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VOL.03

UNKNOWN WORLDS

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Journey to the centre of the Earth

The weird anatomy of a black hole

Exploring Earth's most mysterious oceans

David Attenborough on his worst-ever expedition

Hunting for exoplanets

The daring mission to colonise Mars

Deep-sea monsters lurking in the abyss

Inside the world's most deadly volcano

ONE W

ILLUSTRATION: MAGICTORCH

WAY TO MARS

Both NASA and Mars One have begun preparations for a mission to the Red Planet, but huge obstacles stand in their way. We asked some of the leading experts in space exploration how we'll get there

The race to Mars has begun. First out of the gate was the underdog – Mars One. This private company, staffed by former NASA and ESA employees, plans to put people on Mars within 10 years. And now NASA's Orion programme is in full swing (see page 87). But, as well as all that cold, dark space standing between us and Mars, there are a huge number of obstacles that both teams will have to overcome. How would we launch a colony ship? How would the human body cope? What if something goes wrong? We put these questions to some of the world's leading experts, in a bid to find out how we'll finally set foot on the Red Planet…

SELECTION

Prof Suzanne Bell

Prof Bell works on NASA's Human Research Program, looking at the qualities needed in astronauts taking part in a long-term space mission, such as colonising Mars

WHAT KIND OF PERSON WOULD YOU PICK FOR A MISSION TO MARS?

It goes without saying that working and living in such an extreme environment will require capable individuals who are compatible with each other. They'll be intelligent, fit, adaptable and stable, with great coping and teamwork skills. But there are some other considerations that are more nuanced.

It's no surprise that introverts do better in isolated and confined spaces: the isolation and the social monotony of space require a certain level of introversion. At the same time, there is a level of social warmth associated with extroverts that would be beneficial, as team members rely on one another for social support. So how can this paradox be managed? Well, in this case you can have the best of both worlds – ambiverted individuals have qualities of both introversion and extroversion.

I'd also look for team members who are high in self-monitoring – that's the ability to show concern for, and appropriately modify, your behaviour in a social situation. Have you ever been in a meeting, wanted to say something, and then thought to yourself, "It's not very important that I say this right now"? If so, you were self-monitoring. This will help keep conflicts manageable and the team effectively negotiate the status and power issues that are likely to come up in the new settlement.

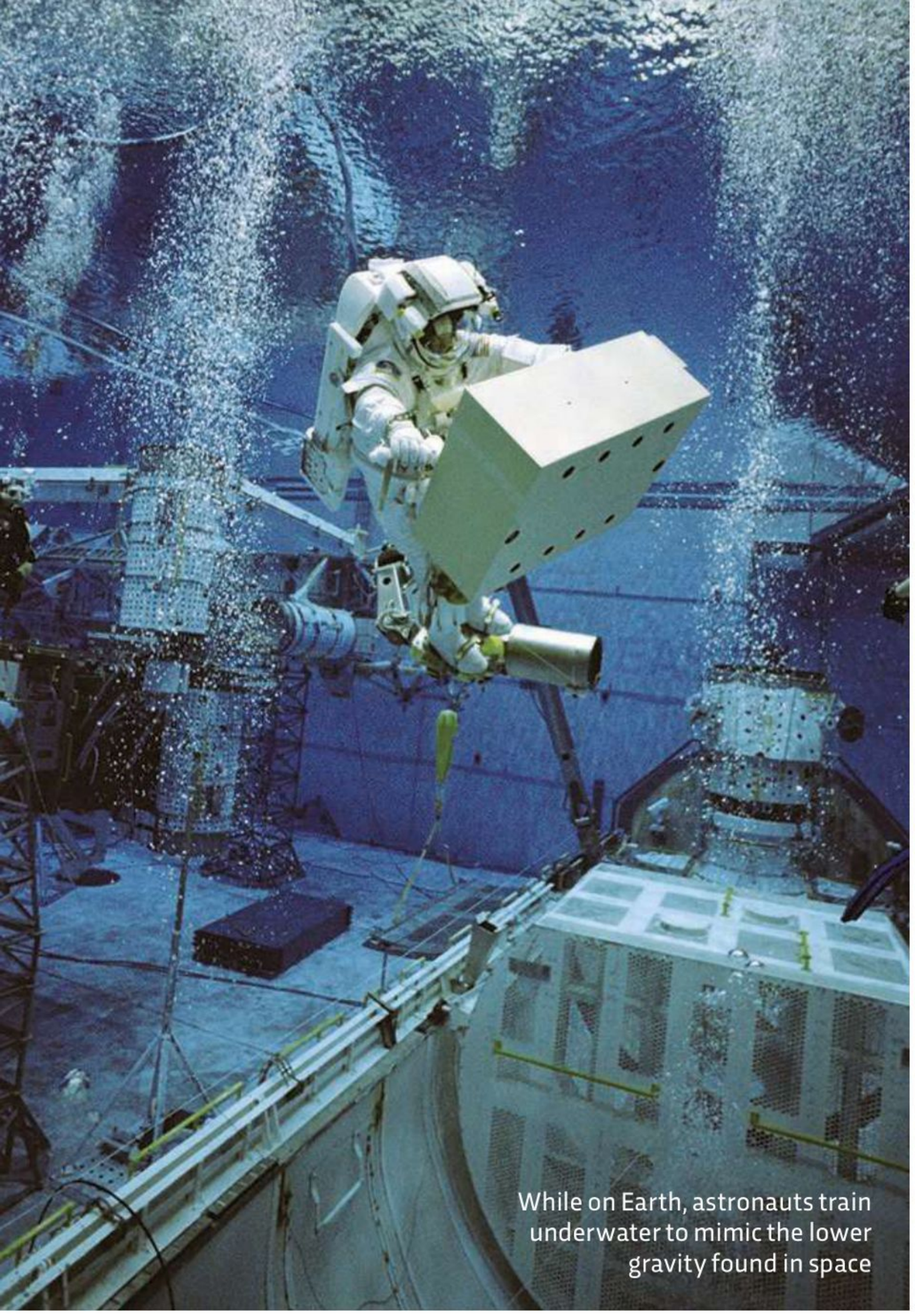
Of course, going to Mars is a risk, but you won't want someone who is too much of a risk-taker: some people take risks because they haven't appropriately weighed up the consequences. Living and working in a hostile environment means that one small mistake could have major consequences; it could even mean the death of the team. So the right person will be able to be careful and responsible in their actions, yet still have a great sense of adventure.

Ensuring team members have shared values is also critical to their compatibility. Personal values are ordered in terms of relative importance, and they drive behaviour. The team that is sent is likely to be diverse in a number of areas. Shared values are critical for bridging these differences. For example, the team may have a mix of scientists and non-scientists (such as the pilot). When the team is faced with a situation that presents competing priorities (for instance, whether to lose data or preserve equipment), the team will more easily agree on a course of action if they have shared values.

"Even the most carefully selected, emotionally stable team members will struggle with the extreme isolation at some point"

HOW WOULD YOU PREPARE SOMEONE FOR A ONE-WAY MISSION TO MARS?

Preparation will involve extensive training, and ensuring that the team has accepted agreed procedures and standards. Training will need to include obvious knowledge and skills (how to land the spacecraft) as well as everyday activities that aren't quite so simple in space (how to go to the bathroom in zero gravity). Teams also will need to be trained in several areas critical to the team's self-sufficiency: learning how to learn, coping skills and teamwork skills. The needs of the settlement will likely change over time and unanticipated events will occur. It's critical to have not only intelligent team



While on Earth, astronauts train underwater to mimic the lower gravity found in space

members but also those who can evolve; for example, those who can self-regulate their learning. Self-regulation is thinking about thinking, using strategic action to learn. There's no human with the perfect skillset for life on Mars: some kind of pilot-cum-farmer-cum-doctor. But if we can teach a candidate to teach themselves, to adapt, to evolve, then they'll have the toolset they need to survive. For example, an astronaut who can identify precisely what part of the landing procedure they're getting wrong, and the training they need to correct the problem, will be more valuable on a long-term mission.

Even the most carefully selected, emotionally stable team members are likely to struggle with the extreme isolation at some point. The team will need to be trained in coping skills – how to identify and respond to difficulties in coping, and strategies for providing support.

Although training will be key to team preparation, many issues will be best resolved with agreed-upon standards. Individuals from different backgrounds may have different views on living standards, personal hygiene or even the treatment of women. Making sure everyone is on the same page regarding these issues can be used to keep conflicts at a manageable level.

NASA

THE MARS ONE CANDIDATE SELECTION PROCESS

2013

202,686

PEOPLE APPLIED TO GO TO MARS

NOVEMBER 2014

663

OF THESE MADE IT THROUGH TO THE FIRST SHORTLIST

2016

6

TEAMS OF **4** INDIVIDUALS WERE SELECTED FOR TRAINING

2031

THE COMMITTEE CHOOSES ELIGIBLE CREWS

NOVEMBER 2014 — 2024 — NOVEMBER 2014

THE AVERAGE AGE OF A CANDIDATE IS **32** IT WILL BE **42** IF THEY DEPART FOR MARS

31

OF THE **663** ARE RESIDENTS OF GREAT BRITAIN

MAGGIE LIEU

Age: 23 From: Coventry Profession: PhD candidate in astrophysics

Why did you apply? It's always been my dream to work for NASA, but it seemed like privatised space travel would become important in my lifetime. I didn't know about the project until the deadline, so I threw together a video on the day and just applied.

What did being selected feel like? It was surreal. I looked up Mars One and it was more serious than I'd thought. I told my mum I had been shortlisted and she just said, "yeah okay". I got a call a few weeks later when she saw me in the newspaper – she didn't realise it was real. It gets more real every day.

What do you think it will feel like to step on to Mars? I don't think anyone knows. Every day more and more people are telling me that I'll get selected. If I actually go to Mars, I think it'll feel like a massive relief. I'll finally realise this incredible dream.

LEWIS PINAULT

Age: 54 From: Twickenham Profession: Innovation Delivery Executive and Researcher, UCL/ Birkbeck Centre for Planetary Sciences

Why did you apply? I believe it's possible to get to Mars safely using existing technologies. We'll be the data – the crew psychology, the effect of radiation and the impact on the human body.

What did being selected feel like? Good. It sounds arrogant, but I wasn't wildly surprised. When I put in my application I was about to join an Antarctic research programme, and I knew my background in planetary geology would fit in with their plans.

What do you think it will feel like to step on to Mars? I dream about it sometimes. I remember the photos from when the first Viking landers touched down on Mars in 1976. It was a rich orange colour with a salmon pink sky. Now we know it looks more brown and the sky is more opalescent. When I dream about it, I see both.

SPACECRAFT

Prof Mason Peck

How will we get to Mars? Prof Peck, former Chief Technologist at NASA, outlines Mars One's plans for making the challenging journey to the Red Planet

HOW WOULD YOU SEND A CREW TO MARS?

The four-person crew will travel to the Red Planet in a transit vehicle – a small space station that will be assembled in low Earth orbit before the crew arrives. In-orbit assembly allows us to build large space systems, like the International Space Station (ISS), that we're unable to launch intact from Earth, for technical or financial reasons.

Once the crew is onboard, the transit vehicle will fire its engines and begin its journey to Mars. This will be the astronauts' home for seven months, and they'll eat, sleep and train in the vehicle's habitat module. Then, when they're near Mars, they'll enter a separate lander module, a bit like the Apollo landers.

The Mars One crew will be launched into space on a SpaceX Falcon 9 rocket

The one-way journey needs less than half the supplies of a round trip. They'll have enough water and oxygen onboard to last them for the whole journey, as well as plants to grow more food should they run out. The transit vehicle will also have an environmental control and life support system (ECLSS) to control air pressure, detect fires, monitor oxygen levels and manage water and waste, but this won't need the longevity of existing ECLSS's, like on the ISS. This reduces the hardware costs involved.

A key feature of Mars One is its use of existing technologies, in contrast to the usual practice of creating a custom-built spacecraft for every mission. So no new launch vehicle will need to be designed for Mars One. Instead, the four-person crew will be carried to the orbiting transit vehicle by a pre-existing system, such as SpaceX's Falcon Heavy. It'll be a similar approach to the way astronauts travel to the ISS today.

We'll continue sending four-person crews to Mars at every launch opportunity – roughly every 26 months, when Mars and Earth align in a way that minimises the propellant needed for the trip. As more colonists arrive, the first Martian settlement will begin to take shape.

HOW WILL YOU LAND ON MARS?

Landing won't be easy. NASA's analysis predicts that a successful six-person mission would need to land 40,000kg on the Martian surface. Mars One's mass will be lower because of its smaller crew, but still, the largest payload delivered to date is just 1,000kg (the Mars Science Lab mission, which landed the Curiosity rover in 2012). This leaves quite a few challenges ahead for Mars One.

Fortunately, NASA's previous successes and investment in future technologies should provide us with a solution. One possibility is aerocapture – slowing the vehicle down by sending it through the Martian atmosphere. This would create a drag force, reducing the craft's orbital energy. Secondly, inflatable aerodynamic decelerators might be used. Currently in development, these expand to create a large, lightweight, heat-resistant body that further slows the vehicle.

Some rocket companies are also looking into landing vehicles through retropropulsion – the Buck Rogers technique of firing rocket engines in front of you to slow yourself down. SpaceX and NASA have agreed to share data on supersonic retropropulsion gleaned from a launch of SpaceX's Falcon 9 in September 2014. This technology can be tested here on

NASA's Orion spacecraft, currently in development, is its flagship vehicle for future Moon and Mars missions

Earth, replicating Mars's atmospheric conditions by performing experiments at just the right altitude. It'll be a combination of these technologies that will allow the Mars One lander to reach the surface.

WILL YOU NEED OTHER SUPPORT MISSIONS?

Absolutely. One strength of the Mars One concept is its focus on infrastructure – it's not just a one-shot, single-purpose mission. In 2018, six years before the first crew's departure, two communications satellites will be launched – one around the Sun and one around Mars – allowing constant communication between Mars and Earth. Laser communications, a new NASA-developed technology, will increase data-frequency transmissions. A demo mission around this time might also test some of the landing procedures. From 2020 through to 2024, there'll be a further series of preliminary missions to carry out some prospecting around the landing site, set up the area for human habitats and collect resources. These initial preparations will mean the first colonists have somewhere to rest and recuperate when they do finally arrive.

"We'll continue sending four-person crews to Mars at every launch opportunity – roughly every 26 months"

ONBOARD ORION

The NASA spacecraft to take humans to Mars and beyond

Orion has been designed to take humans farther than they've ever gone before. The plan is for it to serve as an exploration vehicle, carrying crew, providing emergency abort capability, sustaining crew during space travel, and providing safe re-entry from deep space return velocities.

The plan is to launch Orion aboard the new Space Launch System, sending it into orbit around the Moon. This mission – Exploration Mission 1 – will be used to test the guidance and navigation systems, as well as the radiation protection equipment.

By 2023 the first manned mission will be launched, called Exploration Mission 2. This mission is currently proposed to send astronauts to a captured asteroid, so they can collect samples and bring them home.

Before any humans fly onboard Orion, one hugely important part of the system will be thoroughly tested. The Launch Abort System (LAS) fits around the crew module, with a spike housing three rocket motors. If the main rocket should fail, the LAS's rockets would fire within milliseconds to pull the crew module out of harm's way before deploying parachutes for a safe landing.

But many challenges lie ahead before the final goal of sending astronauts to Mars. At present Orion is designed to only take four astronauts for missions lasting up to 21 days. This is because there isn't enough space to store water and supplies for longer missions. An eventual mission to Mars would rely on various other components, such as a habitat module.

But the need for humans to undertake such missions is something that NASA is convinced is necessary. Exploration Flight Test 1 was just the start of a long journey for NASA, but it is one that could ultimately mark the start of a new wave of human space exploration of our Solar System and will inspire a new generation of scientists and engineers.

Orion undergoing final assembly at the Kennedy Space Center. Technicians ensured that no foreign objects contaminated the spacecraft

NASA, SPACEX

WELLBEING

Dr Kevin Fong

Dr Fong has worked with NASA and is author of *Extremes: Life, Death And The Limits Of The Human Body*. He explains how the body would cope on Mars

WHAT SHOULD A DOCTOR ON A TRIP TO MARS BE MOST WORRIED ABOUT?

A Mars mission crew doctor will have their work cut out. Prevention is always better than cure, so keeping the crew healthy by making sure they eat the right diet, stick to an exercise programme and generally take care of themselves would be important. But a crew physician would be responsible for providing healthcare should any medical emergency arise. With space and power at a premium, and the physician having to be everything from general practitioner and casualty doctor to anaesthetist and surgeon, that would be a tall order. And there's plenty up there in the way of threats: the effects of weightlessness, the risk of decompression illness during space walks, the intense radiation outside the protection of Earth's magnetic field, and micrometeoroids.

The biggest threat to life, though, is not disease or even traumatic injury. Astronaut crews are screened to make sure they're in peak condition, and the spacecraft itself and all activities that take place within it are designed to expose the crew to the lowest possible risk of injury. Day-to-day life would be far safer than in the average house: you can't fall down a flight of stairs, it's hard to start fires and it's nearly impossible to electrocute yourself. Instead, what would most worry a doctor would be being part of a crew that's hurtling through space, powered by rockets with the explosive potential of a small nuclear missile. It's not the medicine you need to worry about, it's the rocket science. We've never lost part of the crew on a space mission: either the engineering works and everybody lives, or it doesn't and everyone dies.

"For now, a combination of drugs, controlled diet and exercise regimes will be what crews rely upon to ward off the deconditioning effects of living with reduced gravity"

WHAT WOULD HAPPEN TO THE HUMAN BODY AFTER A YEAR ON MARS?

Mars doesn't support life any better than the empty space that the crew would have crossed to reach it. It is smaller than Earth and further from the Sun, with a thin atmosphere composed almost entirely of carbon dioxide. So when crews arrive there, they will be completely dependent upon a suite of life support systems, and forced to live in habitats that are suitably shielded from radiation. But the aspect of Martian life that will shape physiology more than any other is the reduced gravity.

Astronauts living on Mars will experience roughly one-third of the gravity that they would on Earth. We already know, from more than 50 years of human space flight, that weightlessness has effects on the human body. Bone and muscles waste rapidly and the heart, which is itself a muscle, deconditions. But other systems are also affected. Hand-eye coordination becomes impaired, the immune system becomes suppressed and astronauts can become anaemic. Prolonged weightlessness can take athletes and turn them into couch potatoes very quickly.

What we don't know for sure is how severe these effects will be on Mars. On the Red Planet there is at least some gravity but it's unclear if

it's enough to protect the astronauts' biology. Over the years, we've studied hundreds of people who've spent time floating weightlessly but only 12 people who've ever experienced reduced gravity on the surface of another world: the Apollo crews who landed on the Moon. And that's left us without enough information to know for sure how severe the problem of life on Mars, at one-third of Earth's gravity, will be.

For now, a combination of drugs, controlled diet and strict exercise regimes will be what crews rely upon to ward off the effects of living on a world with reduced gravity. Some authorities have proposed using short-arm centrifuges to provide a short burst of artificial gravity. But what's clear is that the exploration of Mars will also prove to be an exploration of the limits of the human body.

Exactly how the low gravity conditions on Mars will affect long-term settlers remains, so far, unknown

BELOW: Diego Urbina training as part of the Mars500 mission, which simulated a manned Mars voyage

GETTY, ESA

COLONISATION

Prof Charles Cockell

Prof Cockell is director of the UK Centre for Astrobiology. His lab investigates life in extreme environments. He explains what life will be like for inhabitants

WHAT WILL THE FIRST FEW DAYS BE LIKE?

The new settlers' first priority will be putting in place the basic essentials for survival, and ensuring backup systems function. They'll need to ensure that all oxygen production and recycling equipment is working, and if they're topping up their oxygen from water gathered from the atmosphere (by breaking it down using electrolysis), they'll need to check that the extractor fans collecting atmospheric water are up and running.

In the first weeks, the food the colonists will eat will not be home-grown. They'll be eating dried and preserved rations in boxes. However, they may spend the first two weeks setting up a simple greenhouse so that they can begin to grow food as soon as possible.

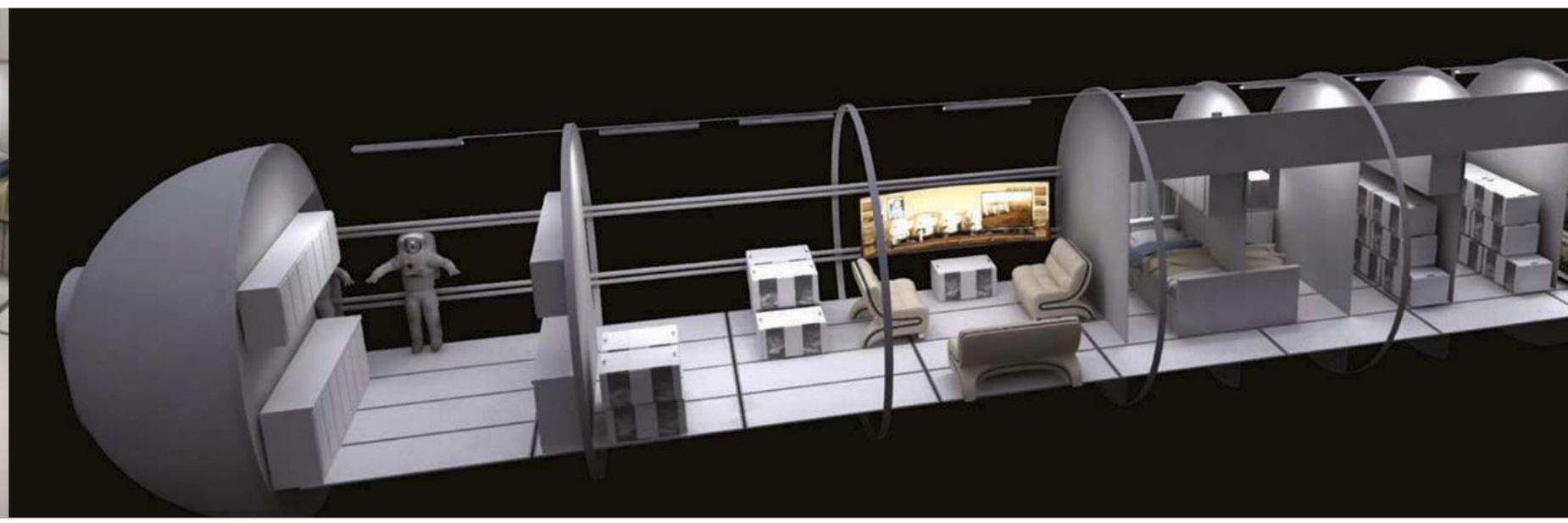
A crucial matter for survival is energy. Whether they're using nuclear or solar energy, they'll need to set up the apparatus, link it to the base and make sure that the power supply is stable and reliable. They may also set up chemical apparatus to make useful things like fuel. Carbon dioxide in the atmosphere, for instance, can be reacted over a catalyst with hydrogen (itself released from water gathered from permafrost or the atmosphere) to make methane fuel to power their robotic rover.

The Sun produces infrequent, but intense, particle streams that can cause severe radiation damage. So the settlers will need to ensure that radiation shielding is in place – for example a layer of Martian rock or water in the walls of their habitat would do the job – and that they have a more resistant shelter to escape to during periods of intense radiation.

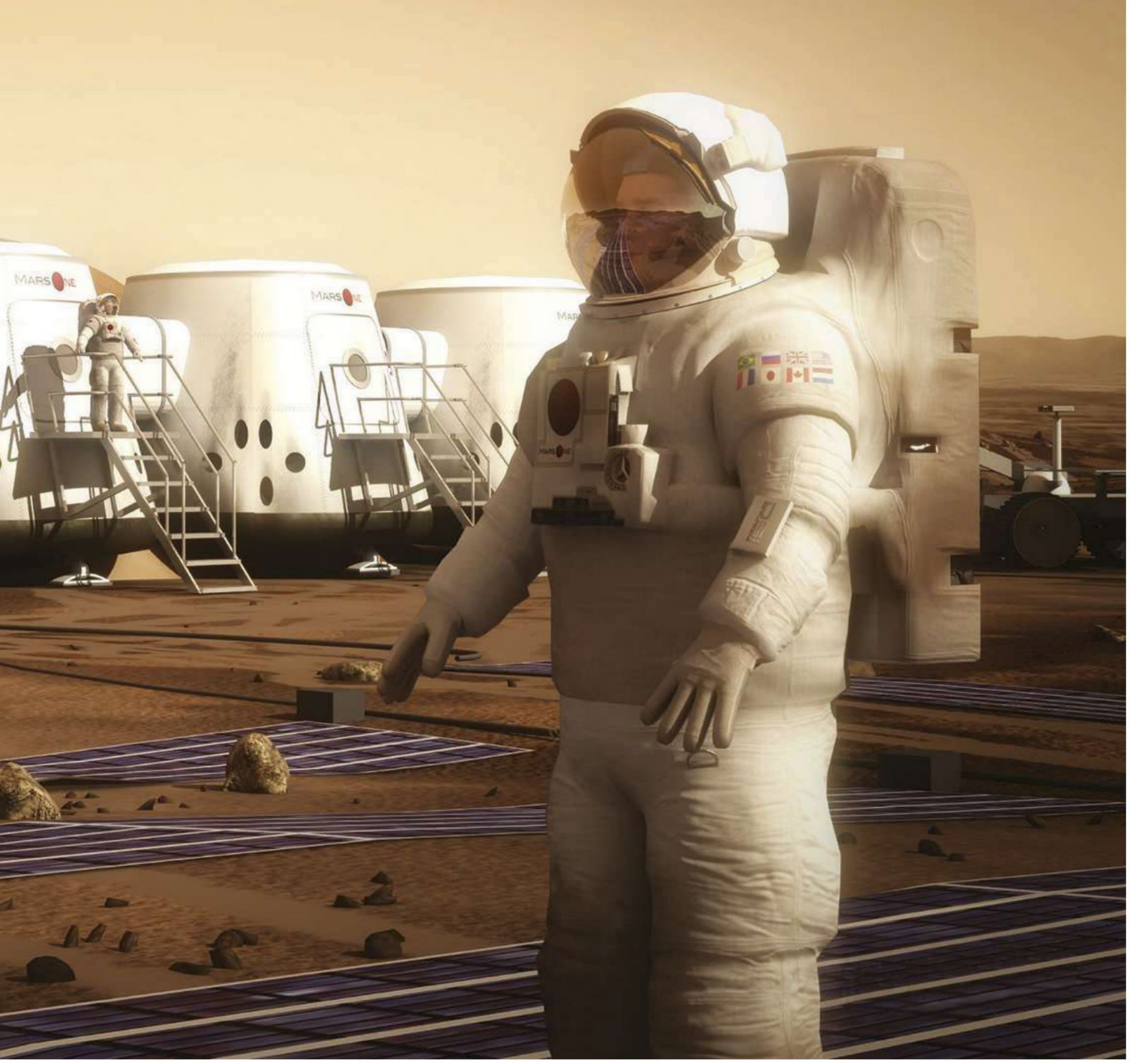
Most of these procedures will have been tested before they land, so in principle it should just be a matter of plugging in the equipment. But they will still need to check and cross-check all of these systems in a potentially lethal environment. The first few days will be a Lego-like frenzy of putting together the first Martian base.

WHAT WILL THE COLONISTS NEED TO THINK ABOUT BEYOND SIMPLE DAY-TO-DAY SURVIVAL?

Beyond the science and planning there is the human story. These explorers will inhabit a deadly environment, trapped in a tiny space with their fellow colonists. Their challenges will come not just from the outside (the Martian environment), but also from the inside – the human challenge. Professionalism and good behaviour will get them a long way as they learn to work together and carry out their mission,



The settlers' living quarters will include a greenhouse for growing fresh vegetables, and a surprisingly comfortable area for rest and relaxation



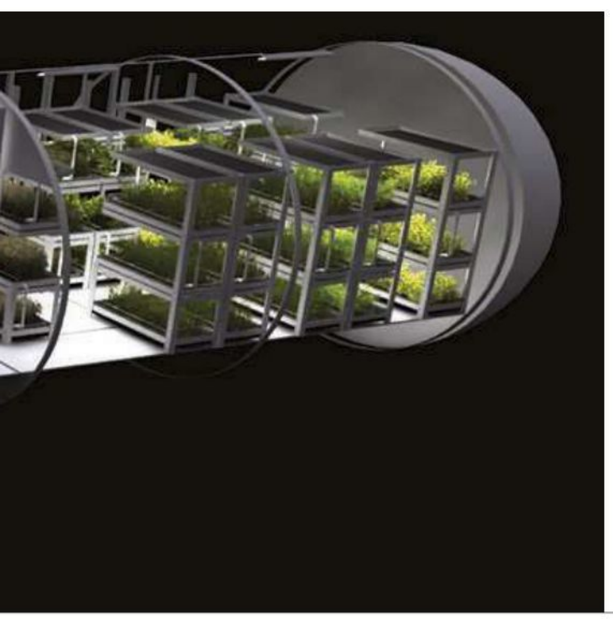
but other things will help. For instance, they'll have small spaces in the station where they can spend time on their own, write messages to loved ones on Earth, paint or read.

We know from the accounts of those who've lived on space stations that growing crops and tending to other creatures helps a great deal, by giving people psychological reprieve from the extreme environment.

As a small group, direct participatory democracy will probably work, but as numbers grow they may need some formal constitution by which to govern themselves. It'll be the first extraterrestrial government. F

The Mars One crew members will need to be capable of living in close proximity to their fellow colonists in a deadly environment

BRYAN VERSTEEG/MARS-ONE.COM X3, NASA



"The Sun produces intense particle streams that cause severe radiation damage. So settlers will need radiation shielding"

MARS ONE TIMELINE

If all goes according to plan...

2018
Crews currently in training replaced by new crews from regular astronaut selection programs.

2022

An unmanned demo mission is launched to test the landing procedures on Mars. Two communications satellites are also sent into orbit, providing constant communication.

2024
Dedicated Mars synchronous communications satellite sent to Mars.

2026

A robotic rover is launched. Once it has arrived on Mars, the rover drives around to find the best location for a settlement. It then prepares the surface for the arrival of the next missions.

2029

The first cargo missions are launched. These carry essential items such as food and solar panels, as well as inflatable living units and equipment to generate water, energy and breathable air.

2031

The first Mars One crew begins the journey from Earth. They are the first humans to embark on a mission to Mars.

2032

The crew members touch down on the Red Planet. After leaving the lander in Mars suits, they are taken by the rover to the prepared settlement to acclimatise, before finishing the setting up of the settlement.

2033

The second four-person crew launches from Earth, landing in 2034. This process repeats roughly every 26 months, and so the colony grows.