

PROBABILISTIC SURVIVABILITY VERSUS TIME MODELING

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ABSTRACT

This presentation documents Kennedy Space Center's Independent Assessment work completed on three assessments for the Ground Systems Development and Operations (GSDO) Program to assist the Chief Safety and Mission Assurance Officer during key programmatic reviews and provided the GSDO Program with analyses of how egress time affects the likelihood of astronaut and ground worker survival during an emergency.

For each assessment, a team developed probability distributions for hazard scenarios to address statistical uncertainty, resulting in survivability plots over time. The first assessment developed a mathematical model of probabilistic survivability versus time to reach a safe location using an ideal Emergency Egress System at Launch Complex 39B (LC-39B); the second used the first model to evaluate and compare various egress systems under consideration at LC-39B. The third used a modified LC-39B model to determine if a specific hazard decreased survivability more rapidly than other events during flight hardware processing in Kennedy's Vehicle Assembly Building.

SUMMARY

Based on the composite survivability versus time graphs from the first two assessments, there was a soft "knee" in the Figure of Merit graphs at eight minutes (ten minutes after egress ordered). Thus, the graphs illustrated to the decision makers that the final emergency egress design selected should have the capability of transporting the flight crew from the top of LC 39B to a safe location in eight minutes or less. Results for the third assessment were dominated by hazards that were classified as instantaneous in nature (e.g. stacking mishaps) and therefore had no effect on survivability vs time to egress the Vehicle Assembly Building (VAB). VAB emergency scenarios that degraded over time (e.g. fire) produced survivability vs time graphs that were line with aerospace industry norms.

PROPOSED TYPE OF PRESENTATION

Oral with a MS PowerPoint presentation.

MAJOR INTEREST OF PAPER

Major Interest of the paper: Space Transportation and Safety, Operational Hazards, Emergencies, Egress, Survival, Decision Making, Probability Distribution Functions, Decision Support Systems, Safety Management, Fault Trees, Figure of Merit.

POINT OF CONTACT

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ADDITIONAL INFORMATION

For more details on the three assessments and the findings, you can read full report "Probabilistic Survivability Versus Time Modeling", NASA/TP-2015-218876 at url address: <http://ntrs.nasa.gov> or <http://hdl.handle.net/2060/20150021266>.



PROBABILISTIC SURVIVABILITY VERSUS TIME MODELING

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AGENDA

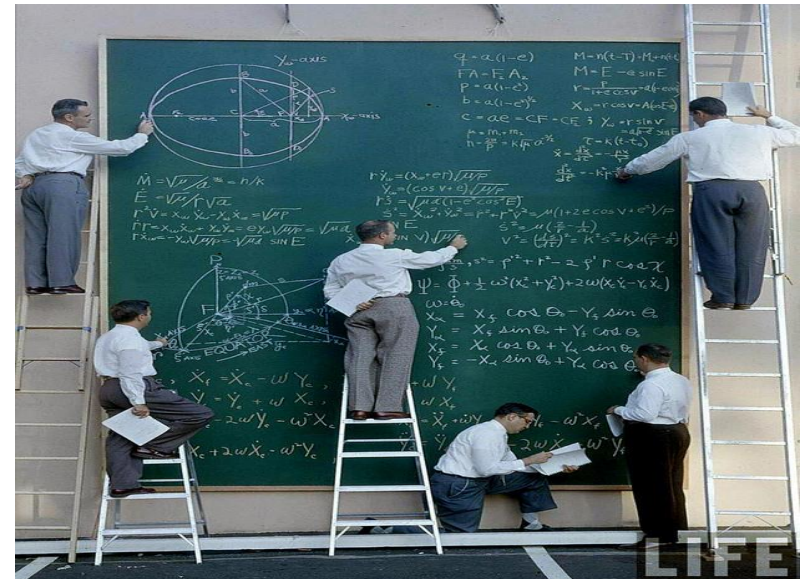
Overview of the Kennedy Space Center (KSC) Independent Assessment Launch Complex 39B (LC 39B) Overview of Assessment

- Methodology
 - Hazard Scenario Development
 - Likelihood of Initiating Event
 - Error Factor and Uncertainty Distribution
 - Survivability Estimate
 - Survivability Estimate Uncertainty
- Calculations
- Results

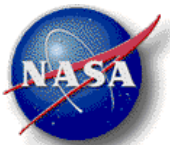
Vehicle Assembly Building (VAB) Overview of Assessment

- Methodology
- Calculations
- Results

Summary



KSC INDEPENDENT ASSESSMENT WHO ARE WE? WHAT DO WE DO?



KSC Independent Assessment (IA)

- Capability funded by the Office of Safety and Mission Assurance from the NASA Human Spaceflight Centers.
- Allows Human Spaceflight Centers to independently review and assess technical and mission risks associated with Program and Projects.
- Provides objective, non-advocating analysis and solutions.



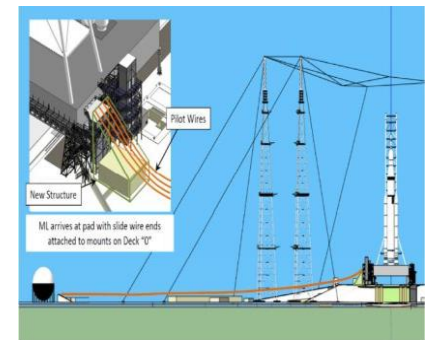
Assessments triggered by multiple Customers

- KSC Center Director
- KSC SMA Director
- Program/Project Managers/Chief SMA Officers
- KSC Directors



Wide variety of subjects

- Systemic processes (e.g. Mission Assurance)
- Institutional (e.g. Personnel Safety)
- Technical (e.g. LC 39B Emergency Egress Assessment)



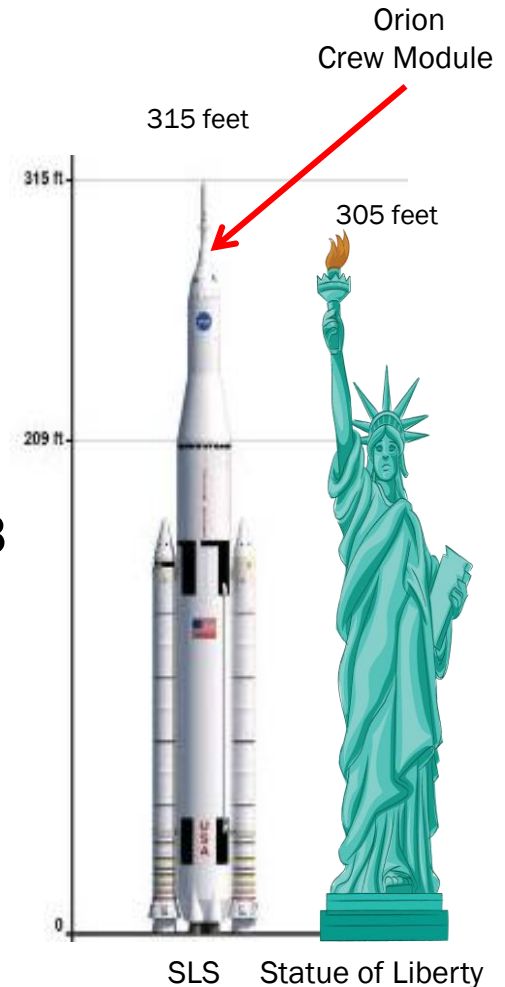
BACKGROUND INFORMATION

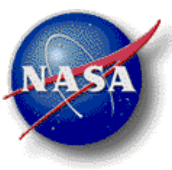
Modernizing KSC's spaceport with capabilities to launch the Orion Crew Module and Space Launch System (SLS).

- Orion Crew Module will taking humans to multiple deep space destinations extending beyond our Moon, to Mars, and across our solar system.
- SLS will carry the Orion Crew Module, as well as cargo, equipment and scientific payloads into deep space.

The SLS will be launched from Launch Complex 39B (LC 39B) at KSC. SLS will be comprised of approximately:

- 2,772,100 pounds of solid propellant.
- 527,400 gallons of Liquid Hydrogen.
- 197,000 gallons of Liquid Oxygen.
- 9,700 gallons of Monomethylhydrazine.
- 300 gallons of Nitrogen Tetroxide.





SURVIVABILITY ASSESSMENTS

KSC IA was requested to perform survivability assessments to assist in program decision making:

- **LC-39B Crew Survivability Assessments (2012).**
 - Evaluated crew survivability during launch countdown at Launch Complex 39B for different emergency egress concepts.
- **VAB Emergency Egress Survivability Assessment (2013).**
 - Built upon methodologies used in LC-39B Crew Survivability Assessment.
 - Evaluated worker survivability during processing of SLS and Orion in the VAB.

ASSESSMENT OVERVIEW

LC 39B EMERGENCY EGRESS ASSESSMENT

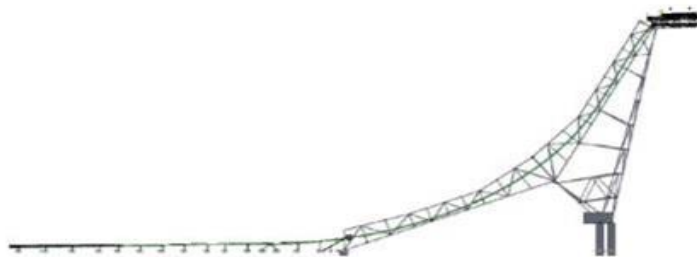
OVERVIEW OF LC 39B ASSESSMENTS

If an emergency situation (fire, imminent explosion, etc.) developed with Orion or SLS during launch countdown,

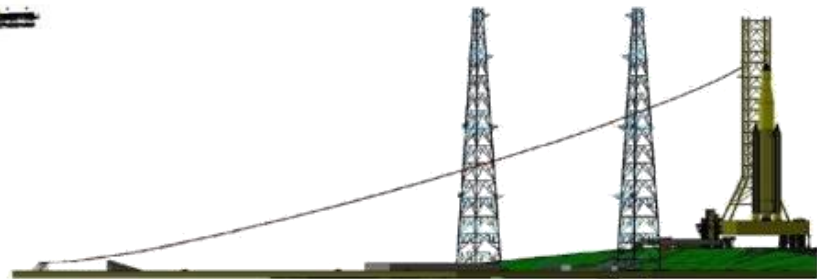
- LC 39B Emergency Egress System quickly transports four astronauts inside the Orion Crew Module to a safe location:
 - Apollo era heritage bunker ~ 1,200 feet west of LC 39B, or
 - Any location outside the blast danger area radius ~ 6,000 feet.

Several emergency egress systems were under consideration (rail, slidewire, elevator, etc.).

- How can each system (defined as Method A1, A2, B1, etc.) be compared other than cost?



Rail System Egress Method



Slidewire System Egress Method

METHODOLOGY

LC 39B EMERGENCY EGRESS ASSESSMENT

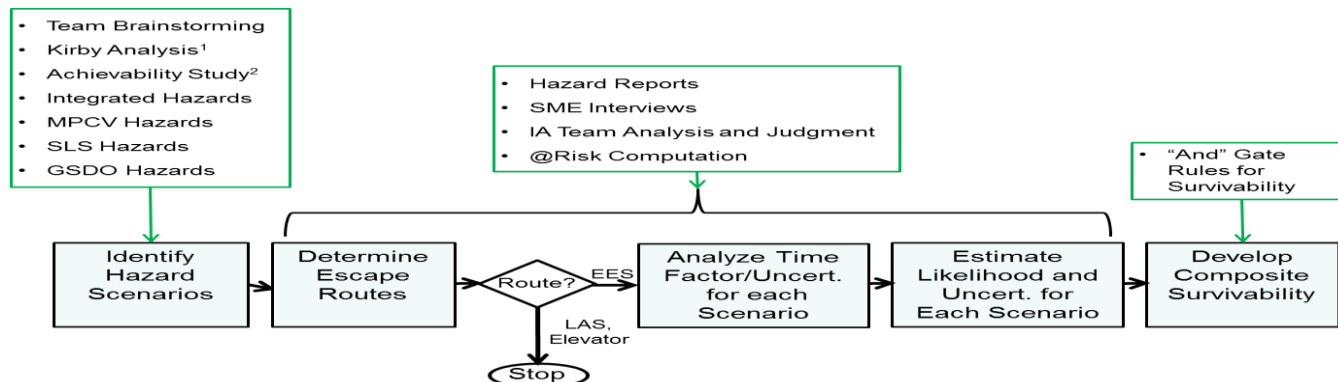
METHODOLOGY OVERVIEW

Problem:

- Find a way to generate data for the figures of merit (a graphical depiction of aggregated quantities used to characterize risk) for evaluating different Emergency Egress Concepts for astronauts at the LC-39B using survivability versus time to safety.

Methodology:

- Develop Ground Rules and Assumptions
- Define Hazard Scenarios
- Determine Initiating Event Probability
- Determine Error Factor and Uncertainty Distribution
- Develop Survivability Estimate
- Establish Survivability Estimate Uncertainty



DEVELOP GROUND RULES AND ASSUMPTIONS

Defined Key Terms. For example:

- Is survival no death, or is survival no death or injuries?
 - Death defined as 0% survival.
- What is the timeframe when the event starts and stops?
 - Two minutes for astronauts to unbuckle and egress out of the Orion Crew Module.
 - Time intervals to reach a safe location were estimated at 0 min, 2 min, 4 min, 6 min, 8 min, 10 min, 13 min, and 15 min.

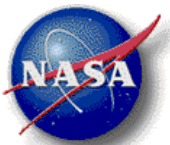
Assessment to evaluate astronaut survivability as a function of time.

- Assumed four astronauts moving together using a single egress method.

What is credible or non-credible event? For example:

- Likelihood of dying from a single object colliding with Earth is 1.6×10^{-9} /year. Given that, should the assessment included survivability from an asteroid strike?

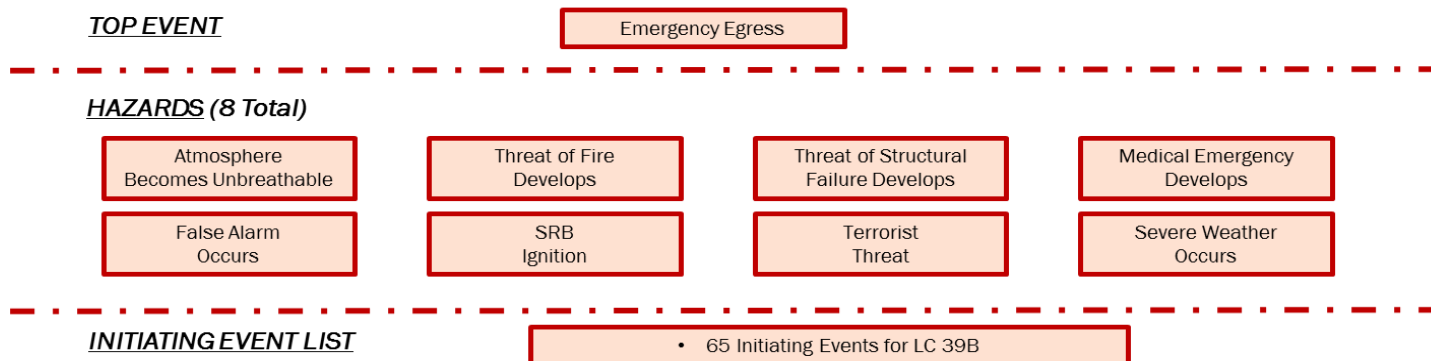




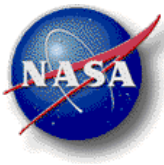
DEFINE HAZARD SCENARIOS

The Fault Tree Analysis (FTA) Method was used to determine which Hazard Scenarios (sequence of events commencing with an initiating event that creates an undesirable outcome) would require an emergency egress. FTA Method resulted in the simplified Fault Tree below which enabled the IA Team to examine all paths from the Initiating Event List to the Top Event to establish credible scenarios.

- **Top Event:** - is the undesirable event.
 - Example: Conduct an emergency egress.
- **Hazard Causes**
 - Hazard – A threat, internal or external to a system, that has the potential to cause harm. The threat is usually a state or set of conditions, but in some circumstances, can be an event or activity
 - Examples: Fire, Unbreathable Atmosphere (Toxic or Smoke), Structural Failure (Explosion), or Other traumatic event (health, weather, terrorist treat, etc.).
- **Initiating Events**
 - Initiating Event – Some anomalous occurrence that would eventually lead to a hazard that would require an emergency evacuation.
 - Examples: Spacecraft Propellant Leak, Launch Vehicle Electrical Fire Starts, Premature Stage Separation Occurs, Ordnance Activation.



METHODOLOGY
Hazard Scenario Development



DETERMINE INITIATING EVENT PROBABILITY

Conducted data analysis and reviewed historical documentation.

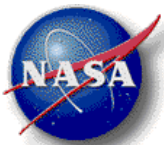
- Define the likelihood of something failing over time.
- Assigned a probability or likelihood of occurrence for each credible Initiating Event developed from the fault tree.

If no numerical data existed, the likelihood of occurrence was characterized by expert elicitation.

- Adjective rating such as medium or very low likelihood can be converted to a median numerical score.

Median value (50th percentile) is the Initiating Event likelihood of occurrence in Failure Space.

- Failure Space describes events or outcomes management does not want to occur.



DETERMINE ERROR FACTOR AND UNCERTAINTY DISTRIBUTION

Determine the interval of values or uncertainty distribution for the likelihood of occurrence of the Initiating Event.

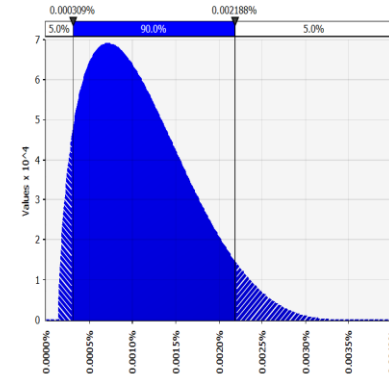
- Error Factor was used as a measure of dispersion around the median.
- IA Team's rule of thumb for selecting an Error Factor:
 - Error factor 0 - 5 : mature system.
 - Error factor 5 - 15: little information available or first application.
 - Error Factor > 15: large uncertainties or no information or data.

Error Factor established Upper and Lower bounds for the uncertainty distribution.

- Lower Bound = Median Value/Error Factor.
- Upper Bound = Median Value* Error Factor.

Palisade Corporation's @RISK (pronounced "at risk") Software was used to combine the Upper and Lower Bounds with the median value to produce a PERT Distribution.

- Error factors are to be used with the lognormal distribution to describe the 5th and 95th percentiles.
- With the PERT distribution, these lower and upper values generated by the error factor method provide end points and not percentiles.



Sample Likelihood
and PERT
Distribution Input



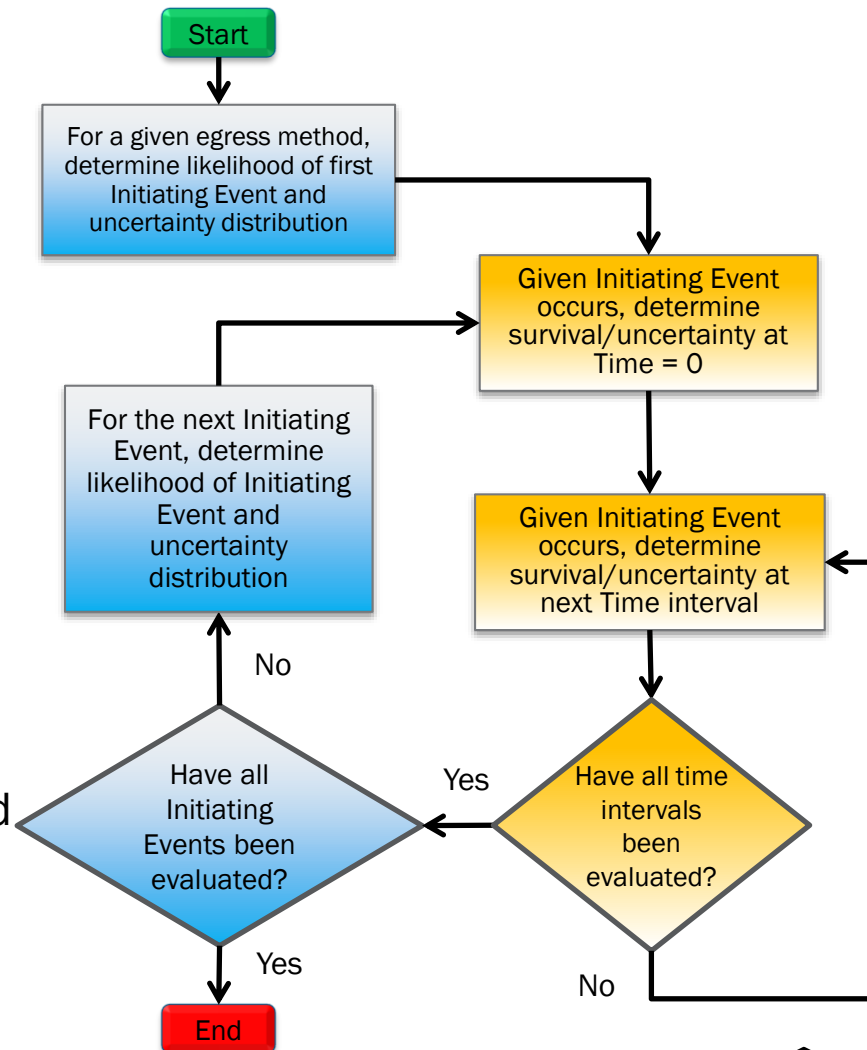
DEVELOP SURVIVABILITY ESTIMATE

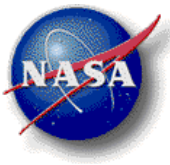
Basis of Estimate for Survival to determine the survival score.

- IA Team consensus.
- Interviews.
- Consequence rating from hazard reports.
- Evaluation of similar systems and historical data.
- Combination of all these methods.

Groundrules

- Assumed the initiating event occurs (set the likelihood to 1).
- Determine astronaut survival at each time interval assuming they all reached a safe haven (a location where they are no longer exposed to the hazard).
- The longer the astronauts were exposed to a hazard, the lower their survival was scored.





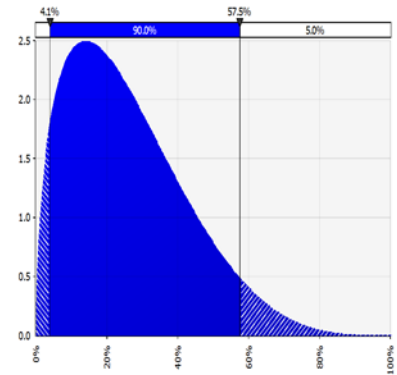
ESTABLISH SURVIVABILITY ESTIMATE UNCERTAINTY

- The Median or “Most Likely” value (median) was the expected survival assuming the initiating event occurred.
- The Maximum or “Good Day” conditions were the optimal conditions (e.g. the event was not as severe as expected). This set the upper bound of the distribution.
- The Minimum or “Bad Day” conditions were where everything worked against the personnel surviving the hazard. This set the lower bound of the distribution.

Selection of these values resulted in an interval of values used to determine the uncertainty PERT distributions in @RISK.

Survival score given the event has occurred was defined in Success Space.

- Success Space (e.g., mission success) describes events or outcomes management does want to occur.



Sample
Survivability and
PERT Distribution
Input



CALCULATIONS

P_E = likelihood of event occurring. [input in Failure Space]

$P_{S|E}$ = probability of surviving if event occurs. [input in Success Space]

Since Failure Space Distribution should not be multiple by a Success Space Distribution, we need to develop the $P_{D|E}$ = probability of dying if event occurs which is calculated by:

$$P_{D|E} = 1 - P_{S|E}$$

P_D = probability of dying due to this event which is calculated by:

$$P_D = P_E * P_{D|E} = P_E * (1 - P_{S|E})$$

P_S = probability of surviving due to this event which is calculated by:

$$P_S = 1 - P_D = (1 - (P_E * (1 - P_{S|E}))) \text{ [output]}$$

$P_{S_{all}}$ = probability of surviving the occurrence of all Initiating Events (assumes events are independent) which is calculated by:

$$P_{S_{all}} = \Pi (P_{S_i}) = P_{S_1} * P_{S_2} * \dots * P_{S_{65}} \text{ [output]}$$

CALCULATIONS (CONT.)

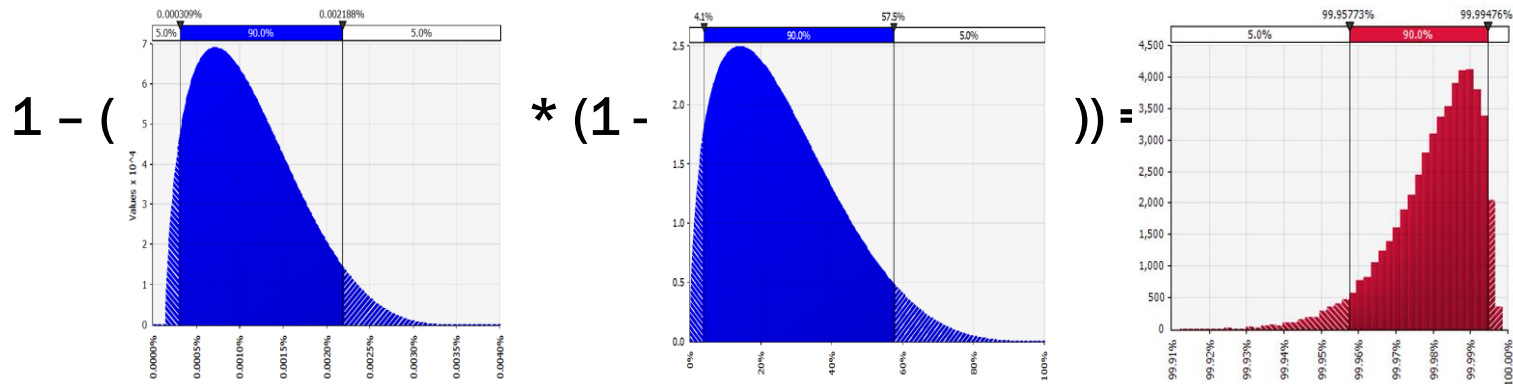
Used @RISK (an add-in to Microsoft Excel) and the Latin Hypercube sampling method when running probabilistic simulations at 50,000 iterations to calculate the output for each time interval (shown below as the red histogram).

- That is, @RISK used the probability distributions embedded in the risk model described in Excel to calculate each 50,000 outcomes.
- Thus, this method simulated 50,000 “what if” Scenarios at one time.

Given the Excel formula is:

$$1 - (P_E * (1 - P_{S|E})) = P_S$$

- For one time interval and one Initiating Event, then the Excel formula with the @RISK add-in software makes:





CALCULATIONS (CONT.)

This probabilistic simulation of the Excel formula produces a PERT distribution with results at the lower bound, most likely/median, and upper bound at a specific time.

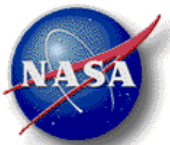
- Generated the graphs the Customer requested was accomplish by exporting the 5th, 50th, and 95th percentiles of the output histogram for each hazard scenarios and the roll-up of all the scenarios at each specific time interval in to MS Excel.

The @RISK software could have been used to generate the same graph. However,

- Eliminating the @RISK graphs for each hazard and time interval speeds up @RISK processing time.
- Final graphs generated in MS Excel were visually appealing to the Customer.

RESULTS

LC 39B EMERGENCY EGRESS ASSESSMENT



RESULTS

IA Team created five MS Excel files to illustrate/compare Astronaut survival by group or by individual credible hazards identified in the FTA
These files were:

- All Scenarios, Fire Only Scenarios, Fire and Structural Failure Scenarios, Structural Failure Scenario, Unbreathable Atmosphere Scenarios.

The largest MS Excel file (All Scenarios) contained:

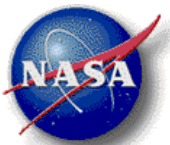
- 1,786 data entries per method of egress of Input Data.
- 2,337 data points generated per method of egress of Output Data.

Below is an example from a single MS Excel file for one time interval, one Initiating Event, and one egress method.

Initiating Event (E)		Event Likelihood (P_E) [Input Data]				% Survivability @ 2 Minutes					
Event No.	Description	Lower Bound	50th Percentile (Median)	Upper Bound	Error Factor	Minimum $P_{S E}$	Most Likely $P_{S E}$	Maximum $P_{S E}$	P_S at 5.00%	P_S at 50.00%	P_S at 95.00%
70	Engine Explosion at Startup Results in Structural Failure	6.00E-04	1.20E-04	2.40E-05	5.0	1.00%	93.00%	100.00%	99.99%	100.00%	100.00%

Figure of Notional Output Data

Output (P_S) generated from @RISK histogram. These points are then plotted in MS Excel.



RESULTS (CONT.)

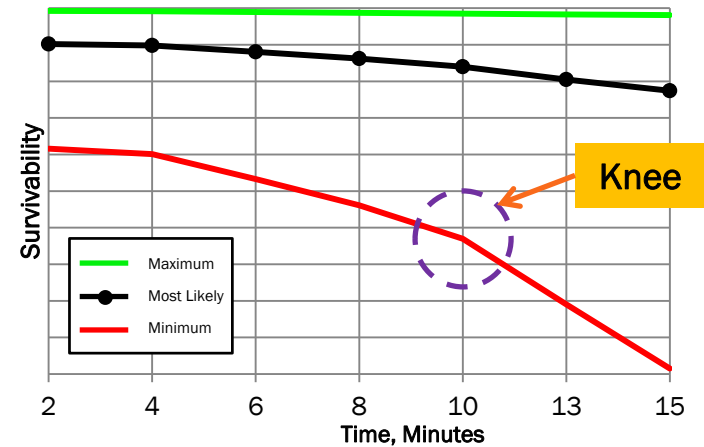
As shown in the top right figure of merit, a “knee” (i.e. significant decrease in survivability) in the top graph can be seen at 10 minutes regardless of egress method.

- Each astronaut has 10 minutes of breathable air in their spacesuits.
- Decrease in crew survivability was attributed to no pre-staging of supplemental portable breathing air units.

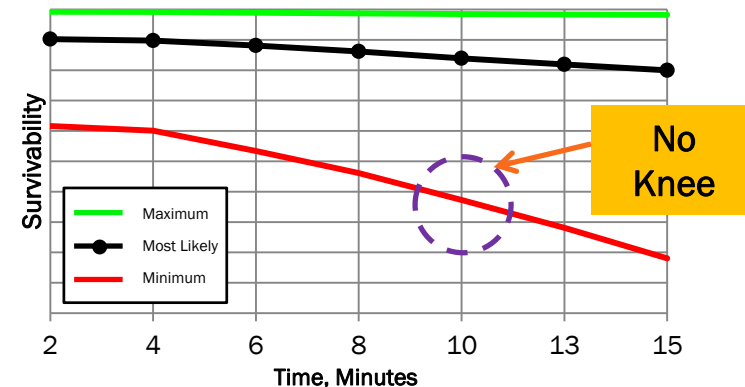
Customer defined mitigation steps will be implemented to eliminate the knee.

- Breathing air unit will be pre-stage to allow astronauts to exchange units.
- With mitigation steps in place, knee at 10 minutes disappears in bottom graph.

Notional LC 39B Emergency Egress
Unbreathable Scenarios Not Mitigated



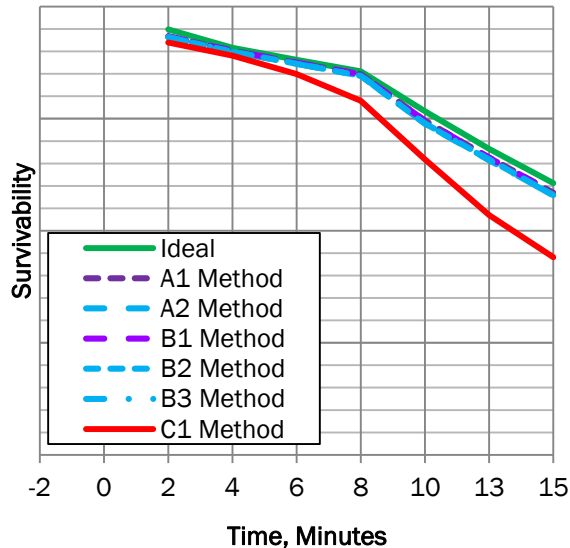
Notional LC 39B Emergency Egress
Unbreathable Atmosphere Scenarios Mitigated



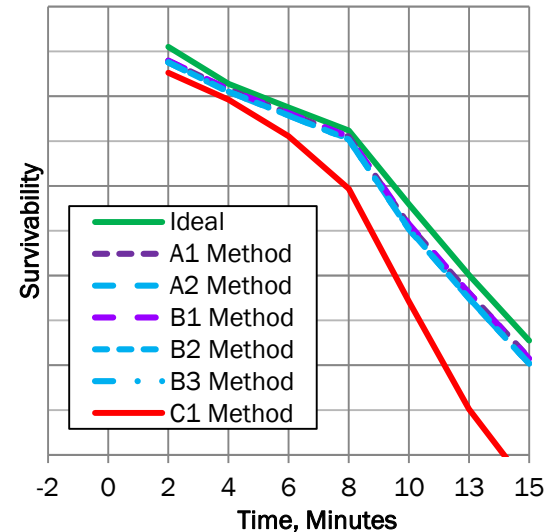


RESULTS (CONT.)

Notional Composite of All Scenarios
Most Likely by EES Method



Notional Composite of Fire + Time-
Dependent Structural Hazard Scenarios
Most Likely by EES Method



Various graphs of the Most Likely values for the seven methods assessed.

- Methods A1, A2, B1, B2, and B3 are roughly the same percentage survivability.
 - Methods A1 and A2 transported Astronauts inside the blast danger zone.
 - All other methods transported Astronauts outside the blast danger zone (~6000 feet).
- However, cost estimates to build Methods A1, B1, and B3 were ~\$40 million more than Methods A2, B2, and C1.

ASSESSMENT OVERVIEW

VAB EMERGENCY EGRESS ASSESSMENT

OVERVIEW VAB ASSESSMENT

Evaluation of workers survivability versus time during processing of SLS and Orion in the VAB at KSC.

For the VAB Assessment,

- IA Team was asked to determine if an Initiating Event(s) produce a “knee” on the curve indicating that survivability decreased more rapidly than the other event(s).
- Evaluated multiple workers (~14 - 90 people) egressing from multiple locations compared to the LC 39B Assessment which assumed four astronauts moving together using a single egress method.
- SLS processing occurs in VAB Highbay 3. There are four highbays in the VAB. Each bay measures:
 - 450 feet high, 209 feet wide, and 228 feet long.



VAB at KSC

OVERVIEW VAB ASSESSMENT (CONT.)

Assembly and testing in VAB occurs over several months.

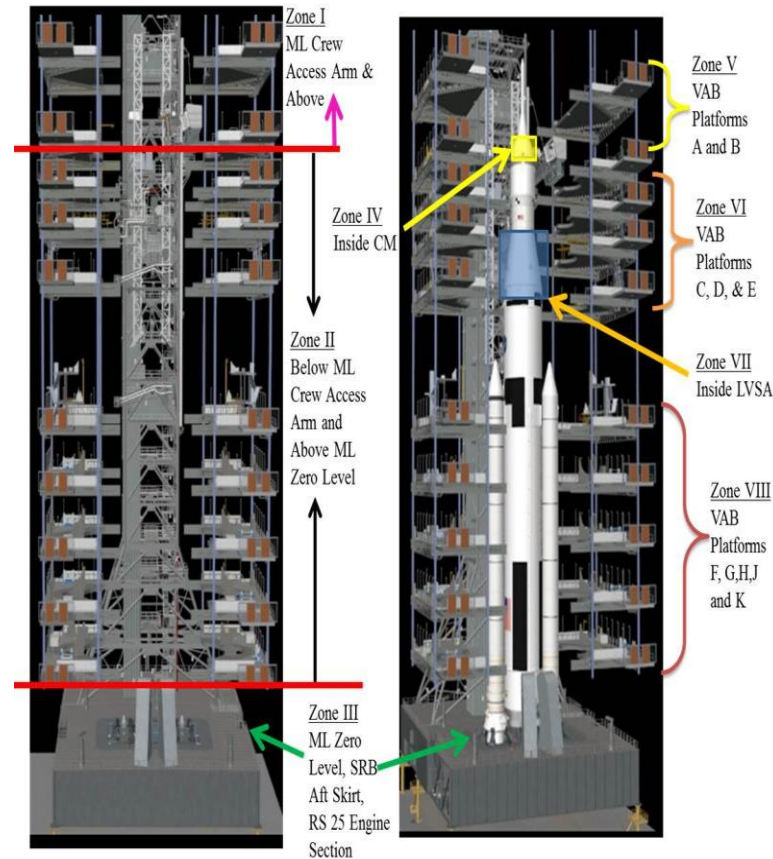
- Created eight different processing phases from the start of solid rocket motor erection to SLS/Orion roll out to the LC 39B.
- Each processing phase had different number of workers in these work locations, and duration of each phase also varied.

Multiple workers located in eight different zones.

- Each worker could take separate paths to reach an exit located ~30 – 180 feet.

Each work zone/phase assessed at eight different time intervals to reach an exit.

- Time to reach an exit was estimated at eight time intervals of: 0 sec, 10 sec, 20 sec, 30 sec, 1 min, 2 min, 3 min, and 5 min.



VAB Zones

METHODOLOGY AND CALCULATIONS

VAB EMERGENCY EGRESS ASSESSMENT

METHODOLOGY

Methodology developed for LC 39B assessment (hazard scenario development, likelihood, survivability estimates, and probability distribution) was used for the VAB assessment.

- FTA for VAB assessment produced 78 Initiating Events.

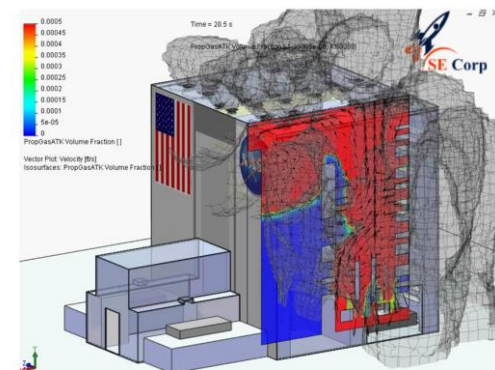
To determine survivability for multiple personnel at multiple locations for a specific time, an Aggregate Survival Level was calculated as a weighted average based on manloading and Survival Level assigned to each Zone.

- Aggregate survival level formula for an individual Initiating Event during one Phase and at one time interval is:

$$P(S_{\text{Aggregate}|E}) = \sum_{i=1}^8 \left[\left(\frac{\text{Headcount}_{\text{Zone } i}}{\text{Total Headcount}} \right) * P(S_{\text{Zone } i}|E) \right]$$

- As outlined in the LC 39B assessment, then P_S for all Zones, one Phase, one time interval and Initiating Event is:

$$P_S = 1 - P_D = (1 - (P_E * (1 - P_{S_{\text{Aggregate}|E}}))) \text{ [output]}$$



Computation Fluid Dynamic Analysis of a Solid Rocket Motor Fire in VAB



CALCULATIONS

One MS Excel File with eight MS Excel Workbooks

- Each Workbook captured the results from a single phase.

The largest MS Excel file contained:

- Eight workbooks (or tabs).
- Each workbook populated rows and columns with data that was:
 - 96 columns wide.
 - 715 rows deep.
- Processing time was between four to six hours for this large file using a dedicated laptop.
 - Laptop was comprised of:
 - Eight i7 Intel, 64 bit Processors.
 - 16 GB RAM.
 - MS Excel 64 bit software.
- An example of one workbook is shown on the next page.



CALCULATIONS (CONT.)

Probability of Survival at Time to Exit = 0 seconds

IF #1 of 4 (for this phase only)		Personnel Headcount by Zone			
Zone 2	Zone 3	Zone 4	Zone 5		
0	0	0	7		

IF #2 of 4 (for all phases)		IF #3 of 4 (for this phase only)			IF #4 of 4 (for this phase only and uses the Uncertainty Distributions from @RISK)						
Scenario	Scenario Likelihood			Survival Level at 0 Seconds			Input				
ID	Description	Min (or 5th Percentile)	Most Likely (or 50th Percentile)	Max (or 95th Percentile)	Work Zone	Min	Most Likely	Max	Scenario Likelihood	Survival Level at 0 sec	Probability of Survival at 0 sec
Scenario #	scenario	Min	MostLikely	Max	zoneNumber	UsecMin	UsecMost	UsecMax			
28	Mobile Launcher Fire Starts	0.000000162	0.00000162	0.00000162	I	1	1	1	+RiskPerc(C18,D14,E14)	+RiskPerc(H14,I14)	=1*(\$AF4*(1-AG14))
15		0.000000162	0.00000162	0.00000162	II	1	1	1	+RiskPerc(H15,I15)	+RiskPerc(H15,I15)	=1*(\$AF4*(1-AG15))
16		0.000000162	0.00000162	0.00000162	III	1	1	1	+RiskPerc(H16,I16)	+RiskPerc(H16,I16)	=1*(\$AF4*(1-AG16))
17		0.000000162	0.00000162	0.00000162	IV	1	1	1	+RiskPerc(H17,I17)	+RiskPerc(H17,I17)	=1*(\$AF4*(1-AG17))
18		0.000000162	0.00000162	0.00000162	V	1	1	1	+RiskPerc(H18,I18)	+RiskPerc(H18,I18)	=1*(\$AF4*(1-AG18))
19		0.000000162	0.00000162	0.00000162	VI	1	1	1	+RiskPerc(H19,I19)	+RiskPerc(H19,I19)	=1*(\$AF4*(1-AG19))
20		0.000000162	0.00000162	0.00000162	VII	1	1	1	+RiskPerc(H20,I20)	+RiskPerc(H20,I20)	=1*(\$AF4*(1-AG20))
21		0.000000162	0.00000162	0.00000162	VIII	1	1	1	+RiskPerc(H21,I21)	+RiskPerc(H21,I21)	=1*(\$AF4*(1-AG21))
23	40 Solid Rocket Booster (SRB) F 0	0	0	0	I	1	1	1	+RiskPerc(C23,D23,E23)	+RiskPerc(H23,I23)	=1*(\$AF23*(1-AG23))
24		0	0	0	II	1	1	1	+RiskPerc(H24,I24)	+RiskPerc(H24,I24)	=1*(\$AF23*(1-AG24))
25		0	0	0	III	1	1	1	+RiskPerc(H25,I25)	+RiskPerc(H25,I25)	=1*(\$AF23*(1-AG25))
26		0	0	0	IV	1	1	1	+RiskPerc(H26,I26)	+RiskPerc(H26,I26)	=1*(\$AF23*(1-AG26))
27		0	0	0	V	1	1	1	+RiskPerc(H27,I27)	+RiskPerc(H27,I27)	=1*(\$AF23*(1-AG27))
28		0	0	0	VI	1	1	1	+RiskPerc(H28,I28)	+RiskPerc(H28,I28)	=1*(\$AF23*(1-AG28))
29		0	0	0	VII	1	1	1	+RiskPerc(H29,I29)	+RiskPerc(H29,I29)	=1*(\$AF23*(1-AG29))
30		0	0	0	VIII	1	1	1	+RiskPerc(H30,I30)	+RiskPerc(H30,I30)	=1*(\$AF23*(1-AG30))
32	54 Other CM/SM Rupture	0.0000000694	0.00000347	0.00001735	I	1	1	1	+RiskPerc(C32,D32,E32)	+RiskPerc(H32,I32)	=1*(\$AF32*(1-AG32))
33		0.0000000694	0.00000347	0.00001735	II	1	1	1	+RiskPerc(H33,I33)	+RiskPerc(H33,I33)	=1*(\$AF32*(1-AG33))
34		0.0000000694	0.00000347	0.00001735	III	1	1	1	+RiskPerc(H34,I34)	+RiskPerc(H34,I34)	=1*(\$AF32*(1-AG34))
35		0.0000000694	0.00000347	0.00001735	IV	1	1	1	+RiskPerc(H35,I35)	+RiskPerc(H35,I35)	=1*(\$AF32*(1-AG35))
36		0.0000000694	0.00000347	0.00001735	V	0.5	0.75	1	+RiskPerc(H36,I36)	+RiskPerc(H36,I36)	=1*(\$AF32*(1-AG36))
37		0.0000000694	0.00000347	0.00001735	VI	0.37	0.72	1	+RiskPerc(H37,I37)	+RiskPerc(H37,I37)	=1*(\$AF32*(1-AG37))
38		0.0000000694	0.00000347	0.00001735	VII	1	1	1	+RiskPerc(H38,I38)	+RiskPerc(H38,I38)	=1*(\$AF32*(1-AG38))
39		0.0000000694	0.00000347	0.00001735	VIII	1	1	1	+RiskPerc(H39,I39)	+RiskPerc(H39,I39)	=1*(\$AF32*(1-AG39))
									+RiskPerc(C41,D41,E41)	+RiskPerc(H41,I41)	=1*(\$AF41*(1-AG41))

$$1 - (P_E * (1 - P_{S|E})) = P_S$$

$$P_E$$

$$P_{S_{zone i | E}}$$

$$P(S_{Aggregate|E}) = \sum_{i=1}^8 \left[\left(\frac{\text{Headcount}_{Zone i}}{\text{Total Headcount}} \right) * P(S_{Zone i | E}) \right]$$

- Trace Precedents and Dependents are on for Cells AF14, AG14:AG22, A022.
- Columns F and K - AE are hidden for clarity.

RESULTS

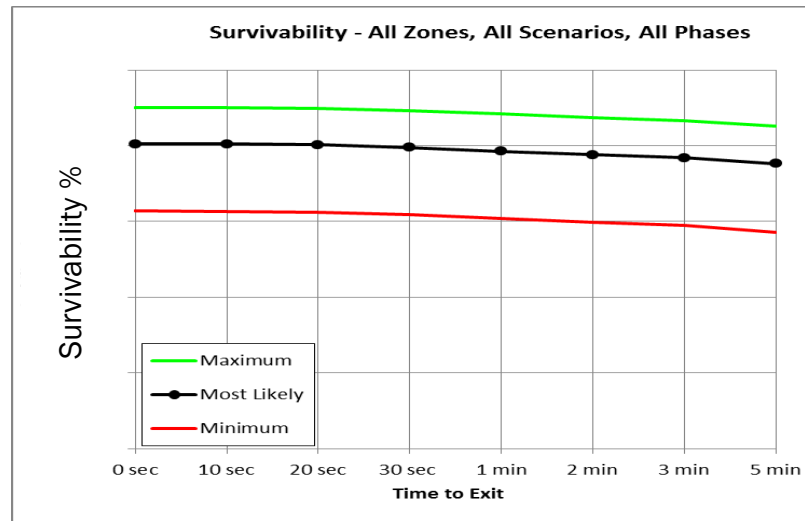
VAB EMERGENCY EGRESS ASSESSMENT

RESULTS

A composite scenario was developed, denoted $P(S_{All})$, which is the probability of surviving all initiating events for a given Phase, each time interval, and for all (aggregated) Zones.

A joint probability that contains 78 probabilities occurring at the same time mark. Thus, the VAB Emergency Egress Analysis formula for the probability of surviving all individual 78 Initiating Events at the same time is calculated in success space by:

$$P_{S_{All}} = \prod (P_{S_i}) = P_{S_1} * P_{S_2} * \dots * P_{S_{78}} \text{ [output]}$$



Notional Composite Survivability vs Time Plot



RESULTS (CONT.)

Pareto Analysis of all the hazard scenarios and all phases revealed slope of the survivability curve is dominated by five Instant Scenarios.

- These instant scenarios were five flight hardware stacking mishaps, arc flash, SRB fire, and propellant tank rupture.
 - Instant Scenarios were defined as: Survivability rapidly decreases within the first few seconds and remains constant thereafter.
- Degrading scenarios survivability estimates were within industry norms.
 - Degrading Scenarios were defined as: Survivability gradually decreases with time required to reach an Exit.

The figures of merit for the VAB assessment provided the decision makers with quantified risk to ground personnel during emergency egress in various operational concepts.

- Egress strategies (build enclosed egress paths, more egress paths, etc.) do not mitigate Instant Scenarios.
- \$6 - \$8 million cost avoidance.

SUMMARY

LC 39B AND VAB EMERGENCY EGRESS ASSESSMENTS



SUMMARY

Graphs developed from these assessments are a decision-informing tool for Project Managers which roll up multiple factors:

- The whole population of the LC 39B or VAB.
- A specific time period.
- A spectrum of potential events.
- Weighted by the likelihood of occurrence of the event.

Both assessments were conducted early in the design process and resulted in cost savings, including \$40 million cost savings in LC 39B emergency egress design.

The information in this presentation is published in NASA Technical Paper “Probabilistic Survivability versus Time Modeling”, NASA/TP–2015–218876 located at url address:

- <http://ntrs.nasa.gov> or
- <http://hdl.handle.net/2060/20150021266>.