervention and evacuation and would preferably be completed in the initial 30 minutes. (Amalich, A. 2015)

HL project sites

The sites where new facilities are planned is Site 1 and Site 5. Site 1 is located close to the fire brigade and the response time will be around 12 minutes or shorter, Site 5 however is placed further away and the response time will be at least 30 minutes. The long response time to Site 5 will become troublesome if the occupants are not able to evacuate themselves and not be able to take shelter in a rescue chamber, or if be the rescue chamber is compromised before they can be reached by the fire brigade.

There will be fire extinguishers spread throughout the facility. Because of the potentially high fire load there will also be access to portable compressed air foam systems (CAFS). Currently it seems that a portable compressed air foam system will be available in the large cavern.

The fire brigade will also have access to a dry riser system throughout the facility but it is not known if the transversal galleries will be included.

HL project – Basic configuration

The primary task of the fire brigade is to prepare for the worst case scenarios when preventive and active fire suppressant systems fail and a fire scenario develops. The basic configuration poses several problems for the fire brigade and some of these is as severe as it makes the configuration not valid from the fire brigades perspective. Figure 6 shows the basic configuration, note that PM57 is not correctly placed in this figure.

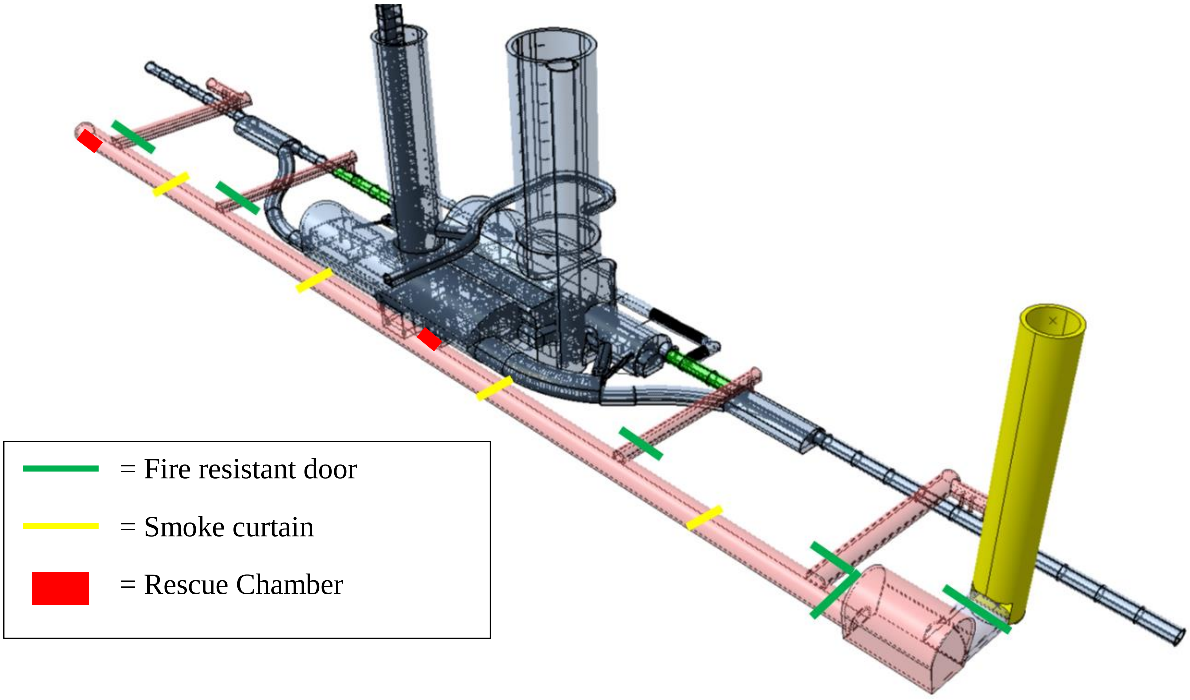

Figure 6 Basic configuration with fire doors, smoke curtains and rescue chambers. Used with permission from CERN.

With the proposed compartmentalization each gallery is its own compartment and the main gallery is only separated into different sections with smoke curtains. The main issue with this layout is that there is only one access point, the surface shaft. This means that the fire and rescue crew as no possibilities to circumvent the fire to evacuate any occupants on the far side and the occupants there will not be able to evacuate themselves. This will also limit the fire brigades' offensive capabilities as they can only attack the fire from a single side and not multiple sides which is the preferred approach. This problem cannot be solved by the proposed rescue chambers as the route can be comprised by fire or smoke and the rescue chamber is not reliable in the case of a direct contact with a fire or a certain level of heat flux. Knowing that people are still trapped within the facility will also affect the actions of the fire brigade and may lead to unnecessary risks for the crews as this limits them to offensive strategies and gives them a time limit situation to deal with.

The second problem is the length of UR57 which is one long compartment. The distance from a safe point to the far end of the facility will give the firefighters less time to work before they will have to moved back renew their air supply. This will make offensive tactics in the other end of the facility inefficient and time costly.

At this time the fire brigade has no plan or experience on how to rescue people from the rescue chambers.

HL Project -Alternative configuration

The alternative configuration gives the fire brigade possibilities of the using two or more access points to the facility for both rescue and firefighting, see Figure 5. Safe points will also be available for retreat when using the access points to the transversal galleries. The problem which arises is that the equipment which can be brought through the LHC is limited and therefore must be available in each of the transversal galleries. This configuration will allow the option to fight a fire from several directions. Due to evacuation to the LHC radiation in the LHC is a factor however, the radiation levels will not be studied in this thesis and is assumed to be acceptable as this alternative was presented by CERN.

Access points in the transversal galleries will not only make it possible for occupants to self-rescue but also give the fire brigade more alternatives to circumvent the fire to rescue personnel from different parts of the facility.

The alternative configuration will have the same compartmentalization and smoke curtain locations as the basic configuration. This means the alternative configuration has the same problems as the basic configuration where UR57 is a single compartment and a fire located in the far end the fire brigades work time will be limited if coming from a safe point in US57. The fire brigades travel distance from a safe-point will be shorter if coming from an access point in the transversal galleries.

3 Analysis

3.1 Evacuees

All occupants of the facility at any time will be personnel. The personnel are considered to be familiar with the facility *e.g.* they know the location of all exits and rescue chambers as well as knowing all safety procedures. Visitors or other occupants unfamiliar with the layout are not taken into consideration as they should not have access to the facility. The occupancy is supposed to correspond to approximately 10 people at the stops but as this number is not certain and the usage of the facility may change over time this number will not limit the evacuation simulations. Instead, occupancy will be determined of reasonable number of workers in different areas.

The personnel was assumed to be composed by a variety of average adults of both genders of working age. Complex social behaviours were not taken into account (e.g., herding). All occupants are assumed healthy and without disabilities or injuries that could impede their evacuation. Accidents which could impede evacuees are not taken into account in the evacuation simulations. This is done to limit the scenarios to a reasonable number. The possibility of an accident severe enough to impede movement is not likely to occur at the same time as a fire incident.

3.2 Scenarios

The selection of scenarios for the evacuation has been done in the joint project in the master thesis *Comparative study of risk analysis methods from a fire safety perspective* (2016). This part of the joint project has produced an event tree analyse to pick out the scenarios which should be evaluated in fire simulations and evacuation models. The chosen scenarios are presented in Table 1.

Table 3 Scenarios for the short technical stop that will be simulated in FDS (Comparative study of risk analysis methods from a fire safety perspective, 2016)

Number	**Description**	**Comment**
1.	Fire in the middle of UR tunnel. All safety measures work as planned. This means that fire detection, evacuation alarm works as intended. The fire doors are closed. The normal ventilation is turned off and the smoke extraction is turned on.	This should be the best possible scenario.
2.	Fire in the middle of UR tunnel. All safety measures fail. This means that fire detection fails. Due to this the evacuation alarm does not start. The normal ventilation will still be on and the smoke extraction will not activate. The fire doors are closed since this is assumed to be the worst case.	This should be the worst case scenario. When the doors are closed, the occupants have less possibility to notice a fire in another part of the tunnel.
3.	Fire in the UR tunnel, near the UA53 gallery. Fire doors to UA53 gallery open (fails). Evacuation alarm fails. Fire detection works which means that normal ventilation is turned off and the smoke extraction is turned on.	If the fire doors by some reason is open, the fire gets more oxygen and can propagate and smoke can spread both in the UA gallery and UR tunnel. People in the dead end of the UA gallery might not notice the fire.
4.	Fire in the UR tunnel, near theUA53 gallery and rescue chamber. Fire doors to UA53 gallery closed. Evacuation alarm fails. Fire detection works, normal ventilation is turned off and the smoke extraction is turned on.	If the fire doors are closed the occupants will only notice the fire if the door cannot withstand it any more or if the CRFS intervenes.
5.	Fire in the UA53. Fire door between UA and UR closed. Occupants are assumed to be in the far end behind the bend in the UA. All safety measures work as planned.	When occupants are in the far end they might not notice a fire that starts in the UA. Since they are in the same compartment as the fire they are directly affected by the fire in an early stage.
6.	Fire in UA53. Detection does not work. Ventilation still on. Evacuation alarm off, fire doors closed. Occupants are assumed to be in the far end behind the bend in the UA.	When occupants are in the far end they might not notice a fire that starts in the UA. Since they are in the same compartment as the fire they are directly affected by the fire in an early stage. Late attention to the fire due to no fire alarm.
(7.)	Fire in the US cavern, starts in the cabinets on the mezzanine. All systems work as planned.	Critical point since evacuating personnel must pass through on their way out.
(8.)	Fire in the US cavern, starts in the cabinets on the mezzanine. All systems fail.	Critical point since evacuating personnel must pass through on their way out.
(9.)	Fire in vertical cables in the PM access shaft. All systems work as planned.	Wants to investigate the ventilations impact on the smoke spread in the shaft.

( ) Will is not simulated

Scenario 1

A fire starts in an electrical cabinet in the middle of UR57 and then spreads to the cable trays above. All safety systems will work in this scenario. This scenario is simulated using FDS+EVAC. Personnel are spread throughout the entire facility. It is assumed no personnel are within 10 meters of the fire at the start of the simulation. Personnel evacuates to the closest safe point which is not considered blocked by smoke. In the basic configuration the safe points are rescue chambers 1, rescue chamber 2 and the safe-area at the bottom of the surface shaft. In the alternative the safe points are the safe-area at the bottom of the surface shaft or the alternative emergency exits. The FDS fire simulation is used to determine when critical levels are reached and if the evacuation will be performed safely. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 2

A fire starts in an electrical cabinet in the middle of UR57 and then spreads to the cable trays above. The detection system is not working. This scenario is simulated using FDS+EVAC with agents detecting smoke as detection method. Personnel are spread throughout the entire facility. It is assumed that no personnel are within 10 meters of the fire at the start of the simulation. Personnel evacuates to the closest safe point which is not considered blocked by smoke. In the basic configuration the safe points are rescue chambers 1, rescue chamber 2 and the safe-area at the bottom of the surface shaft. In the alternative the safe points are the safe-area at the bottom of the surface shaft or the alternative emergency exits. The FDS fire simulation will be used to determine when critical levels are reached and personnel no longer can evacuate using the different egress paths. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 3

A fire starts in the far end of UR57 close to the UA53 entrance. The fire starts in an electrical cabinet and then spreads to the cable trays above. The fire compartment door to UA53 is propped open and the evacuation alarm fails. Detection is done by agents sensing smoke. This scenario is simulated using FDS+EVAC. Two persons are placed in the main part of UA53 and two in the side section. It is assumed no personnel is within 10 meters of the fire at the start of the simulation. Personnel in UA53 evacuates to rescue chamber 2 outside UA53 in the basic configuration. In the alternative configuration personnel in UA53 evacuates through the alternative emergency exit. The FDS fire simulation is used to determine when critical levels are reached and if evacuation can be done safely. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 4

A fire starts in the far end of UR57 close to the entrance to UA53. The fire starts in an electrical cabinet and then spreads to the cable trays above. The fire compartment door to UA53 is closed, the evacuation alarm fails but all other systems work. This scenario is not simulated using FDS+EVAC as detection times cannot be determined. The closed fire compartment door blocks smoke spread to UA53. The personnel within UA53 evacuates to rescue chamber 2 in the basic configuration and to the alternative exit in the alternative configuration. The FDS fire simulation is used to determine when critical levels are reached and personnel can no longer evacuate using different egress paths. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 5

A fire starts inside UA53 and is not noticed by personnel working in UA53B. The fire compartment door to UA53 is closed and all other systems work. This scenario is simulated using FDS+EVAC. Two persons are placed in the side section of UA53. Detection is done by agents sensing smoke. The personnel within UA53 evacuates to rescue chamber 2 in the basic configuration and to the alternative exit in the alternative configuration. The FDS fire simulation is used to determine when critical levels are reached and personnel no longer can evacuate using different egress paths. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 6

A fire starts inside UA53 and is not noticed by personnel working in UA53B. The fire compartment door to UA53 is closed and no systems work. Two persons are placed in the side section of UA53. Detection is done by agents sensing smoke. The personnel within UA53 evacuates to rescue chamber 2 in the basic configuration and to the alternative exit in the alternative configuration. This scenario is simulated using FDS+EVAC. The FDS fire simulation is used to determine when critical levels are reached and personnel no longer can evacuate using different egress paths. The results of the fire simulation are used to evaluate the tenability of the rescue chambers.

Scenario 7

A fire starts on the second floor in US57 in an electrical cabinet and spreads from there. All systems work and fire compartment doors are closed. This scenario will not be simulated or analysed at all because of time constraints.

Scenario 8

A fire starts on the second floor in US57 in an electrical cabinet and spreads from there. No systems work but fire compartment doors are closed. This scenario will not be simulated or analysed at all because of time constraints.

Scenario 9

A fire starts in the access shaft. All systems work. This scenario will not be simulated or analysed at all because of time constraints.

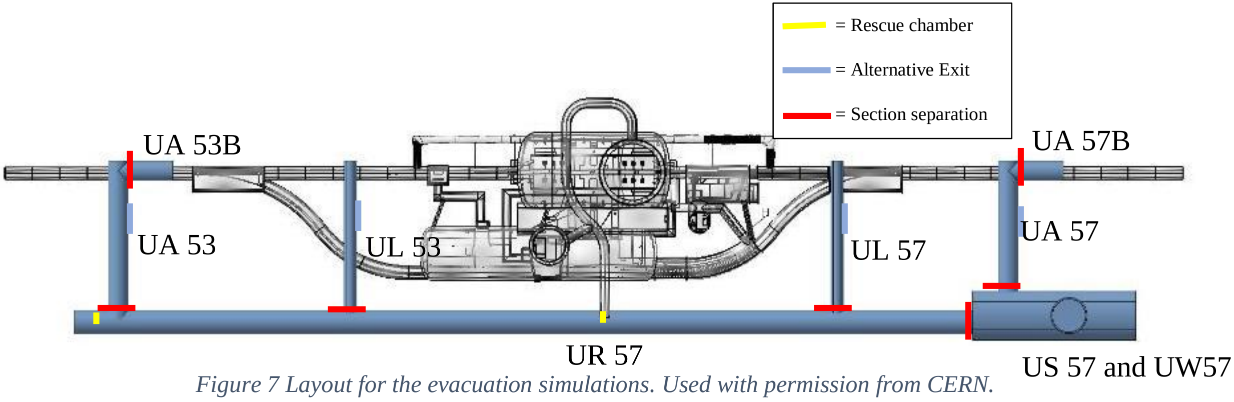

Figure 7 Layout for the evacuation simulations. Used with permission from CERN.

3.3 Results

Simulation results for the chosen scenarios. For each configuration in each scenario five evacuation iterations have been simulated and the average results are presented.

Scenario 7,8 and 9 has not been simulated because of time constraints and no results for these will be presented in this report.

Table 4 Scenario 1 - Results

Scenario 1	Detection	Evacuation	Tenability criteria
Basic configuration	Evacuation alarm starts after 2 minutes. It is possible for agents to detect smoke before this and start individual evacuation.	Both rescue chambers are used. Total evacuation time averages at 4.5 minutes.	Maximum FED by an agent averages at $7,5*10^{-6}$ Temperature limit not reached. Visibility limit reached, only in the same section as the fire, after 12 minutes.
Alternative configuration	Evacuation alarm starts after 2 minutes. It is possible for agents to detect smoke before this and start individual evacuation.	Alternative paths used. Total evacuation time averages at 4.7 minutes.	Maximum FED by an agent averages at $1,2*10^{-5}$ Temperature limit not reached. Visibility limit reached, only in the same section as the fire, after 12 minutes.

Table 5 Scenario 2 - Results

Scenario 2	Detection	Evacuation	Tenability criteria
Basic configuration	No evacuation alarm. Agents detecting smoke initiate evacuation individually. First detection of smoke after 2.1 minutes.	Both rescue chambers are used.	Maximum FED by an agent averages at $3,6*10^{-4}$ Temperature limit not reached. Visibility limit reached, only in the same section as the fire, after 8 minutes. It reaches the visibility limits in the next section to the right at 11 minutes.
Alternative configuration	No evacuation alarm. Agents detecting smoke initiate evacuation individually. First detection of smoke after 2.5 minutes.	Alternative paths used.	Maximum FED by an agent averages at $1,7*10^{-4}$ Temperature limit not reached. Visibility limit reached, only in the same section as the fire, after 8 minutes.

Table 6 Scenario 3 - Results

Scenario 3	Detection	Evacuation	Tenability criteria
Basic configuration	No evacuation alarm. Smoke spreads through the open fire compartment door. Agents initiate evacuation individually by detecting smoke. First detection of smoke will be 6 minutes or longer depending on how far from the entrance they are. No detection after the narrow pathway.	Evacuation from UA53 to rescue chamber 2 in UR53, same section as the fire. Evacuation time cannot be determined due to no detection time in the far end of UA53.	Maximum FED by an agent averages at $1{,}9*10^{-6}$ Temperature limit not reached. Visibility limit reached at UA53 entrance after 11 minutes.
Alternative configuration	No evacuation alarm. Smoke spreads through the open fire compartment door. Agents initiate evacuation individually by detecting smoke. First detection of smoke will be 6 minutes or longer depending on how far from the entrance they are. No detection after the narrow pathway.	Evacuation from UA53 through alternative evacuation path in UA53. Evacuation time cannot be determined due to no detection time in the far end of UA53.	Maximum FED by an agent averages at $4{,}9*10^{-15}$ Temperature limit not reached. Visibility limit reached at UA53 entrance after 11 minutes.

Table 7 Scenario 4 - Results

Scenario 4	Detection	Evacuation	Tenability criteria
Basic configuration	No evacuation alarm. Agents cannot detect smoke due to closed fire compartment door.	Evacuation from UA53 through alternative evacuation path in UA53. Evacuation time cannot be determined due to no detection time.	Maximum FED which could be reached during the simulated time by an agent is about $2{,}9*10^{-8}$ Temperature limit not reached. Visibility limit reached at UA53 entrance after 12 minutes.
Alternative configuration	No evacuation alarm. Agents cannot detect smoke due to closed fire compartment door.	Evacuation from UA53 through alternative evacuation path in UA53. Evacuation time cannot be determined due to no detection time.	No agents are exposed to toxic atmosphere. Temperature limit not reached. Visibility limit reached at UA53 entrance after 12 minutes.

Table 8 Scenario 5 - Results

Scenario 5	Detection	Evacuation	Tenability criteria
Basic configuration	Evacuation alarm starts after 1.8 minutes.	Evacuation from UA53 to rescue chamber 2 in UR57. Has to evacuate past the fire location. Total evacuation time averages at 3.5 minutes.	Maximum FED by an agent averages at $4{,}0*10^{-4}$ The temperature limit is reach in the evacuation path close to the fire at 4 minutes. Visibility limit reached after 3 minutes. After 12 minutes the limit is reached in the side section.
Alternative configuration	Evacuation alarm after 1.8 minutes.	Evacuation from UA53 through alternative evacuation path in UA53. Total evacuation time averages at 3.3 minutes.	Maximum FED by an agent averages at $6{,}6*10^{-10}$ Temperature limit not reached. After 12 minutes, the visibility limit is reached in the side section where the evacuees started and after 15 minutes at the alternative emergency exit.

Table 9 Scenario 6 – Results

Scenario 6	Detection	Evacuation	Tenability criteria
Basic configuration	No evacuation alarm. Agents detecting smoke initiate evacuation individually. First sense of smoke averages at 7.2 minutes.	Evacuation from UA53 to rescue chamber 2 in UR57. Has to evacuate past the fire location. Total evacuation time averages at 9.0 minutes.	Maximum FED by an agent averages at $1{,}5*10^{-4}$ The temperature limit is reach close to the fire in the evacuation path at 4 minutes. Visibility limit reached at the exit of UA53 and in the side section after 13 minutes.
Alternative configuration	No evacuation alarm. Agents detecting smoke initiate evacuation individually. First detection of smoke averages at 7.3 minutes.	Evacuation from UA53 through alternative evacuation path in UA53. Total evacuation time averages at 8.5 minutes.	Maximum FED by an agent averages at $2{,}1*10^{-4}$ Temperature limit not reached. Visibility limit reached in the side section of UA53 after 13 minutes and in front of the alternative evacuation path after 14 minutes.

3.4 Discussion

The length of time simulated within the fire simulations are the main limiting factor in this analysis. The fire simulations have been done as another part of the joint project and this report has been limited to use what was simulated when this report was written. Longer simulation times would have been preferred to be able to evaluate the evacuation scenarios more thoroughly. Tenability limits are not reached several times in several parts of the facility within the simulated timespan. These scenarios, simulations and analysis should be done together with longer fire simulations to give a more complete picture when tenability limits are reached and evacuation are hindered in the entire facility.

What can be observed is that in all scenarios, visibility is the first tenability limit to be reached and that temperature or asphyxiation rarely or never reaches the tenability limits. In the presented results, the FED values reached for asphyxiating gases can be misleading if the location of the agents at the end of the simulation is not taken into account. For scenarios 2, 3, and 4 there are still occupants within the facility when the simulation time has run out. In scenarios 2, 3 and 4 it is because the agents have not detected the fire within the simulations timespan. This will lead to over time increasingly hazardous environments until the agents detect the fire and starts to evacuate. This must be taken into account when looking at the results where neither tenability limits have been reached or evacuation has been completed.

In this report, it was chosen that radiation would not be used as a tenability criterion. The placements of the fires and the interior of the facility is such that evacuees need not pass directly in view of the fire, except scenario 5 and 6. In scenarios 5 and 6 the egress path leads right past the fire but these cases are seen as unacceptable for this reason. Another reason radiation was not looked upon closer was the time constraint for this report. The time constraint and the placements of the fire was the reason radiation was not used as a tenability criterion. However, if a bigger analysis is done with longer simulation times radiation should also be used as a tenability criterion.

This report assumes the fire simulations in FDS have been modelled correctly, these have been done in another part of the joint project. Incorrect user input in the fire simulation could give incorrect results in this analysis.

Since FDS+EVAC uses randomization for a number of parameters, the results of iterations of simulations will not be identical. Simulations did occasionally show signs of a faulty representation. Agents spawning in places where they are immobilized and agents exhibit unnatural behaviour, such as not being able to change exit choices and running in circles. Since this happens irregularly could depend on the randomized placement of the agents. The social forces could perhaps have affected the agents in such a way it would result in this behaviour. Each iteration simulated was reviewed and simulations which showed these behaviours were simulated again.

For each configuration of every scenario, five iterations of the evacuation simulations have been done. This is a quite low number of iterations and to get more overall accurately results and minimize the effects of possible extreme cases more iterations is recommended. This has not been done due to time constraint and delayed delivery on results of the fire simulations.

In Appendix A uncertainty for the evacuation times is presented. This could only be done for scenarios where the evacuation time could be determined. The uncertainty ranges up to 16% but no criteria is set. More iterations should be done to set a criteria and to be able to determine and maybe lower the uncertainty.

The safety of affected personnel depends on the detection time. The scenarios and simulations as modelled do not provide detection times for cases where the evacuation alarm fails. In these cases, detection has to be done through other means for example:

- Detection of smoke by personnel
- Detection of smoke spread through the ventilation system
- Personnel entering the fire compartment
- Surface personnel detects the fire and contacts personnel in the facility
- The fire compartment door fails

FDS+EVAC has a function for agents to sense smoke and start evacuation, in scenarios 2, 3, 4 and 6 this was used. The agent will only be triggered by the smoke. In reality, an agent individual evacuation may be triggered by other personnel alerting them to the danger. For this reason, results should be evaluated for these scenarios only in terms of qualitative relative comparisons between solutions rather than quantitative results.

The function TDET_SMOKE_DENS in FDS+EVAC allowed agents to start evacuating when the smoke density reached a certain level at a set height. This was used when the evacuation alarm disabled in a scenario. The value used corresponded to a very high visibility, see Appendix C, but the idea of this function in FDS+Evac is that the agents will trigger the smoke according to when they are able to smell it. This resulted in agents “detecting” the smoke and evacuating as soon as a certain smoke concentration is reached at a set height. More research should be done on this function in FDS+EVAC as of this moment there is no recommendation how to use this function or set the values. How and when people react to the smoke density without an evacuation alarm would also be good to be able to use this function in a more efficient way. It was still used in this report to be able to simulate the scenarios without an evacuation alarm however the uncertainty of this function should be taken into consideration when viewing the results of the scenarios.

For scenario 4, where the fire compartment door is closed, the simulation does not allow smoke spread to UA53 and thus not allowing the detect function to work. For this scenario the FED agents would be exposed to had to be calculated from the situation outside UA53. This was chosen to be calculated at the end of the simulation to give a value as conservative as possible in the simulated timespan.

The simulated time given in the fire simulations were around 15 minutes which limits the scenarios to this timespan. This time does not even cover half the time it would take the fire brigade to be able to reach the rescue chambers. To evaluate the rescue chambers simulations covering its entire duration or the length of the fire should be done. This however this is more time than what this available in this project. Due to the short simulated time, no conclusion will be made in this part concerning the rescue chambers.

In every scenario the smoke curtains were assumed to work as intended. This limited smoke spread and slowed down the smoke spread well below walking speed, allowing evacuees to easily outpace the smoke front.

Scenario 5 was used to check travel times delivered by the simulations in FDS+EVAC it was compared to hand calculations. The comparison can be seen in Appendix B. A small difference was noticed but it is small enough as it is not considered to affect the conclusions. Number of doors passed by each agents is number to a maximum of two doors. The time it takes to pass these doors is also considered short enough to not affect the conclusions. The same is considered for the incline. Overall the travel time was not a deciding factor in the scenarios, most important was detection time. This is because in scenario 1 and 5 where the evacuation alarm worked evacuation could be done safely in both configurations with a considerable safety margin.

3.5 Conclusion

Scenario 7, 8 and 9 has not been simulated at all and will not be evaluated in this report due to time constraint.

Due to only 15 minutes of fire simulations were available no conclusions can be drawn on the effect on rescue chambers. The fire brigade has a response time of at least 30 minutes and including operation times and therefore the simulated time should be much longer to be able to draw conclusions on the usage on rescue chambers in this regard.

Due to the fire size and smoke curtains the smoke spread in UR57 is below walking speed within the simulated time.

Scenario 1

The results of the simulations of the first scenario show a detection time of 2 minutes which gives more than enough time to evacuate to the safe-area at the shaft, to either a rescue chamber or to an alternative emergency path depending on the configuration. With properly functioning smoke curtains, the simulation shows the smoke is contained and it takes more than three times the time of evacuation until any tenability limit is reached in the section where the fire starts. No evacuation would be hindered within the simulated time. The tenability limits were not reached anywhere but the section where the fire is located.

Scenario 2

The simulated time is not enough to see when or if evacuation from UA53 to rescue chamber 2 would be hindered. Only persons in UR57 detected smoke depending on their location within the fire compartment. The detection time varied between 1,2 minutes to not at all within the 15 minutes simulated. Persons detecting smoke would in reality alarm other personnel to evacuate as well, either through triggering an alarm, over radio or in another manner. If there were no people in UR57 or too far away the fire would not have been detected and no evacuation triggered. This could lead to personnel becoming trapped in transversal galleries as smoke spreads without any evacuation is triggered. The tenability limits were reached only in the section the fire is located and one next to it during the simulated timespan.

Scenario 3

The tenability limits for evacuation to rescue chamber 2 from UA53 was reached at minute 13. Agents located close to the exit of UA53 perceived smoke from 6 minutes up to over 15 minutes depending on their location. Agents placed in the back of the UA53 and the side section did not sense the fire within 15 minutes. In this scenario, safe evacuation can only be achieved if an agent is close to the open door. This cannot be guaranteed and therefore safe evacuation cannot be guaranteed in the basic configuration. In the alternative configuration tenability limits were never reached at the emergency exits. Although not within the simulated time agents will probably sense smoke and evacuate before tenability limits are reached. The open door increases the chances of earlier detection of smoke by personnel but compromises UA53 to smoke spread.

Scenario 4

The tenability limits for evacuation to rescue chamber 2 from UA53 was reached at minute 12. Since detection in this scenario could not be simulated it is unknown if the personnel in UA53 evacuates in time. If the personnel in UA53 do not detect the fire within the time before the tenability limits is reached they must either stay in UA53 or travel through unacceptable environment to reach rescue chamber 2, neither is acceptable. The closed fire compartment door will prolong the time which personnel can stay in UA53 but decreases the chances of the personnel detecting smoke. The alternative configuration allows evacuation without entering any hazardous environments.

The detection time in this scenario is 1.8 minutes. This gives time to evacuate safely in the alternative configuration. In the baseline configuration however although the time is more than enough another problem arises. The fire is located in the path for evacuees trying to leave UA53. There may be possibilities to move around equipment to avoid the fire but this is not known and evacuating towards and past the fire cannot be recommended. It is also impossible for the fire brigade to arrive before the tenability criteria in the entire UA53 due to at least a 30 minutes' response time. In the baseline configuration in this scenario the personnel must be able to pass the fire or extinguish it and neither can be guaranteed.

Scenario 6

Scenario 6 plays out the same way as scenario 5 with one exception. The emergency alarm fails and personnel does not detect the smoke until after 7 minutes. Evacuation to the alternative emergency paths are still done before tenability limits are reached. In the basic configuration, the agents take a minute longer to evacuate but the agents evacuates past the fire and through an area where the tenability criteria are reached.

4 Literature review: Rescue Chambers

Over the years increased safety thinking has increased the demand of safer work environments. The use of safe-areas in underground work environments in the form of refuge alternatives increased. Rescue chamber, refuge chamber, safe haven, rescue capsule, there are many different kinds and names but they are all made for the same reason: to create a safe area for occupants who cannot evacuate themselves. Refuge alternatives allows evacuees to take shelter until rescue services can evacuate them. This kind of safe-areas are mainly used in mines and in construction sites underground but is also used in finished underground areas as an alternative to self-rescue. These kind of safe-areas can be either fixed in place or in form of a mobile chamber. This literature review aims to gather and compile information on the mobile chamber type.

4.1 Definition and Scope

There are many terms of what different safe-areas are called. This project focuses on mobile chambers. A mobile chamber is most often referred to as a rescue chamber or a refuge chamber. The term refuge chamber is the most common used term but the term is also used to describe fixed types of safe-areas. Because there is no unity in terming safe-areas in general there is a high possibility for confusion and misunderstandings when discussing safe-areas. This report will use the term rescue chamber as a term to include all types of mobile chambers.

In this report the definition of a rescue chamber is one used in *Underground mine Refuge Chamber Expectations* Training:

> *"Refuge chambers are movable chambers that are either made of steel or have tents that inflate from a steel skid."* (Margolis, K.A., 2010)

Safe-areas which are in its own an excavated area or has not an internal atmosphere and demands the use of breathing apparatuses will not be a part of the analyse. This report will only look at frigid constructions of chambers and not the inflatable variant.

The term refuge alternative will be used as a collection name for all variants of this type of alternative to self-rescue.

The term self-rescue is used for when occupants can evacuate themselves to a safe area outside without the help of fire brigade or refuge alternatives.

In much of the referenced work the term refuge chamber will be used instead of rescue chamber, but as the term refuge chamber has been found to mean different things in different sources it is not to be equalled to a rescue chamber if not referenced as such. Many of the research done does not identify what kind of refuge alternative is being researched. Where this is the case only information which is relevant to rescue chambers or refuge alternatives in general will be used.

4.2 Regulations

Regulations and guidelines vary between countries when it comes to the implementation of rescue chambers. This section summarizes Swedish and international regulations and guidelines. In this section the terms used are the ones used in the mentioned work.

International Regulations

Refuge chambers in underground metalliferous mines (Department of Industry and Resources)

Western Australia guidelines for refuge chambers in underground metalliferous mines. General guidelines covering most areas of refuge alternative use. Uses the term mobile refuge chamber for rescue chamber.

(Department of Industry and Resources, 2005)

Refuge chambers in underground mines (Government of Western Australia Department of Mines and Petroleum Rescources Safety)
Western Australia guidelines for refuge chambers in underground mines. General guidelines covering of refuge alternative use.

(Department of Mines and Petroleum, 2013)

DACH document - Recommendations for an occupational health and safety concept on underground worksites
Recommendations from German speaking work group D-A-CH.

- Germany: D-DAUB (Deutscher Ausschussfür unterirdisches Bauen (German Committee for Underground Construction)
- Austria: A-FSV (Österreichische Forschungsgemeinschaft Straße – Schiene – Verkehr (Austrian Association for Research on Road, Rail and Transport))
- Switzerland: CH-SIA/FGU (Fachgruppe für Untertagbau (Technical Committee for Mining))

The term emergency cabin used in this document fits this reports definition for rescue chamber.

The protective cabin which is described is not evaluated in this report as it is outside its definition of rescue chamber.

(DACH, 2007)

Final Rule (2008) for Refuge Alternatives for Underground Coal Mines of the US Mine Safety & Health Administration (MSHA)
Final rule sets forth requirements and training for refuge alternatives in underground coal mines. This includes testing, transport, maintenance, inspection and approval in the US. Only general parts for refuge alternatives are used as no direct description fits this report's definition of rescue chamber.

(MSHA, 2008)

NFPA (National Fire Protection Association) 520 Standard on subterranean spaces 2016
US standard for subterranean spaces. General standards for refuge alternatives are evaluated but the specific refuge chamber in the document does not fit this reports definition of rescue chamber.

(NFPA 2015)

Swedish regulations

According to *Fire incidents during construction work of tunnels* (Haukur Ingason, 2010) there is three AFS, Swedish workplace regulaions, which are relevant to underground construction at work. The general AFS regulation Workplace design (AFS 2009:2), which will not be looked into here.

AFS 2010:1 Rock work (Berg och gruvarbeten)
Swedish regulations on rock work which includes underground tunnelling, construction and mining.

(AFS, 2010)

AFS 2010:1 is summarized in *Fire incidents during construction work of tunnels*.

(Ingason, H., 2010)

AFS 2007:7 Breathing apparatus operations (Rök- och kemdykning)
Swedish workplace regulations on the use of breathing apparatus during operations in hazardous environments.

(AFS, 2007)

SveMin 2009 - Fire prevention in mines and rock workings (Brandskydd i gruv och berganläggningar)
Swedish guidelines for fire protection in mines and underground facilities.

(SveMin, 2009)

4.3 Past incidents

This section summarizes past incidents where rescue chambers or refuge alternatives have played a part in the evacuation.

Paris ring road tunnel, France

The A86 ring road tunnel in Paris is a two level tunnel for vehicular traffic, one level for each direction. A fire broke out during construction of the tunnel on a supply train the 5th of March 2002. After unsuccessfully trying to extinguish the fire 19 workers fled to a rescue chamber. The 19 workers were evacuated from the rescue chamber with the help from the fire brigade and breathing apparatus. The fire was not extinguished yet by the time workers were evacuated.

(Ingason, H., 2010)

Missouri lead-zinc operation, USA

According to *Fire incidents during construction work of tunnels* Tattoo magazine reported that a fire had broken out in a truck at lead-zinc mine in USA on January 21st 2010. Of 16 workers all but three successfully evacuated. The three miners escape route were blocked and instead they used their mining equipment to travel 730 m to a designated refuge chamber. A 176 m deep ventilation shaft was used by the fire brigade to enter from the surface. The fire and rescue team travelled around 426 m to locate the refuge chamber occupied by the three miners. It had then been more than 5 hours since the fire started. The miners were evacuated with the aid of a rescue escape hoist.

(Ingason, H., 2010)

Mont Blanc Vehicular Tunnel Fire, France and Italy

On the 24th of March 1999 a truck caught fire in the Mont Blanc tunnel between France and Italy. The fire escalated and resulted in 39 deaths. The fire in the tunnel lasted for over 50 hours and quickly produced black and very toxic smoke.

There were several refuge within the tunnel but only two of the victims had sought shelter in these. However, several fire fighters and other personnel sought shelter in these. In the Mont Blanc tunnel there were no safety corridor attached to the refuges and no evacuation path for those in there. Only by using ventilation ducts and dangerous operation by the fire brigades, people trapped in the refuges, were rescued. 14 fire fighters were hospitalized for their work and one died because of the injuries. The two people who died in a refuge close to the fire would have survived if a safety corridor was connected to the refuge.

The majority of the victims did not go for the rescue chambers but stayed in vehicles or probably tried to make it to the tunnel entrance. Past experience suggest the passengers would have not made it to an emergency exit without guidance from personnel.

(Duffé, P. 1999)

"All the French and Italian firefighters experienced great hardship with their response: almost no visibility, extreme heat, and great difficulty with airpacks in a very hot environment. The status report mentioned the need for training before using this type of equipment, and the fact that the ATMB breathing devices were not compatible with those of the firefighters. In general, all the team leaders have insisted that this kind of response requires a high level of physical and psychological strength, in addition to special training. "(Duffé, P. 1999)

"Refuge areas were therefore chosen for the Mont Blanc Tunnel (every other rest area). They were not connected to fresh air ducts for the evacuation of users, probably because that would have required significant rock excavation with explosives and an extended tunnel closure.

On the other hand, the reversible supply/exhaust duct may be used, but only in difficult and uncertain conditions, as a safety room, as long as no smoke is exhausted at that time. On the Italian side, this allowed the evacuation of the firefighters trapped in the refuge area of rest area 24. On the French side, it allowed the partial progress of Captain Comte, who came to rescue the other Chamonix firefighters trapped in the tunnel. It did not, however, allow their evacuation, nor that of the ATMB agents trapped in rest area 17, for it was too filled with soot, brought in by the fresh air ventilation, as a result of its previous function as exhaust duct." (Duffé, P. 1999)

4.4 Performance and Limitation

There are many different variations of rescue chambers by different specifications from many different manufactures. Therefore, only general recommendations and guidelines will be presented here. When choosing a rescue chamber technical specifications and limitation should be evaluated to fit the proposed use. The areas which has been chosen to be examined is presented below. These are areas are covered in most if not all regulations found. They were deemed relevant to this literature review as they are applicable to rescue chamber or refuge alternatives at large.

Sustainability

An important aspect is the availability of fresh air and other services in the rescue chamber when it is cut off from outer supplies. The DACH documents (2007) recommend a period of at least 24 hours within a fully occupied rescue chamber. Australian guidelines from the Department of Industry and Resources (2005) and the Department of Mines and Petroleum (2011) recommend a period of 36 hours to ensure fire brigades have enough time to reach and evacuate the rescue chamber safely. Swedish guidelines from SveMin (2009) state rescue chambers should be designed to have breathing air for at least 4 hours in mines.

Chamber location

To make rescue chambers a viable option as an alternative to evacuation it is important for the rescue chamber to be located correctly. It should be in reach for relevant evacuees and reachable by the fire brigade to ensure evacuation within the chamber operation span.

The distance from the workplace to closest safe-area in Swedish regulation AFS (2010) is a maximum of 200-300 meters but it also states it depends on several other factors, such as gradient of the location, distance to escape route, distance to surface exits, etc., which should also be taken into account.

In the DACH documents (2007), a cooperation between Germany, Austria and Switzerland, the maximum distance of 500 m to a safe-area is recommended.

The US MSHA (2008) on the other hand sets a maximum travel time of 30 minutes instead of a distance. NFPA 520 for subterranean spaces from NFPA (2015) sets a maximum distance of 610 meters.

The Australian guidelines from the Department of Mines of Petroleum (2013) state that the maximum distance should be assessed based on how far a person, in reasonable state of physical state at normal walking pace can travel using only 50% of their personal breathing apparatuses nominal duration. This gives a more direct approach to calculate the location specific distance which should be acceptable. This is however only applicable where breathing apparatuses are in use.

The distance the fire brigade can travel depends on the specific fire brigades' capabilities, the layout of the area and the situation. This is discussed more in section 4.7.

Another part of placement is the proximity to other things which may compromise the rescue chamber and/or hinder evacuation to and from the rescue chamber. In Australian guidelines from the Department of Mines of Petroleum (2013) it is stated that since the rescue chambers are seen as safe-area their placement should be secured from hazard as much as possible. Potential hazard that should be considered when choosing the placement are fire, explosions, rockfall, flooding or damage from vehicles or equipment. It is also important that the accessibility is not hindered by the placement of the rescue chamber or by equipment or vehicles. It is important that rules for maintaining the area around the rescue chamber are made and upheld. Furthermore, in *Research Report on Refuge Alternatives for Underground Coal Mines* from NIOSH (2007) it is suggested that rescue chambers should rather be placed in a dead-end made specifically for this use or someplace off the main access way. The placement should also avoid potential fire sources. Swedish regulations AFS (2010) states that potential fire loads or vehicles should not be placed in such a proximity as a fire there may compromise a rescue chamber. In the DACH documents (2007) it is also stated that fire loads must be stored at sufficient distance from rescue chambers (emergency cabin) that principally is not designed to protect against direct heat or fire.

Chamber status

According to guidelines in Western Australia from the Department of Industry and Resources (2005) and the Department of Mines of Petroleum (2013), rescue chambers will operate under three different statuses. Communication to and from the rescue chamber must be active at all times and statuses.

Stand-by

Stand-by is the default status when there is no emergency. Several key systems are offline to not exhaust resources but the chamber can be activated immediately in case of an emergency.

Externally supported

The rescue chamber is active and is supplied air and water by an external source, either from the underground facility's own system or through an independent system from a borehole.

Stand-alone

The stand-alone status will start in when the rescue chamber has to be completely disconnected from external support. The stand-alone status has to provide independent life support for occupants within the chamber for at least the duration it is rated for. The rescue chamber must be able to deliver on following services to reach basic requirements during the status: a safe atmosphere, an independent power source, drinking water and maintaining the atmospheric conditions at a safe level.

4.5 Physiological and Psychological Aspects

The physiological and psychological aspects of the implementation of recue chambers are important to achieve the functionality sought. The evacuees must both be able to use the chambers in a correct manner and to actually use them when an emergency arises. In *Underground mine Refuge Chamber Expectations Training* by Margolis, K. (2010) the following issues of chamber use are discussed as support for designing training for the use of rescue chambers.

Physiological

The physiological part of rescue chambers can be split in two parts, operation and occupancy. The occupancy part is the physiological stress which will affect the body by being inside a rescue chamber for long periods of time. Margolis, K. (2010) states that the occupants will face a rather cramped spaced were they could mainly only sit and in an environment that can become unpleasant depending on the outside conditions. This is when the outside conditions are still within the limitations of a rescue chamber. Remaining seated for long periods can lead to several medical risks depending on age and fitness.

The environment inside the chamber can become both very hot and humid which is a stress on the body if endured during a longer time span. Physical discomfort will also put more stress into an already psychologically stressful situation.

The second part is operation. Personnel which will use the rescue chambers has to be able to operate the rescue chamber correctly. This part will be gone through more closely in 4.6 Training and Maintenance.

Psychological

Being in an emergency is often a stressful and demanding psychological environment. This combined with being underground and evacuating to a rescue chamber instead of to the surface could be psychologically hard. The first and most important part is if the personnel will use rescue chambers as an alternative to evacuation out from the facility. According to *Report of the Task Force for Technical Investigation of the 24 March 1999 Fire in the Mont Blanc Vehicular Tunnel* by Duffé, P. (1999) passengers in tunnel fires will not seek emergency exits if not guided by personnel. In the report *Refuge Stations/Bays & Safe Havens In Underground Coal Mining* by DJF Consulting Limited (2003) the following is stated

> *"The natural instinct of a miner in such an emergency situation is to 'run' and get to safety as fast as possible (e.g. a fresh air base or the surface) and is normally the best thing to do."*

Although in this case it is not miners but one can guess that the natural instinct of most people when faced with an emergency underground is to get back to the surface. To encourage evacuees to use rescue chambers when appropriate several steps can be taken. In *Validate the design of a rescue chamber* by Andreé, K. (2013) the issue of making the rescue chamber design more inviting is handled, such as a green door is preferred over a yellow one. However, in *Underground mine Refuge Chamber Expectations Training* by Margolis, K. (2010) clearly pinpoints training and information is a big part to get miners to use rescue chambers. For visitors, passengers and other non-personnel it is important that trained personnel instruct such groups to use refuge alternatives and assist them during the emergency. More on training in section 4.6.

When evacuees are using the rescue chambers in emergencies another set of psychological factors will be influencing the occupants. Using a rescue chamber will put the occupants in a cramped environment. Even with sufficient supplies being in a cramped environment for a long period of time and in combination with the physiological discomforts it can be a highly stressful environment according to Margolis, K. (2010).

> *"However well-designed a refuge chamber is, those inside are inevitably going to experience some negative psychological effects because of the situation."* (Margolis, K. 2010)

This quote clearly describes on one of the problems using refuge alternatives.

4.6 Training and Maintenance

While researching the use of rescue chambers and refuge alternatives training came up many times and was noted to be one of the most important aspect when having rescue chambers or refuge alternatives instead of self-rescue. E.R. Bauer suggests that training in the use of rescue chambers is necessary and in combination with rescue plan for rescue chambers to be potentially lifesaving. NIOSH (2007) comes to the same conclusion that training is critical for correct use. Operation and maintenance, expectation of use and escape and rescue procedures are three areas identified were training is needed. The US MSHA (2008) says that refuge alternative training should be incorporated into existing evacuation drills and training both quarterly and annually. Miners should also be trained to maintain and repair refuge alternatives.

In *Underground mine Refuge Chamber Expectations Training* Margolis, K. (2010) it is pointed out that while it is important to training how to operate the rescue chamber it is also important to train personnel for both the physiological and the psychological impacts of using a rescue chamber during an emergency. This is especially important as usage of rescue chambers can have several physiological and psychological effects which can affect the occupants negativly. It is important they are aware of these effects and know how to handle them.

Since it has also been occasions were chamber alternatives has not been used or been passed by accident as mentioned in *Validate design of a rescue chamber* by Andreé, K. (2013) and *Refuge Stations/Bays & Safe Havens In Underground Coal Mining* by DJF Consulting Limited (2003) it is important for the people in question to know when they shall use them, how they shall use them and where the chambers are located. Also important is what signs to look for to be able to locate a chamber in unideal conditions. Operation of rescue chambers should according to *Research Report on Refuge Alternatives for Underground Coal Mines* by NIOSH (2007) be trained every quarter and if possible in combination with evacuation training and drills.

To have the rescue chambers as a permanent part of evacuation procedures it is important maintenace is done regularly and throughly. In *Research Report on Refuge Alternatives for Underground Coal Mines* by NIOSH (2007) it is stated that proper maintenance and inspections are necessary for refuge alternatives to fulfill their purpose. The Western Australia guidelines from the Department of Mines and Petroleum (2013) states rescue chambers should be ready at all times and suggest an rigorous regime for inspection and maintenance to ensure dependable use.

Keeping rescue chambers maintained will results in both an initial cost and an annual cost. *Research Report on Refuge Alternatives for Underground Coal Mines* by NIOSH (2007) puts a five year annual cost around 20000 US dollars without the cost of moving the chamber. Other than this there will also be costs from regular inspections and training for personnel.

4.7 Fire and rescue services

Kumm, M. (2010, 2013) has done much research on rescue and fire services in underground environments such as tunnel construction and nuclear technical facilities. According to her underground tunnels are in general a difficult task due to both long escape routes and long response times. Tunnel construction is also seen as a complex environment which makes demands on knowledge of the fire brigade. Adaptability is important as there are often unknown parameters affecting the fire which cannot be determined from the outside at arrival. These kind of operations often demands special equipment and resources.

Kumm, M. (2010) points out that self-rescue is always preferred and rescue services should be seen as a compliment to be used when self-rescue is not possible.

Tunnel construction usually provides a harder evacuation scenario before breakthrough as there is only one egress path from the excavation front. At this stage it can be compared to a mine with a moving working face and possibly long evacuation path. Kumm, M. (2013) also found a problem with long evacuation path in nuclear technical facilities. In the same report and in *Rescue operations during construction of tunnels* Kumm, M. (2010) states that rescue chambers or other refuge alternatives are used to compensate for the lack of evacuation paths.

This means the fire brigades often are operating in special environment when coming in contact with rescue chambers. Operation wise the fire brigades can choose an offensive strategy or a defensive strategy. During a fire incident underground there are several tactical approaches for the fire brigade to use. In *Fire incidents during construction work of tunnels* by Ingason, H. (2010) Kumm, M. lists the five following approaches is presented as the fire brigades options during a fire incident at a tunnel construction.

1. Fight the fire from the inside of the tunnel, with the purpose to put out the fire and by this save people in danger.
2. Assist or rescue the people in danger from the inside of the tunnel and take them to a safe environment.
3. Control the airflow in the tunnel in order to take the smoke away from the people in danger or to support the firefighting operation [31]
4. Fight the fire from a safe position to reduce the consequences of the fire.
5. Treat and take care of the people that without assistance rescued themselves to a safe environment.

When rescue chambers are in use fire brigades will be forced depending the situation within the facilities to choose different approaches. Since the rescue chambers has a limit both in time and integrity the fire brigades are forced to choose a strategy where reach trapped occupants and evacuate them or extinguish the fire before the rescue chamber's limitations is reached.

In Sweden operations which needs breathing apparatuses are heavily regulated and is mainly not to be done if not for life saving purposes. However, breathing apparatus operations can also be done after a risk assessment to save assets according to Swedish regulations AFS (2007). If rescue chambers are in use and occupied breathing apparatus operations can be done in order to evacuate these. In Swedish regulations AFS (2007) it is also specified that a risk assessment should be done before sending rescue crews into a dangerous environment.

Kumm, M. (2010) argues the length of possible insertion depends on equipment, training and situational parameters such as visibility, aid, resources and individual physical capacity. Fire brigades can only move a certain distance from a safe-point, limited by fresh air supply and movement speed. Kumm, M. (2010) says transportation speed for fire brigades varied from 0,05 to 1.5 m/s depending on situational parameters in test for tunnel insertion. Long distances limits work time for the rescue services or even prevent them from reaching personnel in need of rescue. Also any evacuees must be taken back the same way. Kumm, M. (2013) makes the conclusion that when using compressed air in breathing apparatuses it is hard to reach further than 300-500 meters without the usage of vehicles.

As Kumm, M. (2013) states rescue chambers are only viable alternative to evacuation if the fire brigade can reach and evacuate the occupants before the chamber is compromised or runs out of air. Since fire brigades has limitations on their work it is important they are consulted in the placement and limitations of rescue chambers before they are put in use to ensure they are a safe alternative.

It has been shown that the believed distances the fire brigades can travel is often longer than the real counterpart, this is mentioned by Kumm, M. (2010). This shows that there is often high faith in the fire and rescue services abilities but the problematic environment of underground tunnels is also underestimated.

Concerning underground nuclear technical facilities when asked by Kumm, M. (2013) both Swedish and international fire brigades wished for more orientation and practices with the kind of environment

4.8 Discussion

Rescue chambers and in extension refuge alternatives are a hard subject to gather information on. The naming and definition are the biggest issue when trying to compile information. Not only do naming differ between countries but also within them. There are multiple names for the definition of the same solution which in itself is must not be a problem, but when the same names are used to describe something different in another work it starts to become one. Multiple names are also used as both an overall name for refuge alternatives and for a single type or variant of a refuge alternative. This could still be solved if there were clear definitions what is investigated in each work but this is more often not the case. When there is no definition of what is research or discussed in a work, and with the naming situation as it is, it becomes detective work to try to figure out what the terms stands for. This is something which often cannot be done and severely limits the ability to compile information in an accurate way. There is a need to make clear definitions on the terms used for refuge alternatives. This is needed to avoid misunderstandings and make it easier to compare and compile information from different sources. It is also important that translations done to English use the correct terms and not direct translations. There are probably many reasons contributing to this problem and in this literature review a number of things which seems to contribute has been noticed.

When trying to review performance specifications and limitations on rescue chambers, the lack of definitions is a big problem. It is also important to notice that although there are recommendations and guidelines, it does not seem to be any regulations on performance standards for rescue chambers. Regulations, recommendation and guidelines differs in different countries on many areas. That rescue chambers should only be used when self-rescue is not possible, is however a common denominator.

There are many differences in regulations and guidelines when it comes to location, egress distance and sustainability. The length of distance differs in different countries but more interesting is that some countries set a specific length while some countries sets a travel time based on movement and breathing apparatuses. To use a travel time is more adjusted to the specific location as it will take into account the complexity and environment of the location but also the equipment used by personnel. However, this is not as appropriate if the evacuees do not have personal breathing apparatuses or is unfamiliar with the layout. The evacuees could be prevented by smoke from traveling the preferred route or not know the way to the closest chamber, thus rendering the measured travel time useless. Using a distance, as most countries seems, to do not take the location specific environment into account which can give different travel times although the distances is the same.

Three of the most important aspects according to several sources are training, maintenance and inspections. The need for maintenance and inspection seems pretty clear as a rescue chamber is an alternative for evacuation and if it is not properly maintained it puts human lives at risk. Training is however an area where there are several areas. Operational training is vital for personnel to be able to use a rescue chamber properly. It is also important to have personnel guiding non-personnel to rescue chambers. This is important as non-personnel tend to not use refuge alternatives as mentioned in the Mont Blanc report by Duffé, P. (1999). Research on both the physiological and psychological parts of refuge alternatives states according to Margolis, K. (2010) that beyond the operational training it is important to also have training on the physiological and psychological effects. If non-personnel in emergency will use the refuge alternatives, it should also be important that personnel can prepare them and assist them during an emergency stay in a refuge alternative. Training on the psychological and physiological stress using a rescue can result in is not covered in regulation. It is mentioned in some of the guidelines as the Australian *Refuge chambers in underground metalliferous mines* from the Department of Industry and Resources (2005) but not in the Australian *Refuge chambers in underground mines* from the Department of Mines and Petroleum (2013) and several others. This could be a sign as these aspects have not yet been given much attention as they should.

As can be seen in earlier incidents there are cases where refuge alternatives have been used successfully as an alternative to self-rescue. In both the cases shown in this review the trapped workers were evacuated with the help of fire brigades before the fire was extinguished. In both of these cases it was possible to circumvent the fire or not pass it to extract the evacuees. In the Mont Blanc case it was not possible to do this for all refuges and as a results two people died trapped in a refuge. Even in the cases where the fire brigades were able to evacuate refuges it was a dangerous operation and several firefighters were hospitalized from injuries sustained. Although these refuges were not rescue chambers it shows that there should be more than one way to reach a refuge alternative to ensure evacuation. It should be noted that the fire in the Mont Blanc tunnel lasted more than 50 hours according to Duffé, P. (1999) which is longer than many rescue chambers are built for.

Since the usage of refuge alternatives is dependent on the intervention of a fire brigade it is important that the relevant fire brigades are consulted before using refuge alternatives as evacuation alternative. Another important point is that underground areas such as mines, construction, tunnels and others are complex environments that fire brigades rarely operate in and often feel to be lacking in training and experience. For example, the study done by Kumm, M. (2013) shows an unanimous feeling of needed for more training in that kind of environments internationally. Training is also important to avoid situation as in the Mont Blanc tunnel where fire fighters became trapped in refuge area and need to be rescue themselves.

Swedish guidelines by SveMin (2009) states that the installation of rescue chambers should be preceded by a risk assessment.

4.9 Conclusion

What can be drawn from this literature review is there is a need for cooperation in naming and definitions around all types of refuge alternatives not only rescue chambers.

Rescue chambers or other refuge alternative can be a valuable asset in securing safe underground environments if they are used in a correct way.

For rescue chambers to be considered a safe evacuation options several steps should be taken considering location, equipment, training and maintenance to ensure it is able to sustain a safe environment during its duration.

Fire brigades are important when using rescue chambers as evacuation alternative and should be part of the implementation process, updated on the environment and able to perform evacuation of the rescue chamber within the chamber duration.

Safe evacuation by self-rescue is always preferred.

4.10 Future studies

- Definition and naming for refuge alternative terms.
- Usage in underground environments other than mines and construction sites.
- Limitations concerning fire protection and other hazards. Safe distances to hazard sources when selecting rescue chamber location.

5 Discussion Case-study

The analysis of the simulated scenarios was limited by several scenario simulations not being able to set detection times. As discussed in chapter 3 the lack of a detection time limits the use of FDS+EVAC. The conclusion of the analysis shows that although evacuation when possible can be done safely if the fire is detected, problems arise with evacuation when personnel get trapped, in these scenarios it is in UA53. This risk can be reduced by using the alternative configuration instead of the basic configuration, the alternative configuration shortens the dead ends beneath acceptable lengths according to French labour law. Scenario 5 and 6 shows that in the basic configuration the only egress path to self-rescue or to a rescue chamber can be blocked by a fire within the occupied fire compartment. The simulations of these scenarios also shows that if this fire cannot be extinguished by the personnel the fire brigade will not arrive in time due to the long response time.

The assumed low occupancy number and layout makes queues improbable. This combined with a slow moving smoke front due to smoke curtains and compartments ensures evacuation can be done safely if the egress path is clear. In some areas however, where there is only one egress path and a fire can still hinder evacuation if the single egress path is blocked by fire or smoke.

The implementation of rescue chambers in the two new facilities is surrounded by a lot of unknowns. Rescue chambers are usually used in mines or underground construction sites and the majority of reports and majority of the research done on the subject are focused on these environments. Although there are similarities with the CERN proposed usage, there are still many differences. Much of the information found cannot be directly implemented on this particular case. Much of the information is for the special environments of mines and underground construction sites. Another problem is the confusion around definitions and usage of terms, which has been pointed out in section 4.1 and 4.8. This adds to the problem of finding and incorporating the findings to the particular CERN case.

The proposed locations of both rescue chambers places them close to possible fire loads. This is more noticeable for rescue chamber 1 placed in the middle of UR57 as it will be surrounded by equipment. As said in the literature review Australian guidelines recommends rescue chambers to be secured from hazards. Swedish regulations say potential fire loads should not be placed in proximity of a rescue chamber. In the DACH document (2007), it is stated that fire loads must be stored at sufficient distance from rescue chambers (emergency cabin) that is not designed to protect against direct heat or fire. Placing the rescue chamber close to potential fire sources can compromise the safety of the rescue chamber. To be able to place the rescue chambers away from potential fire loads additional excavation should be made to house the rescue chambers which NIOSH (2007) suggests should be done for rescue chambers. That additional excavation is however beyond the proposed configuration. A study done by Zhao Huanjuan (2012) suggests that structural integrity due to blasts or shockwaves will not compromise a chamber. There are also few blast risks and rescue chambers should be structural blast proof.

A problem which arises in UR57 is the distance from a safe point to the rescue chambers. Without compartmentalization in UR57 the distance to rescue chamber 2, at the end of UR57, will be 300 - 350 meters depending on if the fire brigade chooses to have one or two fire doors to secure the safe point. During a meeting, CERN fire brigade stated the primary choice is to have two doors to secure the safe point from being compromised if one seal breaks. This will put the distance at 350 meters in the baseline configuration, which according to the fire brigade is not a safe distance for them. This distance is also longer than the distance recommended by the Swedish regulations, which is 200-300 meters, but falls within range recommended by Australian, US and DACH countries recommendations.

The installation of rescue chambers affects the facility and personnel in maintenance, testing and training aspects. A rescue chamber needs an external source of fresh air as not to force the chamber into constant stand-alone mode, which will drain resources and increase maintenance. Fresh air for rescue and refuge chambers are usually provided either through a borehole from the surface or through internal ventilation. A borehole is not probable at the CERN facility as surface impact should be kept to a minimum. Fresh air through the internal system is the more probable approach. This will however make the external air supply to the chamber less reliable and the manufacturer chosen will have to be consulted on connecting the rescue chambers to internal ventilation. The rescue chambers must be clearly marked within UR57 as to be visible even with low visibility conditions.

Installing rescue chambers will require an annual cost in maintenance and inspections after the initial cost. Having rescue chambers as an alternative evacuation path also puts new demands on training. As mentioned in the literature review under Training and Maintenance, training procedures should not only focus on operation of the rescue chambers but also the physical and psychological aspects of occupying a rescue chamber during an emergency. This training should be repeated regularly and can become troublesome as there would not be any personnel in the facility during most of the time. This means when a short stop occurs, personnel will have to repeat training before entering the facility. As short stops can be as short as only a couple of hours and a many people may need to work within the facility, repeating training will shorten work time. This can increase the probability of preparation and training to be rushed or skipped, which would be unacceptable. Inspections and maintenance would also have to be done on the rescue chambers regularly to ensure their functionality.

One of the main reasons of using rescue chambers in mines and underground construction is because creating secondary evacuation paths is problematic. A combination of the distance to the surface and having a moving front makes it difficult and economical expensive to always have alternative evacuation paths to the surface. Therefore, rescue or refuge alternatives are needed to secure the safety of workers. At the CERN facility this is not the case. This facility will have a permanent layout with no moving front that would create new dead ends. Long distances to the surface are also not a problem with the alternative configuration as the new evacuation paths are connected to the LHC instead of to the surface. In the basic configuration the rescue chambers are necessary as an alternative to evacuation but may not be appropriate.

The fire brigade is vital for the usage of rescue chambers. Rescue chambers have limitations of both integrity and time. This means the occupants must be evacuated by the fire brigade before the limitations are reached. Since fire brigades has limitations on their work, it is important that they agree in the placement and limitations of rescue chambers before installation to ensure they are a safe alternative.

The CERN fire brigade has a response time of at least 30 minutes to Site 5. The facility with the basic configuration has only one access/egress path which is the surface shaft. This means that the fire brigade has no possibilities to evacuate any occupants on the far side of a fire and the occupants there will not be able to evacuate by themselves. This also puts the fire brigade on a time constraint and limits them to offensive methods to fight a fire if there is an occupied rescue chamber on the other side of the fire. Another problem is the length of the UR which is one long compartment. The distance from a safe point to the far end of the facility will give the firefighters less time to work before they will have to move back to a safe-point. This will make offensive tactics in the other end of the facility more inefficient and time costly.

Kumm, M. (2010) also points out that self-rescue is always preferred and rescue services should be seen as a complement to be used when self-rescue is not possible.

The rescue chamber design proposed by CERN is shown below in Figure 8.

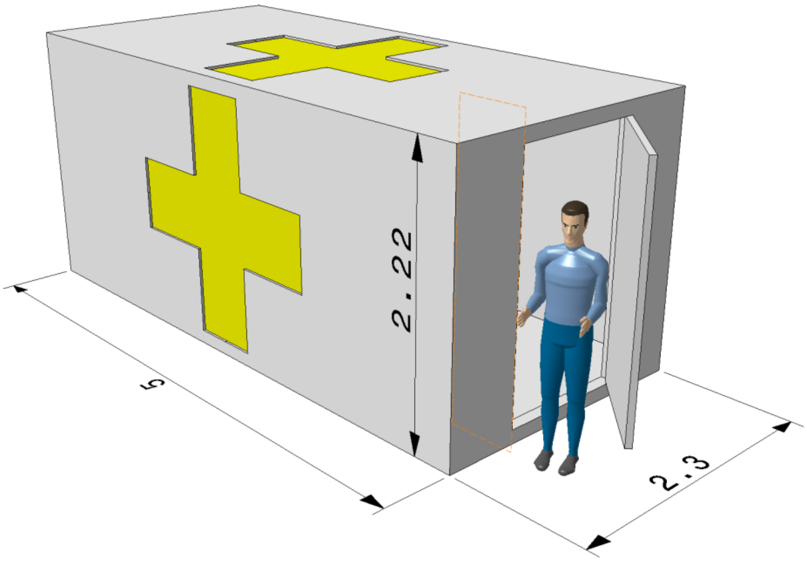

Figure 8 Proposed Rescue Chamber Design. Used with permission from CERN.

This thesis is a part of a larger joint project and has been dependent on results from other parts of the joint project. This has limited the possibilities of this report. Most importantly the fire simulations done in FDS which is used as base in the analysis took both much longer time to make and simulate than expected. The results from these simulations were delivered much later than planned and put a severe time constraint on the work which could be done in the analysis before deadline. The simulated timespan was also much shorter than what had been planned for. This limited their usefulness and limits the results from the analysis to the timespan simulated in the fire simulations.

6 Conclusion

The case-study at CERN has two proposed configurations, the basic configuration and the alternative configuration. The alternative configurations give several advantages the basic configuration do not.

- Shortens dead-end tunnel and reduces the chance of personnel becoming trapped without an egress path.
- Gives the fire brigade more than one access/egress path during an operation in the facility.
- Eliminates the use of rescue chambers and thusly eliminates the problems associated with rescue chamber usage and placement.
- Allows the fire brigade to focus on extinguishing the fire in a safe manner as all personnel should be able to self-rescue.
- If not all personnel can evacuate by themselves for some reason the fire brigade has the possibility to circumvent the fire for rescue operations due to the many access paths.

Advantages of the basic configuration.

- No need for more excavation to the LHC
- No evacuation through the LHC, a possibly radioactive environment even when it is acceptable for evacuation.

7 Future Studies

- Integrity and placement of rescue chambers
- Evacuation to radiation affected environments
- Longer and more complex simulations on the case-study with more iterations

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I. Appendix A

Iteration results for evacuation simulations

Table 10 Scenario 1 - Iteration results

Detection [min]	Scenario 1 Basic	Scenario 1 Alternative
Iteration 1	2	2
Iteration 2	2	2
Iteration 3	2	2
Iteration 4	2	2
Iteration 5	2	2
Average	2	2
Evacuation time [min]	Scenario 1 Basic	Scenario 1 Alternative
Iteration 1	4,5	4,3
Iteration 2	4,5	4,6
Iteration 3	4,4	4,7
Iteration 4	4,3	4,7
Iteration 5	4,6	5,1
Average	4,5	4,7
Maximum FED	Scenario 1 Basic	Scenario 1 Alternative
Iteration 1	8,4E-06	1,6E-05
Iteration 2	6,4E-06	1,6E-05
Iteration 3	7,7E-06	1,1E-05
Iteration 4	7,8E-06	1,0E-05
Iteration 5	7,2E-06	6,4E-06
Average	7,5E-06	1,2E-05

Table 11 Scenario 1 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 1 Basic	Scenario 1 Alternative
Iteration 1	-	-
Iteration 2	0.0	6.9
Iteration 3	-2.6	9.9
Iteration 4	-6.3	8.9
Iteration 5	0.7	16.9

Table 12 Scenario 2 - Iteration Results

Detection time [min]	Scenario 2 Basic	Scenario 2 Alternative
Iteration 1	3,1	2,5
Iteration 2	2,6	2,2
Iteration 3	1,2	3,6
Iteration 4	1,2	1,9
Iteration 5	2,3	2,5
Average	2,1	2,5
Evacuation time [min]	Scenario 2 Basic	Scenario 2 Alternative
Iteration 1	Incomplete but possible	Incomplete but possible
Iteration 2	Incomplete but possible	Incomplete but possible
Iteration 3	Incomplete but possible	Incomplete but possible
Iteration 4	Incomplete but possible	Incomplete but possible
Iteration 5	Incomplete but possible	Incomplete but possible
Average	-	-
Maximum FED	Scenario 2 Basic	Scenario 2 Alternative
Iteration 1	5,68E-04	8,43E-06
Iteration 2	4,58E-04	2,45E-05
Iteration 3	2,04E-04	2,14E-05
Iteration 4	5,10E-05	1,07E-05
Iteration 5	5,38E-04	1,87E-05
Average	3,64E-04	1,67E-05

Table 13 Scenario 2 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 2 Basic	Scenario 2 Alternative
Iteration 1	-	-
Iteration 2	Incomplete	Incomplete
Iteration 3	Incomplete	Incomplete
Iteration 4	Incomplete	Incomplete
Iteration 5	Incomplete	Incomplete

Table 14 Scenario 3 - Iteration Results

Detection time [min]	Scenario 3 Basic	Scenario 3 Alternative
Iteration 1	Unknown	Unknown
Iteration 2	Unknown	13,8
Iteration 3	Unknown	6,2
Iteration 4	Unknown	Unknown
Iteration 5	Unknown	Unknown
Average	-	-
Evacuation time [min]	Scenario 3 Basic	Scenario 3 Alternative
Iteration 1	Incomplete	Incomplete
Iteration 2	Incomplete	Incomplete
Iteration 3	Incomplete	Incomplete
Iteration 4	Incomplete	Incomplete
Iteration 5	Incomplete	Incomplete
Average	-	-
Maximum FED	Scenario 3 Basic	Scenario 3 Alternative
Iteration 1	2,0E-22	0,0E+00
Iteration 2	2,4E-14	6,4E-06
Iteration 3	1,7E-16	2,5E-06
Iteration 4	1,5E-32	5,3E-07
Iteration 5	1,5E-32	3,2E-20
Average	4,9E-15	1,9E-06

Table 15 Scenario 3 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 3 Basic	Scenario 3 Alternative
Iteration 1	-	-
Iteration 2	Incomplete	Incomplete
Iteration 3	Incomplete	Incomplete
Iteration 4	Incomplete	Incomplete
Iteration 5	Incomplete	Incomplete

Table 16 Scenario 4 - Iteration results

Detection time [min]	Scenario 4 Basic	Scenario 4 Alternative
Iteration 1	Unknown	Unknown
Iteration 2	Unknown	Unknown
Iteration 3	Unknown	Unknown
Iteration 4	Unknown	Unknown
Iteration 5	Unknown	Unknown
Average	-	-
Evacuation time [min]	Scenario 4 Basic	Scenario 4 Alternative
Iteration 1	Incomplete	Incomplete
Iteration 2	Incomplete	Incomplete
Iteration 3	Incomplete	Incomplete
Iteration 4	Incomplete	Incomplete
Iteration 5	Incomplete	Incomplete
Average	-	-
Maximum FED	Scenario 4 Basic	Scenario 4 Alternative
Iteration 1	Unknown	Unknown
Iteration 2	Unknown	Unknown
Iteration 3	Unknown	Unknown
Iteration 4	Unknown	Unknown
Iteration 5	Unknown	Unknown
Average	-	-

Table 17 Scenario 4 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 4 Basic	Scenario 4 Alternative
Iteration 1	-	-
Iteration 2	Incomplete	Incomplete
Iteration 3	Incomplete	Incomplete
Iteration 4	Incomplete	Incomplete
Iteration 5	Incomplete	Incomplete

Table 18 Scenario 5 - Iteration results

Detection time [min]	Scenario 5 Basic	Scenario 5 Alternative
Iteration 1	1,8	1,8
Iteration 2	1,8	1,8
Iteration 3	1,8	1,8
Iteration 4	1,8	1,8
Iteration 5	1,8	1,8
Average	1,8	1,8
Evacuation time [min]	**Scenario 5 Basic**	**Scenario 5 Alternative**
Iteration 1	3,5	3,4
Iteration 2	3,7	3,1
Iteration 3	3,4	3,4
Iteration 4	3,2	3,2
Iteration 5	3,7	3,3
Average	3,5	3,3
Maximum FED	**Scenario 5 Basic**	**Scenario 5 Alternative**
Iteration 1	2,7E-04	3,3E-09
Iteration 2	6,7E-04	9,1E-18
Iteration 3	2,7E-04	4,1E-15
Iteration 4	2,7E-04	1,0E-16
Iteration 5	5,0E-04	4,2E-13
Average	4,0E-04	6,6E-10

Table 19 Scenario 5 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 5 Basic	Scenario 5 Alternative
Iteration 1	-	-
Iteration 2	4.1	10.2
Iteration 3	5.0	2.0
Iteration 4	9.8	9.0
Iteration 5	4.9	4.0

Table 20 Scenario 6 - Iteration results

Detection time [min]	Scenario 6 Basic	Scenario 6 Alternative
Iteration 1	7,2	7,9
Iteration 2	6,9	7,7
Iteration 3	7,2	7,7
Iteration 4	7,2	6,9
Iteration 5	7,5	6,6
Average	7,2	7,3
Evacuation time [min]	Scenario 6 Basic	Scenario 6 Alternative
Iteration 1	9,1	8,0
Iteration 2	8,9	8,7
Iteration 3	9,0	8,9
Iteration 4	9,0	9,0
Iteration 5	9,2	7,8
Average	9,0	8,5
Maximum FED	Scenario 6 Basic	Scenario 6 Alternative
Iteration 1	1,19E-04	2,16E-05
Iteration 2	8,71E-05	8,70E-05
Iteration 3	2,04E-04	8,13E-05
Iteration 4	1,21E-04	6,46E-05
Iteration 5	2,23E-04	9,30E-06
Average	1,51E-04	5,28E-05

Table 21 -Scenario 2 - Uncertainty evacuation time

Uncertainty [%] Evacuation time	Scenario 6 Basic	Scenario 6 Alternative
Iteration 1	-	-
Iteration 2	9,9	8.0
Iteration 3	10,7	10.1
Iteration 4	10,7	10.4
Iteration 5	12,4	3.0

II. Appendix B

Comparison of evacuation methods

Here the comparison of travel times between FDS+EVAC and simplified calculations.

Table 22 Travel time comparison – Scenario 5 Basic configuration

Scenario 5 Basic	Evacuation time [min]	Preparation time [min]	FDS+EVAC [min]	Distance [m]	Walking speed [m/s]	Simplfied Calculation [min]
Agent 1	3,99	1,32	0,83	63,00	1,36	0,77
Agent 2	3,55	0,87	0,84	61,00	1,34	0,76

Table 23 Travel time comparison - Scenario 5 Alternative configuration

Scenario 5 Alternative	Evacuation time [min]	Preparation time [min]	Simulation [min]	Distance [m]	Walking speed [m/s]	Simplified Calculation [min]
Agent 1	2,72	0,65	0,23	15,00	1,30	0,19
Agent 2	2,81	0,69	0,29	22,00	1,43	0,26

The comparison was made for scenario 5 as functional evacuation alarm gives a set time for detection. As can be seen the results differentiate but the difference is minor as is seen as not to affect the results.

III. Appendix C

Calculation of the visibility corresponding to TDET_SMOKE_DENS

There are no recommended values for TDET_SMOKE_DENS which controls the agent detection of smoke. The value chosen was therefore picked from the example in the FDS+EVAC user guide. The concept of this variable is to use people sense of smelling the smoke rather than visibility of smoke as trigger for the evacuation.

For this reason, the visibility corresponding to the set value is deemed to be very high (e.g., perfect visibility conditions). This has been checked using the equations from SFPE Section 2 Chapter 13 *Smoke Production and Properties* by G.W. Mulholland (2008).

The TDET_SMOKE_DENS which is set in the FDS+EVAC code is the mass concentration [mg/m^3]

m = mass concentration in the room [g/m^3]

K_m = extinction coefficient per unit mass [m^2/g]

K = extinction coefficient [m^{-1}]

S = Visibility [m]

$$K = K_m * m$$

$$K = 7{,}6\ g/m^3 * \left(\frac{0{,}1}{1000}\right) g/m^3 = 0{,}00076\ m^{-1}$$

$$S = \frac{3}{K}$$

$$S = \frac{3}{0{,}00076\ m^{-1}} \approx 4000\ m$$

Since the sensing height is set to 1.8 meters the agents will start detect the smoke as soon as the mass concentration reaches 0.1 mg/m^3 at a height of 1.8 meters (this corresponds to the assumed height of the human nose).

IV. Appendix D

Example of FDS+EVAC code used and explanation on using results from combined fire and evacuation simulations to simulate evacuation iterations.

When a combined FDS+EVAC simulation modelling both fire and evacuation there is two files produced, a .FED and an .EFF file. By running an evacuation only simulation in FDS+EVAC from a location where these files are present they will be loaded if the command EVACUATION_MC_MODE is set to true and the command EVACUATION_DRILL is set to false. This way iterations can be done without running the entire fire simulation again as these files contain of the information the evacuation simulations uses from the fire simulation.

(Korhonen, T. 2015)

Below is code for evacuation only simulation for scenario 5.

```
&HEAD CHID='UA_detect_evac'/

=====================EVAC MESHES==============================
&MESH IJK=322,75,1, XB=0.0,64.4, 0.0,15.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUSUWF0',/
&MESH IJK=322,75,1, XB=0.0,64.4, 0.0,15.0, 5.0,5.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUSUWF1',/
&MESH IJK=1600,30,1, XB=-320.0,0.0, 1.0,7.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUR',/
&MESH IJK=27,225,1, XB=10.2,15.6, 15.0,60.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUA7',/
&MESH IJK=27,225,1, XB=15.6,30.6, 54.0,59.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUA7B',/
&MESH IJK=15,270,1, XB=-53.0,-50.0, 7.0,61.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUL7',/
&MESH IJK=15,270,1, XB=-228.0,-225.0, 7.0,61.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUL3',/
&MESH IJK=27,270,1, XB=-314.0,-308.6, 7.0,61.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUA3',/
&MESH IJK=27,270,1, XB=-308.6,-293.6, 54.0,59.0, 1.0,1.2,
EVAC_Z_OFFSET=1.0, EVACUATION=.TRUE., EVAC_HUMANS=.TRUE.,
ID='EvacUA3B',/

========================INPUT================================
&TIME T_END=900.0/
&MISC EVACUATION_MC_MODE=.TRUE., EVACUATION_DRILL=.FALSE. /
&SURF ID='EVAC_WALL', RGB= 200,0,200, EVAC_DEFAULT=.TRUE. /
&SURF ID='INV', COLOR='INVISIBLE', DEFAULT=.TRUE. /

================= Evacuation GEOMETRY ==========================
----------------------UR--------------------------------
&OBST XB=-50.8,0.0,3.2,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 1.1
&OBST XB=-50.8,0.0,1.0,1.8,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 1.2
&OBST XB=-97.8,-53.6,4.6,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 2.1
&OBST XB=-94.8,-53.6,1.0,3.2,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 2.2
&OBST XB=-126.8,-97.8,3.4,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 3.1
&OBST XB=-139.4,-94.8,1.0,1.8,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 3.2
&OBST XB=-181.0,-132.8,3.4,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 4.1
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&OBST XB=-184.0,-139.4,1.0,1.8,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 4.2
&OBST XB=-224.0,-181.0,4.8,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 5.1
&OBST XB=-221.8,-184.0,1.0,3.2,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 5.2
&OBST XB=-224.0,-223.2,3.4,4.8,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 5.2.2
&OBST XB=-308.6,-228.4,3.4,7.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 6.1
&OBST XB=-308.6,-228.4,1.0,1.8,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ 6.2
&OBST XB=-132.8,-127.8,3.2,5.6,0.0,2.2, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ RC1
&OBST XB=-319.2,-314.2,1.2,3.6,0.0,2.2, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ RC2
&OBST XB=-314.0,0.0, 1.0,7.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ FloorUR
--------------------------UL-------------------------------
&OBST XB=-50.8,-50.0,7.0,61.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUL7', SURF_ID='INERT'/ UL17
&OBST XB=-225.8,-225.0,7.0,61.0,0.0,3.0, EVACUATION=.TRUE., MESH_ID='EvacUL3', SURF_ID='INERT'/ UL13
&OBST XB=-53.0,-50.0, 7.0,61.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ FloorUL7
&OBST XB=-228.0,-225.0, 7.0,61.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/
FloorUL3
--------------------------UA-------------------------------
&OBST XB=-314.0,-309.4,19.0,41.6,0.0,1.6, EVACUATION=.TRUE., MESH_ID='EvacUA3', SURF_ID='INERT'/
UA3Top
&OBST XB=-310.2,-308.6,11.0,14.6,0.0,2.2, EVACUATION=.TRUE., MESH_ID='EvacUA3', SURF_ID='INERT'/
UA1BottomRight
&OBST XB=-314.0,-312.2,12.2,14.6,0.0,2.2, EVACUATION=.TRUE., MESH_ID='EvacUA3', SURF_ID='INERT'/
UA3BottomLeft
&OBST XB=-314.0,-308.6, 7.0,61.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/
FloorUA3
&OBST XB=-308.6,-293.6, 54.0,60.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/
FloorUA3B
&OBST XB=10.2,14.8, 20.0,42.6, 0.0,1.6, EVACUATION=.TRUE., MESH_ID='EvacUA7', SURF_ID='INERT'/ UA7Top
&OBST XB=10.2,15.6, 15.0,60.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/ FloorUA7
&OBST XB=15.6,30.6, 54.0,59.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/
FloorUA7B
-------------------------USF0 Also in Fire geometry------------------------------
&OBST XB=48.0,48.2, 0.0,15.0, 0.0,12.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/
WallUWF0
&OBST XB=0.0,1.2,6.2,7.0,0.0,3.8, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/ QXL
&OBST XB=1.2,2.0,6.2,8.0,0.0,3.8, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/ QXR
&OBST XB=0.0,64.4, 0.0,15.0, 0.0,0.0, EVACUATION=.TRUE., MESH_ID='EvacUR', SURF_ID='INERT'/
FloorUSUWF0
&OBST XB=37.8,48.0,0.0,6.2,0.0,3.8, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/ Safe-
zone1
&OBST XB=37.8,38.0,6.2,10.2,0.0,3.8, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/ Safe-
wall
&OBST XB=45.8,46.0,6.2,10.2,0.0,76.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/
Vertical Transport 1
&OBST XB=43.6,46.0,6.0,6.2,3.0,76.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/
Vertical Transport 2
&OBST XB=38.0,45.8,10.0,10.2,0.0,76.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF0', SURF_ID='INERT'/
Vertical Transport 3
-------------------------USF1 Also in fire geometry------------------------------
&OBST XB=48.0,48.2,0.0,15.0,0.0,12.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/
WallUWF1
&OBST XB=37.8,43.6,1.6,10.2,0.0,12.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Shaft
&OBST XB=0.0,48.0,0.0,1.6,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=14.0,35.0,1.6,12.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=43.6,48.0,1.6,6.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=46.0,48.0,6.0,10.2,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=37.8,48.0,10.2,12.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=16.0,44.0,12.0,15.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=44.0,48.0,13.0,15.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=0.0,14.0,1.6,6.0,4.0,4.2, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/ Floor
&OBST XB=3.0,10.0,12.0,15.0,3.8,4.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/
GratedFloor
&OBST XB=1.0,3.0,12.0,14.0,3.8,4.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/
GratedFloor
&OBST XB=0.0,14.0,6.0,12.0,3.8,4.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/
GratedFloor
&OBST XB=10.0,14.0,12.0,13.6,3.8,4.0, EVACUATION=.TRUE., MESH_ID='EvacUSUWF1', SURF_ID='INERT'/
GratedFloor
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&OBST XB=37.4,37.8,4.2,5.8,4.0,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ Cable tray 1
&OBST XB=37.4,37.8,9.2,10.8,4.0,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ Cable tray 2
&OBST XB=21.6,34.0,1.0,4.0,4.2,7.2, SURF_ID='INERT', EVACUATION=.TRUE./ Faraday cage
&OBST XB=44.0,46.0,4.8,5.6,4.2,6.4, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=44.0,46.0,14.2,15.0,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=34.0,38.0,13.6,14.4,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.0,34.0,5.0,5.4,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.0,34.0,6.4,6.8,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=17.0,17.4,3.6,8.0,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=18.6,19.0,3.6,8.0,4.2,6.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=5.0,8.8,6.0,6.4,4.0,6.0, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=4.4,4.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=9.4,9.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=14.4,14.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=19.4,19.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.4,24.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=29.4,29.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=34.4,34.6,0.8,1.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=4.4,4.6,5.4,5.6,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=9.4,9.6,5.4,5.6,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=19.4,19.6,4.0,4.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.4,24.6,4.0,4.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=29.4,29.6,4.0,4.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=37.4,37.6,5.2,5.4,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=4.4,4.6,10.8,11.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=9.4,9.6,10.8,11.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=12.4,12.6,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=19.4,19.6,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.4,24.6,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=29.4,29.6,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=37.4,37.6,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=4.4,4.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=9.4,9.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=19.4,19.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=24.4,24.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=29.4,29.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=34.4,34.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=46.0,46.2,9.8,10.0,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=46.0,46.2,6.2,6.4,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=44.4,44.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=39.4,39.6,14.0,14.2,0.0,3.8, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=22.0,35.0,1.2,3.8,0.0,2.4, SURF_ID='INERT', EVACUATION=.TRUE./ Saferoom
&OBST XB=21.0,23.0,11.6,14.6,0.0,2.6, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=26.0,28.0,11.6,14.6,0.0,2.6, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=31.0,33.0,11.6,14.6,0.0,2.6, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=2.0,10.0,7.0,10.6,0.0,3.2, SURF_ID='INERT', EVACUATION=.TRUE./ Obstruction
&OBST XB=0.0,1.0,3.2,3.8,4.8,5.4, SURF_ID='INERT', EVACUATION=.TRUE./ UR Inflow
&OBST XB=0.4,1.0,0.6,3.2,4.8,5.4, SURF_ID='INERT', EVACUATION=.TRUE./ UR Inflow
&OBST XB=0.4,48.0,0.0,0.6,4.8,5.4, SURF_ID='INERT', EVACUATION=.TRUE./ UR Inflow
&OBST XB=47.4,48.0,0.6,3.8,4.8,5.4, SURF_ID='INERT', EVACUATION=.TRUE./ UR Inflow
&OBST XB=47.4,48.0,3.2,3.8,5.4,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ UR Inflow
&OBST XB=45.4,47.4,3.2,3.6,6.4,6.8, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=45.4,45.8,3.6,5.0,6.4,6.8, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=44.8,45.8,5.0,5.4,6.4,6.8, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=1.4,48.0,10.8,11.6,10.4,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=39.4,40.2,10.8,11.6,11.0,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=12.8,13.6,13.8,15.0,4.2,4.8, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=12.8,21.0,13.8,14.4,4.8,5.6, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=20.4,21.0,11.6,13.8,4.8,5.6, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=20.4,21.0,11.6,12.4,5.6,10.2, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=20.4,21.0,8.2,11.6,9.4,10.2, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=1.0,34.8,8.2,8.8,10.2,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=34.2,34.8,8.2,8.8,11.0,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 Smokeduct
&OBST XB=12.2,12.8,13.8,15.0,4.2,4.8, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 inflow
&OBST XB=12.2,12.8,13.8,14.4,4.8,7.2, SURF_ID='INERT', EVACUATION=.TRUE./ UA17 inflow
&OBST XB=0.0,1.0,4.0,4.8,5.0,5.6, SURF_ID='INERT', EVACUATION=.TRUE./ UR Smokeduct
&OBST XB=0.4,1.0,4.0,4.8,5.6,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ UR Smokeduct
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&OBST XB=0.4,1.0,4.8,6.6,10.2,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ UR Smokeduct
&OBST XB=0.4,34.8,6.6,7.2,10.2,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ UR Smokeduct
&OBST XB=34.2,34.8,6.6,7.2,11.0,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ UR Smokeduct
&OBST XB=39.4,40.2,11.6,13.2,11.2,12.0, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=1.4,36.0,3.4,4.2,10.4,11.0, SURF_ID='INERT', EVACUATION=.TRUE./ Inflow
&OBST XB=0.4,48.0,0.6,1.2,7.2,7.8, SURF_ID='INERT', EVACUATION=.TRUE./ Supply vent
&OBST XB=0.4,48.0,13.8,14.4,7.2,7.8, SURF_ID='INERT', EVACUATION=.TRUE./ Supply vent
&OBST XB=-1.0,-0.8,1.0,7.0,0.0,6.0, SURF_ID='INERT', EVACUATION=.TRUE./ Fire compartment UR
&OBST XB=-53.0,-50.0,9.8,10.0,0.0,3.0, SURF_ID='INERT', EVACUATION=.TRUE./ Fire compartment UL17
&OBST XB=-228.0,-225.0,9.8,10.0,0.0,3.0, SURF_ID='INERT', EVACUATION=.TRUE./ Fire compartment UL13
&OBST XB=10.2,15.6,16.8,17.0,0.0,5.0, SURF_ID='INERT', EVACUATION=.TRUE./ Fire compartment UA17
&OBST XB=-314.0,-308.6,9.8,10.0,0.0,5.0, SURF_ID='INERT', EVACUATION=.TRUE./ Fire compartment UA13
&HOLE XB=8.8,11.8,3.0,6.0,3.99,4.21, EVACUATION=.TRUE./ F1Hole
&HOLE XB=27.0,31.0,9.0,11.2,3.99,4.21, EVACUATION=.TRUE./ F1Hole
&HOLE XB=8.8,11.8,3.0,6.0,3.79,4.21, EVACUATION=.TRUE./ Hole
&HOLE XB=27.0,31.0,9.0,11.2,3.79,4.21, EVACUATION=.TRUE./ Hole
&HOLE XB=15.8,18.8,1.2,2.4,3.79,4.21, EVACUATION=.TRUE./ Hole
&HOLE XB=47.98,48.21,12.0,14.0,4.0,6.0, EVACUATION=.TRUE./ Door UW top evac
&HOLE XB=53.0,55.8,6.0,9.0,3.79,4.01, EVACUATION=.TRUE./ Hole
&HOLE XB=51.4,54.2,11.4,13.2,3.79,4.01, EVACUATION=.TRUE./ Hole
&HOLE XB=-1.01,-0.79,1.4,3.0,-0.02,2.2, EVACUATION=.TRUE./ Fire compartment UR door
&HOLE XB=-52.8,-51.2,9.79,10.01,-0.02,2.2, EVACUATION=.TRUE./ Fire compartment Door UL17
&HOLE XB=-227.8,-226.2,9.79,10.01,-0.02,2.2, EVACUATION=.TRUE./ Fire compartment Door UL13
&HOLE XB=10.8,12.4,16.79,17.01,-0.02,2.2, EVACUATION=.TRUE./ Fire compartment UA17 door
&HOLE XB=-313.4,-311.8,9.79,10.01,-0.02,2.2, EVACUATION=.TRUE./ Fire compartment Door UA13
========================================Evac Geometry
ends=============================================


========================================Evac Input
Starts===============================================

------------------------------------------EXITS----------------------------------------------
&EXIT ID='SafeZone', IOR=-2,
COLOR='BLUE',
XB = 46.6,48.0, 6.2,6.2, 1.0,1.2/
&EXIT ID='UA3EXIT', IOR=+1,
COLOR='BLUE',
XB = -308.6,-308.6 46.0,47.2 1.0,1.2/
&EXIT ID='UL3EXIT', IOR=-1,
COLOR='BLUE',
XB = -228.0,-228.0 46.0,47.2 1.0,1.2/
&EXIT ID='UL7EXIT', IOR=-1,
COLOR='BLUE',
XB = -53.0,-53.0 46.0,47.2 1.0,1.2/
&EXIT ID='UA7EXIT', IOR=+1,
COLOR='BLUE',
XB = 15.6,15.6 46.0,47.2 1.0,1.2/

------------------------------Doors---------------------------------
&DOOR ID='UA3DOOR', IOR=-2,
MESH_ID='EvacUA3',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UA3DOOR2',
XB= -314,-308.6, 7.0,7.0, 1.0,1.2/
&DOOR ID='UA3DOOR2', IOR=+2,
MESH_ID='EvacUR',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UA3DOOR',
XB= -314,-308.6, 7.0,7.0, 1.0,1.2/
&DOOR ID='UA3BDOOR', IOR=-1,
MESH_ID='EvacUA3B',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UA3BDOOR2',
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XB= -308.6,-308.6, 54.0,59.0, 1.0,1.2/
&DOOR ID='UA3BDOOR2', IOR=+1,
MESH_ID='EvacUA3',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UA3BDOOR',
XB= -308.6,-308.6, 54.0,59.0, 1.0,1.2/
&DOOR ID='UL3DOOR', IOR=-2,
MESH_ID='EvacUL3',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UL3DOOR2',
XB= -228,-225, 7.0,7.0, 1.0,1.2/
&DOOR ID='UL3DOOR2', IOR=+2,
MESH_ID='EvacUR',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UL3DOOR',
XB= -228,-225, 7.0,7.0, 1.0,1.2/
&DOOR ID='UL7DOOR', IOR=-2,
MESH_ID='EvacUL7',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UL7DOOR2',
XB= -53,-50, 7.0,7.0, 1.0,1.2/
&DOOR ID='UL7DOOR2', IOR=+2,
MESH_ID='EvacUR',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UL7DOOR',
XB= -53,-50, 7.0,7.0, 1.0,1.2/
&DOOR ID='UA7DOOR', IOR=-2,
MESH_ID='EvacUA7',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UA7DOOR2',
XB= 10.2,15.6, 15.0,15.0, 1.0,1.2/
&DOOR ID='UA7DOOR2', IOR=+2,
MESH_ID='EvacUSUWF0',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UA7DOOR',
XB= 10.2,15.6, 15.0,15.0, 1.0,1.2/
&DOOR ID='UA7BDOOR', IOR=-1,
MESH_ID='EvacUA7B',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='UA7BDOOR2',
XB= 15.6,15.6, 54.0,59.0, 1.0,1.2/
&DOOR ID='UA7BDOOR2', IOR=+1,
MESH_ID='EvacUA7',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='UA7BDOOR',
XB= 15.6,15.6, 54.0,59.0, 1.0,1.2/
&DOOR ID='URDOOR', IOR=+1,
MESH_ID='EvacUR',
EXIT_SIGN=.TRUE.,
KEEP_XY=.TRUE.,
TO_NODE='URDOOR2',
XB= 0.0,0.0, 1.8,3.2, 1.0,1.2/
&DOOR ID='URDOOR2', IOR=-1,
MESH_ID='EvacUSUWF0',
EXIT_SIGN=.FALSE.,
KEEP_XY=.TRUE.,
TO_NODE='URDOOR',
XB= 0.0,0.0, 1.8,3.2, 1.0,1.2/
```

```
----------------------------------Stairs----------------------------------
&DOOR ID='DOORSTAIRF1', IOR=+2,
MESH_ID='EvacUSUWF1',
EXIT_SIGN=.TRUE.,
TO_NODE='STAIRCORN',
XB= 0.0,1.0, 12.0,12.0, 5.0,5.2/
&CORR ID='STAIRCORN',
FYI='Stair in the upper left corner of the us',
MAX_HUMANS_INSIDE=20,
EFF_LENGTH=5.0,
FAC_SPEED=0.7,
TO_NODE='DOORSTAIRF0'/
&ENTR ID='DOORSTAIRF0', IOR=+2,
MESH_ID='EvacUSUWF0',
XB= 3.0,3.0, 14.0,15.0, 1.0,1.2/
&DOOR ID='DOORSTAIR2F1', IOR=+1,
MESH_ID='EvacUSUWF1',
EXIT_SIGN=.TRUE.,
TO_NODE='STAIR',
XB= 15.8,15.8, 1.2,2.4, 5.0,5.2/
&CORR ID='STAIR',
MAX_HUMANS_INSIDE=3,
EFF_LENGTH=3.0,
FAC_SPEED=0.7,
TO_NODE='DOORSTAIR2F0'/
&ENTR ID='DOORSTAIR2F0', IOR=+1,
MESH_ID='EvacUSUWF0',
XB= 18.8,18.8, 1.2,2.4, 1.0,1.2/

---------------------------Evacuation calculation and Human properties--------------
&PERS ID='Personnel', FYI='Based on Evac Adult, Male+Female diameter and velocity',
DEFAULT_PROPERTIES='Adult',
VELOCITY_DIST=1, VEL_LOW=1.2, VEL_HIGH=1.6,
PRE_EVAC_DIST=1,PRE_LOW=30.0,PRE_HIGH=80.0,
DET_EVAC_DIST=1,DET_LOW=110.0,DET_HIGH=110.0,
TDET_SMOKE_DENS=0.1,
HUMAN_SMOKE_HEIGHT=1.80,
DENS_INIT=4.0,
OUTPUT_SPEED=.TRUE.,
OUTPUT_FED=.TRUE.,/

------------------------------Initial positions and EVHO----------------------------
&EVHO ID='UWF0',
XB= 37.8,64.4, 0.0,15.0, 1.0,1.2/
&EVHO ID='UWF1',
XB= 37.8,64.4, 0.0,15.0, 5.0,5.2/
//&EVAC ID= 'PERSONNELUA3',
NUMBER_INITIAL_PERSONS = 2,
XB=-314.0,-308.6, 7.0,61.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'RC2',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
&EVAC ID= 'PERSONNELUA3B',
NUMBER_INITIAL_PERSONS = 2,
XB=-308.6,-293.6, 54.0,59.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'UA3EXIT','UL3EXIT','UA7EXIT','UL7EXIT','SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUL3',
NUMBER_INITIAL_PERSONS = 2,
XB=-228.0,-225.0, 7.0,61.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'RC2',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUL7',
NUMBER_INITIAL_PERSONS = 2,
```

```
XB=-53.0,-50.0, 7.0,61.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELURA',
NUMBER_INITIAL_PERSONS = 2,
XB=-80.0,0.0, 1.0,7.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELURB',
NUMBER_INITIAL_PERSONS = 2,
XB=-141.0,-80.0, 1.0,7.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELURC',
NUMBER_INITIAL_PERSONS = 2,
XB=-230.0,-141.0, 1.0,7.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'RC2',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELURD',
NUMBER_INITIAL_PERSONS = 2,
XB=-320.0,-230.0, 1.0,7.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'RC2',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUA7',
NUMBER_INITIAL_PERSONS = 2,
XB=10.2,15.6, 15.0,60.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUA7B',
NUMBER_INITIAL_PERSONS = 2,
XB=15.6,30.6, 54.0,59.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUSF0',
NUMBER_INITIAL_PERSONS = 4,
XB=0.0,64.4, 0.0,15.0, 1.0,1.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/
//&EVAC ID= 'PERSONNELUSF1',
NUMBER_INITIAL_PERSONS = 4,
XB=0.0,15, 0.0,15.0, 5.0,5.2,
KNOWN_DOOR_NAMES = 'SafeZone',
KNOWN_DOOR_PROBS = 1.0,
PERS_ID = 'Personnel'/

------------------------------Plotting flowfields-----------------------------------
&SLCF PBZ=1.0, QUANTITY = 'VELOCITY', VECTOR=.TRUE.,EVACUATION=.TRUE. /
&SLCF PBZ=5.0, QUANTITY = 'VELOCITY', VECTOR=.TRUE.,EVACUATION=.TRUE. /
&TAIL /
```