

Advanced EVA: airlocks, rescue and suit contingencies



Conceptual visualization — EVA safety is a complete chain: suit, consumables, airlock, communications, buddy support, rescue path and return criteria.

Design extravehicular activity as a complete chain: preparation, airlock, mobility, tools, return, rescue and recovery after anomalies. The buddy system turns mutual monitoring into an explicit operational rule rather than an informal habit.

Before starting — Prerequisites: modules 00 to 40 recommended as relevant. Every important symbol is defined at first use.

Mastery objectives

- budget EVA consumables, rescue time, airlock availability and assisted-return margin as one system
- design rescue interfaces before a casualty occurs, including rover, suit, communications and medical handoff
- distinguish a suit anomaly, casualty problem and contaminated-airlock problem during triage
- protect rescuer reserve and settlement recovery capability while returning the casualty safely

1. EVA begins before the hatch opens

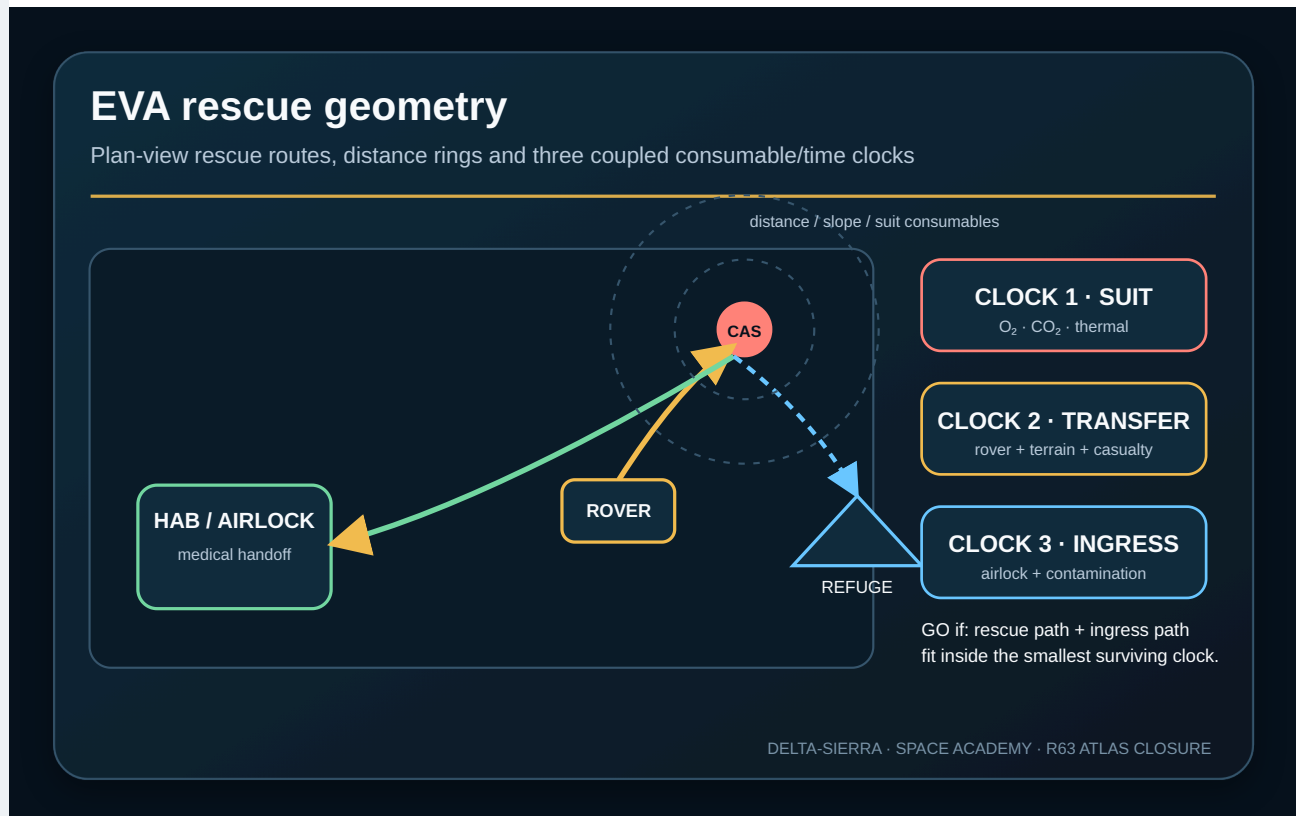
The sortie begins with suit preparation, consumable checks, tools, communications, work plan and abort criteria. A defect missed inside the airlock becomes much more expensive once a crewmember is far from the habitat.

2. Airlock: pressure, contamination and operational throughput

The airlock transfers people, atmosphere and dust. Its cycle manages depressurization, repressurization, leak checks, purge, storage and contaminated equipment. Airlock time belongs in the EVA budget and can become a bottleneck when several teams need to work outside.

3. Suited mobility: fatigue and real geometry

A tool that is easy in shirtsleeves can become difficult with pressurized gloves and limited mobility. Design must test grip, torque, visibility, posture and access. Repetitive tasks are organized so that excessive physical effort does not turn simple work into a return-to-base risk.



Rescue radius is constrained by casualty condition, transport, airlock availability and the refuge path at the same time. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.

4. Buddy system and mutual monitoring

Crewmembers monitor one another for suit state, mobility, behavior and consumption. The principle does not require them to stand side by side at all times, but ensures that a human or hardware anomaly can be noticed by another person.

5. Rescue when a crewmember cannot walk

The plan covers towing, rover transport, assisted airlock entry and medical handover. Reduced apparent weight on Mars helps some motions, but inertia remains. A suited person with equipment is still a large mass that must be accelerated, stopped and passed through limited

openings.

6. Lost communications or a suit alarm

Not every alarm has the same response. Some demand immediate return, while others require work stop and diagnosis. Procedures distinguish a suspected sensor fault from a real system failure without asking the crewmember to take additional risk merely to confirm the problem.

7. EVA consumables budget: several limits at once

EVA duration is not set by one gauge. Oxygen, carbon-dioxide removal, battery energy, cooling water, thermal state and fatigue impose several simultaneous limits. The plan must preserve a return reserve and then an additional reserve for helping a crewmember. An excursion consuming 95 percent of theoretical capacity leaves almost no room for a detour, stuck tool or slower travel. The budget is therefore updated during the EVA and secondary tasks are dropped before return margin is compromised.

8. Crewmember rescue: design the return before the accident

An injured crewmember may be unable to walk, control posture or operate airlock interfaces. The EVA system needs a method to move the combined body-and-suit mass, secure the casualty to rescue equipment and bring two people through the airlock in degraded configuration. A procedure that assumes manual carrying for several kilometres is not credible. Operating radius must include this case; as distance grows, vehicles, communications and consumable reserve become increasingly necessary.

9. Airlocks and contamination: return without bringing the terrain inside

An airlock manages pressure and contamination at the same time. Martian dust accumulates on seals, joints and external surfaces and can then enter occupied volumes. Return procedures include inspection, dust removal or containment, seal monitoring and separation of dirty

equipment. Repeated cycling is also a maintenance load: pumps, valves, sensors and seals are tracked by cycle count and symptoms. Changes in pump-down time or leakage can reveal degradation before failure. The airlock is monitored like a vehicle rather than treated as a simple door.

10. Worked example: rescue return endurance

A crewmember is 1.8 km from the airlock. Normal return speed is 3.0 km/h, so travel time is 0.6 h = 36 min. With a 40% assistance penalty, speed falls to 1.8 km/h and return takes 1 h. If emergency endurance is only 50 min, the location is incompatible with an assisted-return scenario unless a mobile rescue capability is available.

Calculated case study: return-time budget after an EVA anomaly

TEACHING ASSUMPTION — Planned life-support endurance is 8 h. After 3.25 h outside, the crew must preserve a 1.5 h contingency reserve and 0.75 h for airlock passage and medical handover.

Let T_{max} be endurance in hours; T_{elapsed} time already used; T_{reserve} the contingency reserve; T_{airlock} airlock and handover time; and T_{return} the maximum time available for return.

$T_{\text{return}} = T_{\text{max}} - T_{\text{elapsed}} - T_{\text{reserve}} - T_{\text{airlock}} = 8 - 3.25 - 1.5 - 0.75 = 2.5$ h. At an assumed assisted speed $v = 2$ km/h, maximum return distance is $d = v \times T_{\text{return}} = 2 \times 2.5 = 5$ km.

The result is not a real EVA radius. It illustrates the budgeting rule: reserve and airlock time are commitments that must be subtracted before estimating return capability.

11. Exercise

Plan an EVA 2 km from habitat and sequentially inject radio loss, ankle injury and a pressure alarm. For each case state the abort criterion, return route and role of the buddy.

12. Reasoned solution

First calculate the radius permitted by nominal return, then repeat the budget assuming one crewmember requires assistance and average speed falls sharply. The mission uses the more restrictive radius and preserves consumable reserve. If there is no way to transport an immobile crewmember, distance must be reduced or a rescue vehicle added.

13. Validation mini-project

Create a complete EVA operations package: airlock cycle, consumables, tools, communications, weather limits, abort criteria, rescue, assisted return, medical handover and technical debrief.

Advanced EVA is a rescue system that begins before the hatch opens

An extravehicular activity is not simply work performed outside. It is a chain linking suit readiness, airlock configuration, crew physiology, route planning, communications, consumables, tools, contamination control and a credible return path. The mission should be designed so that a predictable failure does not immediately convert productive work into an unrecoverable emergency.

The crew therefore plans abort criteria before departure. A suit anomaly, communication loss, unexpected fatigue, rover issue or weather-related visibility change needs a defined response that depends on distance and remaining resources. “Return if necessary” is too vague. Operators need to know when to stop the task, which route to take, whether one crewmember can assist another and what minimum consumable margin must remain at the airlock.

Airlocks are both pressure machines and contamination boundaries. Cycling consumes time and may consume gas depending on the architecture. Dust carried on suits can migrate into seals, bearings, electronics and the habitat. Layout must support buddy inspection, donning and doffing, tool transfer, rescue of a non-ambulatory person and decontamination without blocking the only pressure boundary.

Suit consumables have multiple independent limits. Oxygen quantity, carbon-dioxide removal, thermal control, electrical energy and water can each set the return deadline. The safest “remaining time” is controlled by the first resource to reach its protected limit, not by the

largest gauge. Human heat production and workload can also change consumption faster than a nominal timeline assumes.

Rescue has to be physically demonstrated. A conscious crewmember with an injured ankle, an unconscious crewmember and a suit with damaged mobility present different problems. Mars gravity reduces weight but not inertia, suit bulk or awkward geometry. The team must prove that available people and hardware can move a casualty through the planned route and airlock before relying on rescue as a mitigation.

Twelve control ideas for EVA, airlock and rescue operations

1. Define the EVA success condition and the abort condition together

Every EVA has objectives, but it also needs explicit conditions that stop work: consumable reserve, suit fault, crew medical symptom, loss of critical communication, navigation uncertainty or inability to maintain the planned rescue radius. The abort logic should be brief enough to remember and visible in procedures. It protects crews from the natural tendency to continue after investing time reaching the worksite.

Abort is not synonymous with failure. A crew that returns early while preserving people, suits and a recoverable system has executed the contingency correctly. Mission culture should reward correct conservative decisions so individuals do not hide fatigue or nuisance alarms to avoid disappointing the team.

2. Airlock throughput is an operational capacity

Donning, checks, pressure transition, egress, return, dust removal and doffing all take time. If several people or a casualty must pass through one lock, the airlock can become a bottleneck that controls rescue duration. Layout, storage and hatch geometry should be tested with suited crew and emergency hardware rather than judged from drawings.

The lock also needs a degraded strategy if a valve, sensor or pump fails. Can pressure be equalized manually or through an alternate path? Is another lock available? Can a person in a compromised suit wait safely? The answers determine how far the crew should travel from the habitat.

3. Consumable time is the minimum of several independent margins

A suit may show sufficient oxygen while carbon-dioxide scrubbing, battery energy or cooling water is closer to its limit. Operators should monitor each relevant resource and compute a conservative return margin based on workload. A single “percentage remaining” can obscure which subsystem actually controls endurance.

The reserve is protected for return and troubleshooting, not treated as useful work time. If the crew routinely uses contingency reserve to finish tasks, the nominal plan is too aggressive. Measured consumption from previous EVAs should update future planning rather than assuming every person and task matches one design average.

4. Thermal stress changes both performance and resource use

Hard physical work increases metabolic heat. The suit must remove that heat while maintaining acceptable humidity and temperature around the body. If cooling degrades, the crew can reduce workload, rest, change task sequence or abort. Thermal discomfort can also impair judgment before it becomes a clear equipment alarm.

Tool design and worksite posture matter because inefficient movement increases metabolic cost. A task easy in shirtsleeves can become exhausting in a pressurized suit with limited reach. EVA procedures should be developed from suited tests so timeline and consumable estimates reflect real biomechanics.

5. Communication loss needs a local script

A crew should not improvise from silence. The plan defines how long to attempt alternate channels, whether to move to a relay point, what visual or local signals remain available, and when loss of contact automatically triggers return. Navigation and buddy contact must remain possible even if Earth or habitat radio is unavailable.

Communication architecture can also fail partially. One crewmember may hear but not transmit; the rover link may work while the habitat link fails. Procedures should distinguish these cases and avoid unnecessary exposure while still preserving the ability to coordinate rescue.

6. Buddy checks are a human redundancy layer

Each crewmember can see parts of the other person's suit that are difficult for the wearer to inspect. Before egress and during stops, buddies can check connectors, visible damage, dust accumulation, tool security and behavioral signs of heat stress or confusion. This redundancy is valuable precisely because it uses a different observation path from suit sensors.

Buddy responsibility must not become vague social reassurance. Checklists identify specific items and trigger words. If one crewmember calls an abort for a defined reason, the pair follows the rule rather than negotiating under time pressure unless the procedure explicitly allows a branch.

7. Mobility radius should be based on rescue, not only on nominal travel capability

A rover can carry a healthy crew far from the habitat, but a rover failure or injured crewmember can transform the return problem. The mission should compare walking or alternate-vehicle capability, suit reserve, terrain and time. Distance becomes acceptable only when there is a credible degraded return path.

Rescue caches, tow capability or a second vehicle can extend the radius, but only if maintained and reachable. A theoretical asset parked at the habitat may not help a crew beyond walking range if no one is available to deploy it in time.

8. Casualty movement is a mechanical task that must be rehearsed

Mars gravity reduces the force needed to support body mass compared with Earth, but a suited casualty remains bulky and inertial. Dragging can damage the suit or snag hoses; carrying can overload the rescuer and make falls more likely. A stretcher, sled or rover interface should be selected and tested for the actual terrain and hatch geometry.

The rescue plan also addresses who controls the casualty's suit and how status is monitored during transport. An injured person may still be conscious and able to manage consumables; an unconscious person may require the buddy to interpret alarms and protect connectors. These are different procedures.

9. Dust control begins outside the pressure boundary

Dust can adhere to fabric, joints, seals and tools. The return sequence should remove as much contamination as practical before opening the clean habitat side. Dedicated dirty zones, suit interfaces or cleaning tools can reduce migration, but every added step consumes time and may be difficult during rescue.

The emergency plan therefore distinguishes normal decontamination from life-saving return. A casualty with a failing suit may need immediate ingress even if that brings more dust inside. The habitat then shifts to a post-event contamination response. Safety priorities should be explicit before the conflict occurs.

10. Tool and sample plans must leave hands and interfaces available for emergencies

Crews can become overloaded with containers, tethers and tools at the end of a successful EVA. A rescue or suit anomaly then demands free hands and uncomplicated movement. Packing rules should prioritize securing or abandoning replaceable equipment rather than forcing the crew to carry everything back during a contingency.

Tool attachment also protects suits from puncture and prevents debris from being lost. Sharp edges, rotating tools and hot equipment need stowage positions that do not interfere with the airlock or casualty handling. Worksite logistics is therefore part of EVA safety engineering.

11. Airlock contamination and rescue priorities can conflict

A normal return may include brushing, vacuuming, inspection and controlled staging before inner-hatch opening. During an emergency, those steps may be shortened or skipped to protect a person. The habitat should have a plan for the contamination that will then enter: isolate the receiving zone, protect sensitive equipment, clean surfaces and inspect seals.

This prevents hesitation at the worst moment. The crew does not need to choose between sanitation and rescue from first principles while someone is injured. The emergency priority is decided in advance, and the downstream cleanup capability makes that decision survivable for the habitat.

12. Debrief closes the loop between human performance and hardware reliability

After every EVA, operators compare planned versus actual timeline, consumable use, fatigue, communication quality, tool performance and anomalies. Small observations such as a stiff connector or repeated stumble can signal a design problem before it causes an incident. The debrief should capture both telemetry and subjective experience.

Changes then enter configuration and training control. Moving a tool, changing a route or altering an abort threshold should be documented and tested rather than passed informally between crews. EVA safety improves through cumulative operational memory.

EVA calculation laboratory: return margin and rescue radius

Formula 1 — return-time margin after an anomaly

$$M_{\text{return}} = T_{\text{limiting}} - T_{\text{return}} - T_{\text{reserve}}$$

Starting question

After an anomaly, how much time margin remains beyond the planned return and protected reserve?

Read aloud

Read: “return margin equals limiting consumable time minus estimated return time minus protected reserve.”

Symbols, pronunciation and meaning

T_{limiting} is time until the first critical suit resource reaches its limit under current conditions; T_{return} is estimated time to reach a safe pressure boundary; T_{reserve} is protected contingency; M_{return} is extra margin.

Units

All terms are in the same time unit, typically minutes.

Origin and status of values

Limiting time should come from the most restrictive suit resource and current workload. Return time comes from route and mobility assessment, not merely straight-line distance.

Why this operation

Subtraction protects both the expected trip and contingency. A negative result means the planned return is not credible under the stated assumptions.

Substitution and calculation

If limiting time is 110 min, estimated return is 55 min and protected reserve is 25 min: $M = 110 - 55 - 25 = 30$ min.

Calculator entry

Enter $110 - 55 - 25$.

Mental estimate

About half of 110 min is 55; removing another 25 should leave about half an hour.

Independent check

Add $30 + 55 + 25 = 110$ min to recover the limiting resource time.

Physical or operational interpretation

Thirty minutes of margin can absorb slower movement or troubleshooting, but it should not automatically be converted into extra work after the anomaly.

Plain-English translation

The crew has roughly thirty minutes beyond the modeled return and protected reserve.

Variation / sensitivity

If an injury increases return time to 80 min, margin falls to 5 min. If the limiting resource also degrades to 95 min, the same plan becomes negative by 10 min.

Limit / assumption

This simple margin assumes the limiting-time estimate is reliable. Real suit faults can change consumption dynamically, so conservative updating and early abort are essential.

What this does not prove

A positive return margin is not proof of crew survival. The limiting resource can deteriorate faster than predicted, casualty handling can slow the return, and the habitat or airlock may itself be unavailable when the crew arrives.

Boundary case to test

At $M_{\text{return}} = 0$ the modeled plan is exactly on its protected boundary, leaving no tolerance for further delay. A negative margin is an immediate redesign or abort signal. Because T_{limiting} is uncertain, the operational check should use a conservative lower estimate rather than the most optimistic resource duration.

Formula 2 — maximum rescue radius from a round-trip time budget

$$d_{\text{max}} = v_{\text{degraded}} \times (T_{\text{travel}} / 2)$$

Starting question

How far from the habitat can a crew operate if the rescue plan requires a round trip at a conservative degraded speed?

Read aloud

Read: “maximum one-way distance equals degraded speed times half of the travel-time budget.”

Symbols, pronunciation and meaning

v_{degraded} is conservative return speed; T_{travel} is total time available for outbound plus return travel inside the chosen contingency budget; d_{max} is one-way distance.

Units

If speed is kilometres per hour and time is hours, distance is kilometres.

Origin and status of values

Degraded speed should come from suited or rover contingency tests over representative terrain. Travel-time budget comes after protecting work, reserve and airlock time.

Why this operation

Dividing by two allocates equal nominal time to outbound and return travel. Multiplying speed by one-way time gives distance.

Substitution and calculation

If degraded speed is 2 km/h and the travel budget is 1.5 h total: one-way time = 0.75 h; $d_{\text{max}} = 2 \times 0.75 = 1.5$ km.

Calculator entry

Enter $2 \times (1.5 \div 2)$.

Mental estimate

At two kilometres per hour, three quarters of an hour is one and a half kilometres.

Independent check

A 1.5 km outbound leg and 1.5 km return at 2 km/h requires 1.5 h total, matching the budget.

Physical or operational interpretation

The result is a planning radius for this specific degraded return mode, not a limit on what the rover can physically drive in normal conditions.

Plain-English translation

In plain language: if rescue depends on moving at only 2 km/h, the crew should not plan beyond about 1.5 km under this time budget.

Variation / sensitivity

If terrain cuts degraded speed to 1 km/h, radius halves to 0.75 km. Adding a reliable rescue vehicle can change the governing contingency entirely.

Limit / assumption

The model assumes similar outbound and return terrain and constant speed. Slopes, obstacles, casualty handling and navigation uncertainty require additional margin.

What this does not prove

This radius is a geometric timing bound, not proof that a rescue route is traversable or that communications, navigation and casualty transport will work over that distance. Terrain and asymmetry can make the return leg slower than the outward leg.

Boundary case to test

If degraded speed is zero or the available travel-time budget is zero, the allowed radius must be zero. The division by two is valid only when the time budget is allocated symmetrically; a steep return climb or casualty transport breaks that assumption and requires separate outbound and inbound times.

Contingency cases: rehearse the return before the anomaly

A crewmember reports increasing heat stress but no suit alarm

The buddy takes the symptom seriously because human sensation can precede a threshold alarm. Work stops, the crew reduces exertion and checks suit indications, hydration status and cooling settings. If symptoms do not resolve promptly or the route is long, the conservative

action is return. Continuing high-workload tasks to “see if it improves” consumes both physiological and suit margin.

After return, telemetry and task video can reveal whether the cause was workload, cooling performance, garment fit or procedure. The event may justify changing task posture, tool leverage or work-rest cycles. Human performance data is an engineering input.

Habitat radio is lost while buddy communication still works

The pair follows the preplanned communication-loss branch. They attempt the alternate channel or relay point for the declared interval while maintaining mutual contact and navigation. If habitat contact is required for continued work, they begin return rather than finishing the task. The local buddy link prevents isolation but does not automatically replace lost mission support.

The crew records whether the failure was terrain masking, equipment or network configuration. Repeated dead zones can change route design or justify a relay. A known communication shadow should not remain an undocumented surprise.

One rover cannot move after the crew reaches the worksite

The decision starts with the degraded return plan. Can both crew walk safely inside suit reserves? Is a second vehicle available, and how long will deployment take? Can the failed rover provide shelter, power or communications while waiting? Work objectives become secondary until the return path is secured.

If rescue asset arrival consumes most of the suit margin, the crew may need to begin walking toward a rendezvous rather than remain stationary. These branches should be calculated in advance for representative distances, because the worst time to discover them is after a mobility failure.

A crewmember cannot walk after a fall

The buddy checks immediate hazards, consciousness, suit integrity and the casualty’s resource status before movement. The selected sled, stretcher or rover interface is deployed according to training. Nonessential tools and samples are abandoned if they interfere with transport. The route may change to avoid steep or rough terrain even if it is longer in distance.

Transport speed is compared with consumable margin continuously. Habitat personnel prepare the airlock and medical receiving area before arrival. Rescue is a coordinated system action, not solely a physical carrying task performed by the buddy.

Dust contamination is extreme after an emergency return

Life safety justifies shortening normal decontamination, but the habitat then treats the receiving zone as contaminated. Airflow can be managed to protect cleaner areas, exposed surfaces and seals are inspected, and sensitive equipment is isolated until cleaning is complete. Suit and tool handling remains documented so dust does not migrate unknowingly.

This case illustrates layered defenses. Normal prevention reduces routine dust load, while post-ingress containment protects the habitat when prevention must be bypassed. An architecture that has only a perfect normal process is brittle during emergencies.

A suit displays conflicting remaining-time estimates

Operators should identify which underlying resource measurements drive each estimate rather than selecting the larger number. If oxygen, battery and thermal systems disagree, the first conservative limit controls return unless a sensor fault can be independently demonstrated. The crew also considers workload and route conditions that can make the prediction optimistic.

After safe return, the discrepancy is investigated before the suit is cleared for another EVA. A countdown display is a derived product; reliable decisions require confidence in the sensors and models beneath it.

EVA contingency practice with reasoned solutions

Exercise 1 — Calculate return margin

A suit's limiting resource is estimated at 95 min. Return takes 50 min and the procedure protects 20 min reserve. What margin remains?

► Reveal the reasoned solution

Exercise 2 — Identify the limiting resource

Oxygen time is 160 min, battery time 125 min, carbon-dioxide control 140 min and cooling 150 min. Which value controls the conservative endurance estimate?

► Reveal the reasoned solution

Exercise 3 — Plan a rescue-radius calculation

Degraded walking speed is 1.5 km/h and only 80 min are available for total outbound-plus-return travel in the selected contingency. Estimate the symmetric one-way radius.

► Reveal the reasoned solution

Exercise 4 — Prioritize during a rover failure

The crew has reached a science site when its rover fails. What question comes before sample collection?

► Reveal the reasoned solution

Exercise 5 — Handle communication loss

Buddy radio works but habitat contact has failed. What should determine whether the task continues?

► Reveal the reasoned solution

Exercise 6 — Choose decontamination priority

A casualty arrives with a suspected suit injury and heavy dust. Should normal decontamination be completed before medical ingress?

► Reveal the reasoned solution

Exercise 7 — Design a buddy check

Name four categories a buddy can inspect that complement onboard sensors.

► Reveal the reasoned solution

Exercise 8 — Close the learning loop

Actual consumable use was 20% higher than planned during a drilling EVA. What should change before the next similar sortie?

► Reveal the reasoned solution

EVA contingency cases: suit anomalies, rescue and ingress

A suit glove develops reduced mobility during a tool-intensive task

The crewmember stops the high-force operation and the buddy inspects the glove and wrist interface for visible damage, dust accumulation or mechanical restriction. Reduced dexterity increases the chance of dropping tools, overexertion and poor connector handling even if pressure integrity remains normal. The team can switch to a lower-demand task only if return capability and suit status remain acceptable.

After ingress, the glove is not cleared merely because it held pressure. Bearings, restraint layers and contamination are examined, and the tool task is reviewed for excessive force or awkward posture. A mobility symptom can be an early maintenance signal.

A crewmember trips repeatedly on a route previously considered easy

Repeated stumbles may indicate fatigue, visibility loss, changed terrain, suit restriction or a medical issue. The buddy checks the person and the pair reduces pace rather than normalizing the pattern. If balance or cognition is uncertain, return begins while resources remain generous.

Route design is updated from the event. Small obstacles that look insignificant in imagery can become important in a suit with limited downward visibility. Marking or grading high-traffic paths may reduce future metabolic load and fall risk.

The airlock outer hatch cannot fully indicate closed

Operators distinguish a true latch problem from a sensor problem before changing pressure. Visual or mechanical secondary confirmation may be available, but the procedure should define exactly what evidence permits continuation. Cycling against an uncertain hatch state can threaten the pressure boundary.

If the lock cannot be made trustworthy, the crew uses the alternate ingress path if one exists or remains in the safest available configuration while support prepares recovery. Redundant sensing has value only when crews know how to arbitrate disagreement.

A suit begins losing pressure slowly during return

The crew treats trend rate and remaining travel time as a dynamic margin. The buddy can inspect for obvious external damage while movement continues toward safety if stopping would waste critical time. Nonessential equipment is abandoned and the habitat prepares rapid ingress. If a patch or isolation action is trained and can be applied faster than continuing, the procedure defines that branch.

The key is to avoid both extremes: ignoring a slow leak because current pressure is still acceptable, or spending excessive time troubleshooting far from the airlock while reserve disappears. Trend, distance and repair confidence drive the choice.

One crewmember becomes confused and gives inconsistent answers

The buddy assumes a possible physiological or suit-environment problem until proven otherwise. Work stops, suit telemetry and status are checked, and the pair returns. Debate about whether the person is “just tired” is inappropriate in the field because cognitive change can impair self-assessment and equipment management.

Habitat medical support prepares for evaluation. Later review considers carbon-dioxide control, thermal stress, dehydration, workload, sleep and other causes. Human signs are treated as legitimate sensors in the EVA system.

The primary navigation display fails in low-visibility dust

The crew transitions to the independent navigation method identified in planning: local beacons, rover reference, inertial/odometry aids, marked route or buddy cross-check depending on architecture. If position uncertainty exceeds the allowed envelope, return becomes the objective rather than continuing toward a target.

Navigation contingency is strongest when it does not depend on the same display, power bus or software path as the failed system. Independence matters more than having multiple icons that share one hidden source.

A rescue sled cannot fit through the inner airlock arrangement

This failure should be found in drills, not during a casualty. The design team can change stowage, hatch approach, sled geometry or the procedure for transferring the casualty inside the lock. A device that works outdoors but cannot complete the last two metres into medical care is not a complete rescue system.

Full-path validation includes corners, handholds, temporary tool clutter and the possibility that only one helper is available. Geometry under emergency load is a verification requirement.

A crew pair returns with one communication channel intermittent

Because contact still exists intermittently, the temptation is to finish the final task. The preplanned rule should instead consider whether loss can become total before the next safe decision point. The pair can move toward a stronger relay position while preserving buddy contact and route awareness.

Afterward, antenna placement, connector movement and terrain geometry are reviewed. Intermittency often provides diagnostic clues that a binary pass/fail test after return might miss.

Suit cooling remains functional but water reserve is falling faster than expected

Operators compare actual workload and coolant usage with the predicted profile. If the cooling consumable is now the limiting resource, the return clock changes even though oxygen and battery remain generous. The team reduces work intensity and heads back according to the new conservative limit.

The discrepancy feeds future planning. A task with high arm force or repeated climbing may consume more cooling resource than a timeline based mainly on distance. Consumable models should be task-sensitive where evidence supports it.

A sharp tool damages an external suit cover but not the pressure layer

The buddy secures the tool and inspects the affected region without unnecessarily stressing it. If pressure and other suit functions remain stable, the procedure may permit controlled return rather than emergency ingress, but further work with the damaged area is avoided. The damage is documented so maintenance can inspect hidden layers.

Tool design and stowage are reviewed because preventing recurrence is more valuable than relying on the pressure layer to survive repeated insults. Protective outer layers are part of the system even when they are not the final gas barrier.

A planned EVA crosses beyond walking return range using one rover

The mission should identify what rescues a crew if that rover becomes immobile. A second independently deployable vehicle, cached support or proven repair capability can close the gap. Without such a path, normal rover range is not a safe EVA range. The crew might deliberately limit distance until rescue assets mature.

This is a system-level trade between science reach and infrastructure. Expanding geographic exploration often requires expanding rescue logistics first.

An emergency ingress bypasses normal dust removal

Once the casualty is stable, the receiving area becomes a contamination-control problem. Airflow, portable filtration, surface cleaning and seal inspection are used to prevent dust from migrating to sleeping, medical or sensitive equipment zones. Suit and tool locations are tracked until decontamination is complete.

Designating a dirty emergency receiving zone makes this manageable. The habitat does not need to choose between human rescue and preserving every normal cleanliness rule because it has a downstream containment layer.

A crewmember reports that the return route feels longer than the outbound trip

Fatigue, slope direction, tool load and reduced visibility can make return performance worse even over the same path. Planning that assumes symmetric speed may therefore be optimistic. Measured outbound and return times from previous EVAs should inform route-specific margins.

If the crew is carrying samples or assisting a tired partner, the difference can grow further. Return estimates should be updated during the EVA rather than remaining frozen at the pre-mission value.

Post-EVA review finds a recurring connector mistake

If multiple crews struggle with the same connector orientation or latch, retraining alone may not be sufficient. The interface can be redesigned with better keying, tactile feedback, lighting or labeling. Procedures can include a buddy confirmation until the hardware change is available.

Human-error data should improve design. Repeated difficulty is evidence about the interface, not proof that every new operator independently failed to pay attention.

EVA design dossier: rescue verification and long-duration readiness

Design dossier — calculate the contingency from the worksite back to pressure safety

Return planning should include more than travel distance. The crew may need to secure tools, reach the rover, traverse terrain, enter the airlock, connect support equipment and complete enough pressure transition to reach a safe environment. An anomaly at the worksite can therefore have a longer time-to-safety than the map suggests.

Drills should measure the complete sequence under realistic suited conditions. The protected reserve is then based on demonstrated time plus uncertainty, not on walking speed alone. This is particularly important for distant sites where every minute of airlock handling consumes the same suit resources as travel.

Design dossier — distinguish suit leak response by rate and location

A rapidly growing leak near a reachable component may justify immediate local action, while a slow stable leak can favor uninterrupted return. The procedure should consider whether applying a patch requires bending, tool use or buddy exposure that could make the situation worse. The crew should not assume every pressure loss has the same best response.

Training can use representative leak-rate scenarios so operators learn to interpret trend rather than react to the word “leak” alone. The priority remains reaching a safe pressure boundary with the largest credible margin.

Design dossier — prepare the airlock for a casualty before the crew arrives

Habitat support can clear equipment, configure the lock, stage medical gear and determine who will receive the casualty while the EVA pair is still returning. This parallel preparation reduces the time a compromised suit spends outside. Communications should transmit only the information needed to configure the response rather than burdening the buddy with long reporting requirements.

Roles are preassigned so several helpers do not block the hatch or compete for access. Rescue throughput depends as much on interior choreography as on the outdoor transport device.

Design dossier — manage suit-to-suit differences explicitly

Two suits of the same model can have different maintenance history, battery health, cooling performance or fit. EVA planning should use each suit's current configuration and demonstrated consumable margins rather than treating them as interchangeable serial numbers. The pair's conservative endurance is often controlled by the weaker current configuration.

Configuration records also protect rescue. If one suit has a temporary limitation, the buddy and control room know what intervention is possible and what tools or spare components are relevant.

Design dossier — include medical self-rescue capability in tool planning

Minor injury management outside may require a simple immobilization aid, vision cleaning method or means to stabilize a person until ingress. The objective is not to create a full field hospital but to preserve mobility and suit integrity. Any medical item carried must be operable with gloves and compatible with pressure garments.

Payload decisions compare this capability against mass and clutter. High-value contingency tools are those that meaningfully change whether the crew can return, not those that duplicate treatment better performed inside the habitat.

Design dossier — control fatigue before it becomes an emergency

EVA timelines should include expected high-workload periods and opportunities to slow or rest. Heart rate or other physiological indicators may help where available, but buddy observation and self-report remain important. A crew that reaches the worksite already near its fatigue limit has reduced capacity for the unexpected return.

Post-EVA data can identify tasks whose mechanical design creates unnecessary effort. Improving tool leverage or moving a work surface can create more safety margin than simply increasing nominal suit consumables.

Design dossier — make route markers resilient to dust and darkness

A route that depends on subtle visual landmarks may become difficult under dust, low sun angles or local darkness. Navigation aids should be visible or detectable under the conditions that matter for emergency return. Markers, beacons or mapped waypoints also need a failure mode so one missing cue does not erase the route.

The crew should practice returning with the primary navigation aid unavailable. Familiarity with alternate cues reduces cognitive load when another anomaly is already consuming attention.

Design dossier — verify suitport or airlock interfaces after any hardware change

Changing a suit component, storage rack or internal handrail can alter clearance during ingress. Rescue geometry is especially sensitive because a casualty cannot reposition themselves to fit. Configuration changes around the lock should therefore trigger a physical clearance check with representative suit bulk and rescue hardware.

This prevents gradual “barnacle growth” of useful equipment around the airlock from eroding the emergency path. The rescue corridor is protected space, not spare storage.

Design dossier — measure contingency performance, not only nominal EVA productivity

An EVA program can look increasingly efficient because crews complete more tasks per hour, while rescue time and reserve quietly worsen as routes extend. Performance reviews should track distance to safety, protected consumable margin, communication coverage, casualty-movement drill time and airlock turnaround alongside science or maintenance output.

This keeps operational success aligned with survivability. Productivity is valuable only when the system still has room to absorb the failure that has not happened yet.

Final synthesis for mission qualification

Final synthesis — EVA distance is governed by the worst credible return, not the best nominal rover trip

Exploration range should expand only as rescue infrastructure expands. The critical question is what happens after a rover failure, a mobility injury, communication loss or suit anomaly at the farthest point. If the only answer assumes the same hardware that has just failed, the operational radius is overstated. A defensible EVA envelope links terrain, degraded speed, suit reserve, alternate transport, airlock throughput and the number of people available to assist a casualty.

Final synthesis — the airlock is part of the rescue vehicle

The last metres of an EVA can dominate survival time because the crew still must pass through hardware, pressure transitions and interior handling before reaching a safe environment. Rescue verification should therefore include the full path from worksite to medical receiving area, with realistic suit bulk, tools, dust and casualty geometry. A stretcher that reaches the habitat door but cannot negotiate the lock is not rescue capability. The airlock layout must be protected from storage creep and rechecked after configuration changes.

Final synthesis — operational memory keeps EVA safety from resetting with each crew

Consumable trends, communication dead zones, awkward connectors, repeated fatigue points and near-misses should accumulate into a controlled knowledge base. Procedures, route plans, hardware modifications and training then evolve from evidence rather than anecdote. The objective is not to eliminate uncertainty but to make every EVA leave the next crew with a better model of the suits, terrain and rescue system. A mature EVA program learns faster than hazards can repeat.

Qualification notes

Qualification note — protect a minimum communication and navigation package

Even when mission radios and mapping displays are highly capable, the contingency architecture should retain a simpler independent means of maintaining buddy coordination and returning toward safety. The backup does not need every feature of the primary system; it needs

enough independence to support the abort path when the main network or display is the failed element.

Qualification note — treat suit maintenance status as part of EVA planning

A suit recently repaired, a battery near retirement or a component under temporary inspection interval may justify a shorter route or larger reserve until confidence is restored. The planning tool should therefore read current configuration and maintenance state, not only suit model. Operational limits follow evidence about the actual hardware being worn.

Qualification note — verify rescue after crew composition changes

A rescue method proven with one crew may not remain valid when body sizes, strength, injury limitations or staffing change. Requalification should include representative team composition and the possibility that the strongest person is the casualty. The goal is a method supported by equipment and procedure, not by one exceptional individual.

Qualification note — preserve a conservative return trigger after success

Crews are most tempted to spend reserve when the work is going well and only one final task remains. Procedures should make the protected return trigger culturally non-negotiable unless a higher-level emergency requires otherwise. Finishing a sample or tightening one last fastener is never worth converting contingency margin into routine work.

Final rescue note

A credible EVA program keeps enough unused capability that the crew can absorb slower-than-planned movement, a delayed airlock cycle or an assisting task during return. If nominal work consumes all of the measured endurance, rescue exists only on paper because the first ordinary delay erases the remaining safety margin.

Final training note

Contingency drills should rotate roles so every qualified crewmember practices being rescuer, casualty assistant, airlock receiver and control-room coordinator. Role rotation exposes interface assumptions and prevents the rescue plan from depending on one person who may be unavailable during the event.

Completion note

Before approving the next EVA, the control team should compare planned range, rescue method, current suit health, airlock availability and crew fitness in one integrated review. A strong result in four categories cannot compensate for a missing fifth category that breaks the return path. EVA authorization is therefore a system decision, not a checklist of independent green lights.

Interactive beginner glossary

The terms below connect suit engineering with the actions a crew must take in the field.

- EVA — Extravehicular activity: planned work performed outside the protected pressurized habitat or vehicle.
- airlock — A pressure chamber used to transfer people or equipment between environments at different pressure.
- egress — The controlled act of leaving the protected vehicle or habitat for EVA.
- ingress — The controlled return from EVA into a protected pressure boundary.
- abort criterion — A predefined condition that requires the crew to stop the task and transition toward safety.
- consumable — A limited resource used during EVA, such as oxygen, battery energy or carbon-dioxide removal capacity.
- limiting resource — The resource predicted to reach its protected limit first and therefore control endurance.
- return margin — Time or resource remaining after accounting for expected return and protected contingency.
- buddy system — A paired operating method in which crewmembers monitor and assist each other.
- buddy check — A structured visual or functional inspection performed by one crewmember on another.
- rescue radius — The maximum practical distance consistent with a defined degraded return or rescue capability.
- degraded mode — A reduced-capability operating state used after a failure while preserving essential functions.

- thermal control — The suit function that keeps body and equipment temperatures within acceptable limits.
- metabolic load — The rate at which a person produces heat and uses physiological resources while working.
- work-rest cycle — A planned alternation of activity and recovery used to manage fatigue and heat.
- communication loss — A condition in which one or more planned voice or data links are unavailable.
- relay point — A location or device used to restore communication around terrain or range limitations.
- casualty — A person who is injured, ill or otherwise unable to continue normal operations.
- non-ambulatory — Unable to walk without assistance.
- stretcher — A device used to support and move a casualty.
- sled — A low-friction transport device that can move a casualty or cargo over a surface.
- contingency reserve — Resource intentionally protected for abnormal conditions rather than planned task completion.
- suit integrity — The condition of the suit pressure boundary and critical life-support interfaces.
- pressure boundary — The sealed structure that separates the pressurized crew environment from the external atmosphere.
- dust mitigation — Measures used to reduce dust attachment, transport and entry into equipment or habitat.
- decontamination — Controlled removal or containment of unwanted material from suits, tools or surfaces.
- configuration control — Tracking the approved state of hardware, software and procedures so changes remain traceable.
- tool tether — A restraint that keeps equipment attached to the crewmember or worksite.
- post-EVA debrief — Structured review of timeline, anomalies, human performance and hardware behavior after return.
- return-to-service check — Verification required before a suit, airlock or tool is cleared for another operational use.

Operational review checklist

- Define success and abort criteria in the same EVA plan.
- Calculate endurance from the first limiting resource, not the most generous display.
- Protect return and contingency reserve from routine task extension.
- Measure airlock cycle and casualty throughput with suited drills.
- Plan alternate pressure and egress paths where architecture permits.
- Use measured workload and consumable history to update timelines.
- Give communication-loss cases explicit local actions and return triggers.
- Base operating radius on a credible degraded return or rescue mode.
- Demonstrate casualty movement with actual suits, terrain and hatch geometry.
- Keep buddy checks specific enough to complement electronic monitoring.
- Provide a method to abandon or secure nonessential tools during rescue.
- Separate normal dust decontamination from emergency ingress priorities.
- Prepare the habitat receiving zone for a contaminated emergency return.
- Debrief every EVA and route recurring issues into configuration and training control.
- Do not clear a suit after an unexplained alarm or timing discrepancy without investigation.

EVA calculation studio: return margin, consumables, pressure and rescue geometry

EVA planning is not an endurance contest. A sortie is acceptable only while several independent limits remain positive: life-support consumables, electrical energy, thermal control, communications, physical ability, navigation confidence, airlock availability and a credible rescue path. The equations below are teaching models for reasoning about those limits.

Formula A – limiting return margin

Question. After accounting for the trip home and a protected reserve, how much time remains before the earliest limiting resource is reached?

$$M_{\text{return}} = T_{\text{limiting}} - T_{\text{return}} - T_{\text{reserve}}$$

Read aloud. “Return margin equals limiting time minus return time minus reserve time.”

Teaching calculation. Earliest modeled limit $T_{\text{limiting}} = 180$ min, expected return $T_{\text{return}} = 70$ min and protected reserve $T_{\text{reserve}} = 40$ min. $M_{\text{return}} = 180 - 70 - 40 = 70$ min.

Interpretation. A positive result is necessary but not sufficient. If navigation, mobility or airlock status deteriorates, T_{return} may increase and the margin must be recalculated.

Formula B – idealized oxygen endurance

Question. In a simplified mass budget, how long does a usable oxygen quantity last at a stated consumption rate?

$$t_{\text{O}_2} = m_{\text{O}_2, \text{usable}} / \dot{m}_{\text{O}_2}$$

Read aloud. “Oxygen endurance equals usable oxygen mass divided by oxygen mass-flow rate.”

Teaching calculation. Use a purely illustrative training model with 0.90 kg usable and 0.06 kg/h average modeled consumption. $t_{\text{O}_2} = 0.90 / 0.06 = 15$ h.

Unit check. $\text{kg} \div (\text{kg/h}) = \text{h}$.

Important limit. This number is not a suit operational endurance recommendation. Real EVA duration is constrained by multiple consumables, metabolic rate, carbon-dioxide control, thermal conditions, battery capacity, suit design and mission rules.

Formula C – idealized electrical endurance

Question. How long can usable electrical energy support an average electrical load?

$$t_E = E_{\text{usable}} / P_{\text{avg}}$$

Teaching calculation. With a hypothetical 1.8 kWh usable energy reserve and 0.25 kW average electrical demand, $t_E = 1.8/0.25 = 7.2$ h.

Reverse check. $0.25 \text{ kW} \times 7.2 \text{ h} = 1.8 \text{ kWh}$.

Limit. Peak loads and low-temperature battery behavior can constrain operations before the simple energy quotient is reached.

Formula D – symmetric rescue radius

Question. What is the farthest distance compatible with an out-and-back travel-time reserve in a simple symmetric model?

$$R_{\text{rescue}} \leq v_{\text{degraded}} \times t_{\text{available}} / 2$$

Teaching calculation. With degraded movement speed 2 km/h and 1.5 h allocated to travel, $R_{\text{rescue}} \leq 2 \times 1.5 / 2 = 1.5$ km.

Unit check. $\text{km/h} \times \text{h} = \text{km}$.

Limit. The division by two assumes outbound and return travel take equal time. Carrying an injured person, slope or terrain can make return much slower, so this is an upper bound for the simplified case.

Formula E – pressure force on a hatch or panel

Question. Why can a modest-looking pressure difference create a large mechanical force over a large area?

$$F = \Delta P \times A$$

Read aloud. “Force equals pressure difference multiplied by area.”

- **F:** force, newtons.
- **ΔP :** pressure difference, pascals.
- **A:** area, square metres.

Teaching calculation. For a deliberately simple example, $\Delta P = 20 \text{ kPa} = 20,000 \text{ Pa}$ and $A = 0.50 \text{ m}^2$. $F = 20,000 \times 0.50 = 10,000 \text{ N}$.

Unit check. $\text{Pa} = \text{N/m}^2$; $\text{N/m}^2 \times \text{m}^2 = \text{N}$.

Interpretation. Pressure equalization and mechanical interlocks matter because force scales directly with both pressure difference and area.

Formula F – partial pressure of a gas in an ideal mixture

Question. In an ideal gas mixture, what partial pressure corresponds to a gas fraction?

$$p_i = x_i \times P_{\text{total}}$$

Read aloud. “Partial pressure of component i equals its mole fraction multiplied by total pressure.”

Teaching calculation. For a purely illustrative mixture with $x_i = 0.20$ and $P_{\text{total}} = 70 \text{ kPa}$, $p_i = 0.20 \times 70 = 14 \text{ kPa}$.

Unit check. Dimensionless fraction×kPa = kPa.

Limit. This calculation describes mixture composition under the ideal model. It does not establish physiological safety, suit set points or decompression procedures.

Formula G – average pressure-change rate

Question. How quickly did pressure change over a measured interval?

$$r_P = \Delta P / \Delta t$$

Read aloud. “Pressure-change rate equals pressure change divided by elapsed time.”

Teaching calculation. If a test volume changes by 12 kPa over 6 min, average rate magnitude is $12/6 = 2$ kPa/min.

Interpretation. A rate helps compare events and detect whether a trend is accelerating or stabilizing when recomputed over successive intervals.

Limit. An average rate can hide fast transients. Operational limits must come from the actual system design and procedures, not this generic example.

Formula H – decontamination reduction model

Question. If a modeled process removes a stated fraction of a surface contaminant indicator, what amount remains?

$$C_{\text{after}} = C_{\text{before}} \times (1 - \eta_{\text{decon}})$$

Teaching calculation. If a teaching indicator begins at 80 arbitrary units and a modeled step removes 75%, remaining fraction is 0.25; $C_{\text{after}} = 80 \times 0.25 = 20$ units.

Independent check. Removed amount = $80 - 20 = 60$ units, which is 75% of 80.

Limit. Real decontamination effectiveness is contaminant-, surface-, method- and condition-dependent. One indicator or modeled efficiency cannot prove comprehensive cleanliness.

Integrated EVA turn-back exercise

In a teaching scenario, the earliest remaining resource limit is 160 min away. Estimated return time is 65 min and policy preserves 35 min reserve. A new terrain condition increases return time by 20 min. Calculate the margin before and after the change.

Solution. Initial margin = $160 - 65 - 35 = 60$ min. Revised return time = 85 min. Revised margin = $160 - 85 - 35 = 40$ min. The correct operational lesson is not merely “40 min remain”: the changed terrain has consumed one third of the previous margin and may also change mobility energy and rescue assumptions, which must be reviewed separately.

EVA calculation laboratory: endurance is a budget, not a clock on the sleeve

An EVA ends safely only if oxygen, carbon-dioxide removal, electrical energy, cooling, communications and crew capability all retain adequate margin for return and contingency actions.

Idealized oxygen endurance

$$t_{\text{O}_2} = m_{\text{usable}} / \dot{m}_{\text{O}_2}$$

Read aloud. Oxygen endurance equals usable oxygen mass divided by oxygen consumption rate.

Teaching scenario only. Suppose a training model assigns 0.90 kg usable oxygen and a modeled metabolic consumption of 0.06 kg/h. Idealized endurance is $0.90/0.06 = 15$ h. A planned 6 h EVA would have an oxygen-only ratio of $15/6 = 2.5$.

Limit. These are invented teaching values, not suit specifications. Real EVA duration is constrained by several consumables and physiological limits; the first limiting resource governs.

Electrical endurance

$$t_E = E_{\text{usable}} / P_{\text{average}}$$

With a hypothetical 1.8 kWh usable battery and a 0.25 kW average electrical demand, ideal endurance is $1.8/0.25 = 7.2$ h. If heaters, pumps or communications increase the average load, endurance falls. The same calculation should therefore be repeated for nominal, cold-case and rescue modes.

Unit check. kWh ÷ kW = h.

► Exercise — identify the limiting resource

First-Man EVA rescue: the survival clock starts before the distress call

Advanced EVA planning treats rescue as part of mission design. A suited crew may face mobility injury, suit leak, loss of cooling, rover failure, navigation uncertainty or airlock unavailability. The rescue architecture must answer who detects the event, who can reach the crew, how the casualty is transferred, which pressure boundary receives them and what happens if the nearest nominal airlock is itself the failed element.

Recognise

crew report, telemetry,
missed checkpoint

Stabilise

oxygen, cooling,
mobility, shelter

Recover

buddy, rover, tow or
rescue team

Repressurise

airlock/refuge
available and
medically ready

Rescue radius is set by time-to-consequence

Distance alone is misleading. A crew 6 km away on easy terrain with a healthy rover may be more recoverable than a crew 2 km away across a steep boulder field. The operational radius should therefore be derived from detection delay, preparation time of the rescue asset, transit, casualty transfer and repressurisation, all compared with the casualty's limiting consumable or physiological clock.

Mission planners should also ask what happens when the injured person cannot assist. Can the healthy crewmate move a suited casualty? Is there a litter or mechanical aid? Can the rover accept an incapacitated suited person? Does the airlock geometry allow transfer without removing life support prematurely? A rescue concept that works only for a walking casualty is incomplete.

The airlock can be part of the emergency

Dust contamination, fire, pressure-control failure or a blocked hatch can make the planned ingress route unavailable. Distant operations need alternate refuge or ingress strategies. These do not have to duplicate the full habitat, but they should extend survival long enough for a controlled recovery and be compatible with the pressure and contamination constraints of the suit.

Exercise: reject an attractive science route

A geology site lies 11 km from the habitat and can be reached with comfortable rover energy margin. However, the rescue rover is undergoing maintenance, the route has no pressurised refuge and a suited casualty cannot be transported in the science rover without removing cargo that is already on board. Energy says "reachable"; rescue architecture says "not dispatchable." Delay the route or restore a credible casualty-recovery path before departure.

An EVA rescue remains safe only while all relevant consumable and timing clocks stay above their protected reserves. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.

Operational qualification lab: rescue an EVA crewmember without creating a second casualty

An EVA contingency is a coupled problem in physiology, suit resources, navigation, airlock configuration and human workload. The wrong instinct is to run toward the casualty before defining the resource clock. A rescue plan begins by identifying what is failing, how quickly it can become unsurvivable, what route is still usable and whether the rescuer's own suit and ingress path remain protected.

Separate diagnosis from rescue priority

The crew does not need a perfect diagnosis before acting, but it does need the right hazard class. A slow mobility impairment with stable suit pressure is different from rapid pressure loss, rising carbon dioxide, loss of cooling or incapacitation. The first radio call should therefore capture a small set of discriminating indicators: suit pressure trend, oxygen status, carbon-dioxide warning, cooling status, location, mobility and consciousness. These observations determine whether the priority is self-return, buddy assistance, emergency oxygen, rapid ingress or shelter in a nearer pressurised volume.

Rescue time margin

$$M_{\text{time}} = t_{\text{limit}} - (t_{\text{detect}} + t_{\text{reach}} + t_{\text{stabilize}} + t_{\text{ingress}})$$

1 – Concrete question

Does the planned rescue sequence finish before the limiting suit or physiological clock expires?

2 – Intuition

Start with the available clock and subtract every delay that must occur before the casualty reaches a safer pressurised state.

3 – Quantities

Estimate the limiting time conservatively, then include detection, travel, stabilization/transfer and ingress.

4 – Formula

Time margin equals the limiting duration minus the sum of required rescue durations.

5 – Read aloud

"M time equals t limit minus t detect plus t reach plus t stabilize plus t ingress."

6 – Symbols

Each t is a duration; M_{time} is the remaining margin after the planned sequence.

7 – Pronunciation

The subscript names the phase; it is not a multiplication term.

8 – Units

Use one time unit throughout, commonly minutes.

9 – Convention

A positive margin means the sequence fits inside the assumed clock; negative margin means it does not. The sign convention must be stated.

10 – Why subtraction

Each phase consumes part of the finite clock, so delays add before being removed from the available time.

11 – Assumptions

The limiting clock itself may be uncertain. Use a conservative bound rather than the most optimistic estimate.

12 – Unit check

$\text{min} - (\text{min} + \text{min} + \text{min} + \text{min}) = \text{min}.$

13 – Numerical case

Conservative rescue limit: $t_{\text{limit}} = 40 \text{ min}.$

Detection and decision: 4 min.

Travel to casualty: 10 min.

Stabilisation and transfer: 7 min.

Ingress and repressurisation: 11 min.

Total rescue chain = $4 + 10 + 7 + 11 = 32 \text{ min}.$

$M_{\text{time}} = 40 - 32 = 8 \text{ min}.$

14 – Operations

Add unavoidable durations first: $3 + 8 + 5 + 9 = 25$. Subtract from the 32-minute limit.

15 – Algebra check

Required sequence plus margin should recover the limit:
 $25+7=32$ min.

16 – Mental estimate

The sequence consumes roughly three quarters of the clock, so a single-digit-minute margin is plausible.

17 – Interpretation

Seven minutes is not “spare EVA time”; it is uncertainty and execution margin.

18 – What it does not prove

It does not prove the casualty can be physically moved, that the route is clear or that the airlock is ready.

19 – Sensitivity

If ingress is delayed by six minutes because the airlock is occupied, margin drops to one minute. Airlock configuration is therefore part of EVA rescue readiness.

20 – Practice

Guided exercise. Recompute rescue margin for a 40-minute conservative limit with phase times 4, 10, 7 and 11 minutes.

Detailed guided correction.

1. Rescue-chain time = $4 + 10 + 7 + 11 = 32$ min.
2. Margin = $40 - 32 = 8$ min.
3. Eight minutes is the remaining temporal protection under the assumed limit; it is not a guarantee because terrain, suit performance and casualty condition may add delay.

Autonomous exercise. Route A reaches the casualty in 8 minutes but crosses terrain assessed to add a 20% chance of a 6-minute delay. Route B requires 11 minutes with no identified delay mechanism. Other rescue phases total 20 minutes and the protected limit is 40 minutes. Compare deterministic margins and explain the route choice.

► Autonomous correction – open after attempting the exercise

21 – Mission decision

If predicted margin falls below the accepted rescue threshold, change the architecture: stage a rover, move the safe haven, shorten the traverse or precondition the airlock before EVA.

Protect the rescuer and the airlock

Rescue equipment should be staged around credible casualty modes: tow aids, connectors, emergency oxygen interfaces if designed, restraint, medical receiving equipment and a route clear enough for two suited people. The airlock must be able to receive the casualty without forcing unsafe improvisation. A second EVA crewmember becoming exhausted, contaminated or resource-limited can convert one emergency into two.

Qualification drill

Plan a rescue from a worksite 600 m from the habitat. Inject one mobility injury, then repeat with a suit-cooling warning. For each case, identify the limiting clock, the minimum observations needed, the rescue route, the role of the second crewmember and the airlock state before the casualty arrives. Explain one circumstance in which aborting the science task earlier is safer than relying on a technically possible rescue.

Source context. NASA EVA tools, crew training and NASA-STD-3001 provide the operational and human-systems context. The timing values above are teaching assumptions, not suit certification data. [NASA JSC — Crew & Operations Training](#).

R61 EVA rescue architecture: save the casualty without consuming the settlement's last safe margin

An EVA rescue is a system problem involving the casualty, rescuers, suits, rovers, airlocks, medical handoff, contamination control and settlement consumables. A rescue plan that focuses only on reaching the casualty can create a second casualty or contaminate the only usable

airlock. The course therefore treats rescue as a staged architecture with explicit clocks and boundaries.

Use multiple clocks instead of one “time remaining” number

Track oxygen or breathing-gas margin, battery margin, carbon-dioxide control, suit thermal state, injury progression, rover return time, airlock cycle time and medical preparation. The limiting clock can change during the event. A casualty who initially has adequate oxygen may later become limited by cooling failure or a medical condition. The command team should update the controlling clock after every major configuration change.

Primary-source bridge — NASA spacewalking tools. NASA’s EVA material provides primary context for the tools and operational discipline of spacewalks. R61 uses that foundation to build a Mars rescue chain that includes transport, ingress and medical transfer. [Official source.](#)

Pre-plan rescue interfaces, not just rescue vehicles

Can an incapacitated suited crewmember fit through the rover hatch? Can the airlock accept two suited rescuers plus the casualty? Where can a damaged suit be stabilised without contaminating a clean volume? Which attachment points permit dragging or lifting without damaging life-support hardware? These questions need physical rehearsal with representative suits and mass, not a diagram reviewed in a meeting.

Airlock availability is part of rescue radius

A rover may be able to reach a casualty within the mobility budget while the designated airlock is unavailable because of contamination, pressure fault or maintenance. Rescue planning should identify alternate ingress routes or protected delay options, and it should include the full time from distress call to a medically usable environment. The true rescue radius is therefore set by end-to-end time, not only driving speed.

Primary-source bridge — NASA-STD-3001 Volume 2. NASA-STD-3001 provides human-systems requirements and context relevant to crew health, habitability and operational safety. R61 uses it as a primary bridge while clearly treating the Mars rescue architecture as Delta-Sierra training design. [Official source.](#)

Contamination can conflict with urgent medical access

If the casualty has been exposed to unknown dust, chemical material or a process fluid, the team may need to balance decontamination against medical delay. Predefine which contamination classes allow rapid medical ingress, which require an intermediate dirty volume, and which PPE the receiving medical team needs. The plan must prevent “perfect decontamination” from delaying a life-saving intervention while still protecting the habitat.

Rescuer workload and reserve must remain protected

Do not spend every available rover, suit and trained operator on one casualty unless the consequence justifies it. Keep enough capability to respond if the first rescue vehicle fails or another crewmember develops a problem. This means the rescue commander needs a reserve policy before the emergency, not an improvised decision made under emotional pressure.

Rescue drill — casualty recovered, airlock not yet safe

A casualty reaches the habitat with ten minutes of comfortable suit margin, but the primary airlock atmosphere sensor disagrees with an independent portable instrument. The correct response is not automatic immediate cycling. Use the alternate verified path if available, compare instruments, protect the casualty's medical clock and set an abort criterion. The lesson is that rescue success is not achieved at the hatch; it is achieved when the casualty reaches a safe medical state without creating a new hazard.

Rescue equipment should be standardised where possible

Compatible attachment points, common communication connectors, familiar medical interfaces and standardised restraint methods reduce cognitive load during an emergency. Where suit or rover generations differ, the rescue inventory should include the adapters needed to bridge them. Compatibility should be demonstrated with physical drills rather than assumed from interface drawings.

Medical handoff begins before ingress

The receiving medical team needs injury mechanism, suit pressure history, oxygen or carbon-dioxide concerns, contamination status, medications already given and expected arrival time. A concise structured message allows the habitat team to prepare the correct area and equipment while rescue is still in motion. This prevents the airlock door from becoming the first moment medical planning begins.

Every rescue drill should generate design changes

Measure time lost to awkward hatches, difficult attachments, poor lighting, unclear labels, incompatible tools and communication confusion. Treat these delays as engineering data. A recurring thirty-second problem in training can become critical when a casualty has only minutes of physiological margin, so rescue exercises should feed hardware and layout changes as well as crew proficiency.

A rescue plan is incomplete until the casualty can cross the airlock and enter medical care without creating a second hazard. Pedagogical synthesis by Delta-Sierra from the primary sources cited in this course; schematic, not to scale.