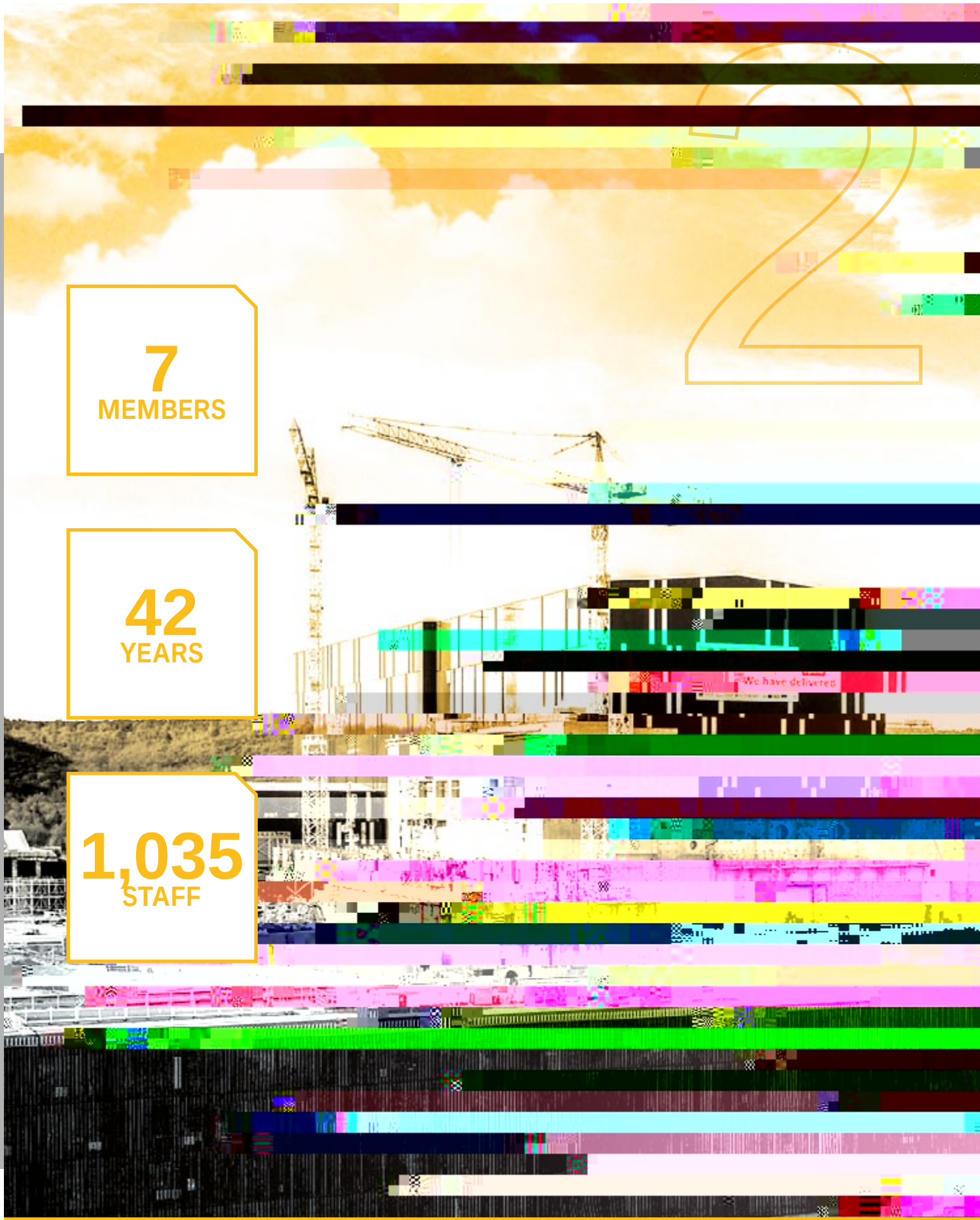
7
MEMBERS
42
YEARS
1,035
STAFF

ITER
An "international project that aims to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes, an essential feature of which would be achieving sustained fusion power generation." (From Article 2 of the ITER Agreement)

PROJECT MEMBERS
The People's Republic of China, the European Atomic Energy Community (Euratom), the Republic of India, Japan, the Republic of Korea, the Russian Federation, and the United States of America are the seven signatories to the ITER Agreement.

THE ITER AGREEMENT
Signed by all Members in November 2006, the ITER Agreement establishes the ITER Organization and defines the joint implementation of the ITER Project.

ITER ORGANIZATION
Established to construct, operate, exploit, and de-activate the ITER facilities in accordance with project objectives; encourage the exploitation of the ITER facilities by the laboratories, other institutions and personnel participating in fusion energy research and development programs of the Members; and promote public understanding and acceptance of fusion energy. (Article 3)

ITER COUNCIL
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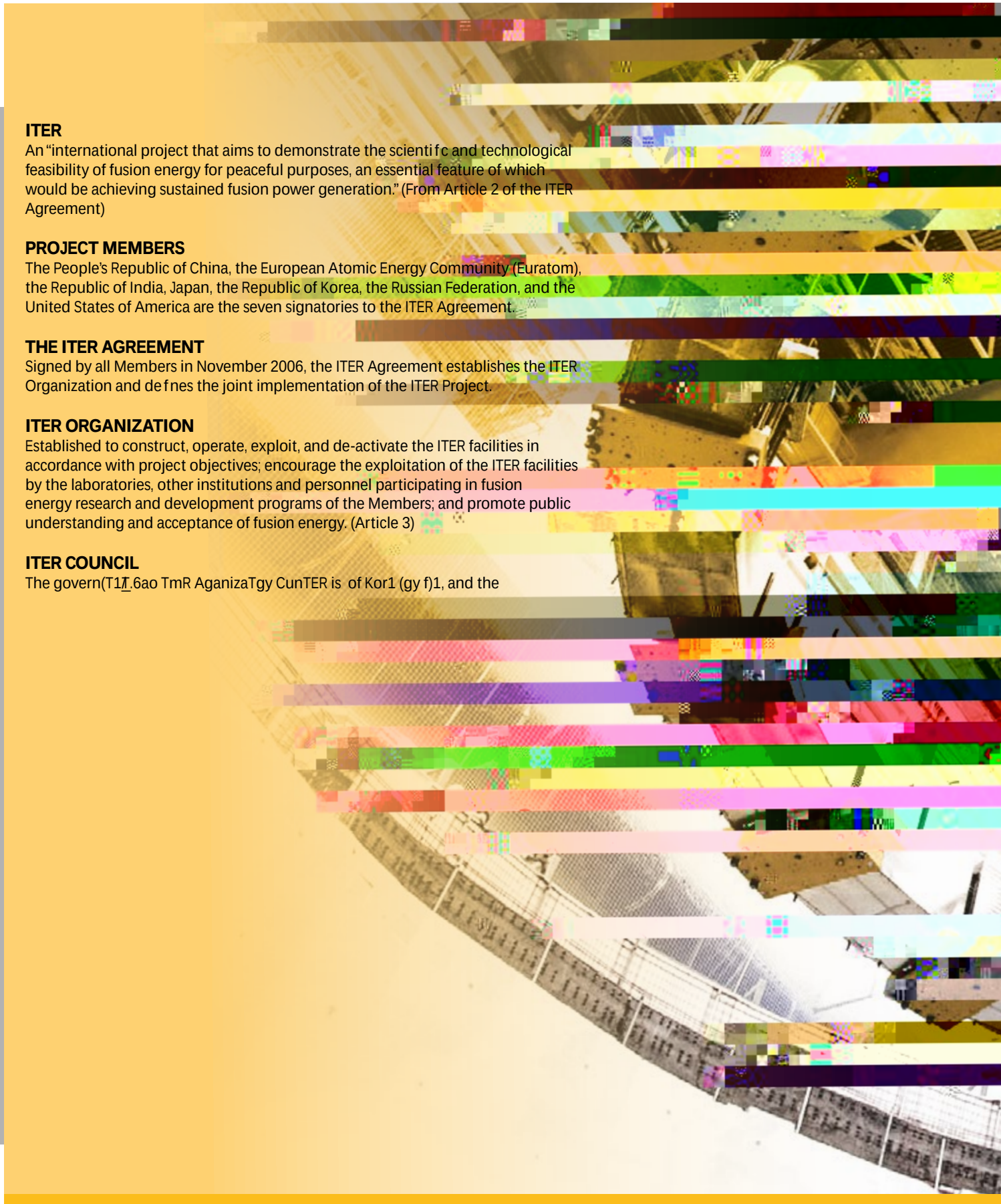

In September, poloidal eld coil #5 (PF5) becomes the second ITER magnet to be lowered into the machine assembly pit.

2021

Foreword from the Chair of the ITER Council **5**

Foreword from the Director-General **7**

Project Status **8**

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- Assembly and Installation 14

Engineering and Manufacturing Update **20**

Science and Operation **30**

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Looking Ahead **61**

A central column will help to brace the sectors of the vacuum vessel as they are aligned and welded. Each sector will be suspended from a radial beam like the one seen here during docking tests.

FOREWORD FROM THE CHAIR OF THE ITER COUNCIL

As Chair of the ITER Council from 1 January 2020 to 31 December 2021, I can con□rm that the actors of the ITER Project—the ITER Organization, the Domestic Agencies, and the representatives of the Members—have managed with determination and anticipation to make the most of the di□cult circumstances caused by the Covid-19 pandemic.
We were used to meeting in person; this became impossible. We counted on in-person factory inspections; we were forced to innovate with remote technologies. We were on track in working according to the Baseline 2016 schedule; we now know that the project schedule and cost must be re-baselined to re□ect the new reality accurately.

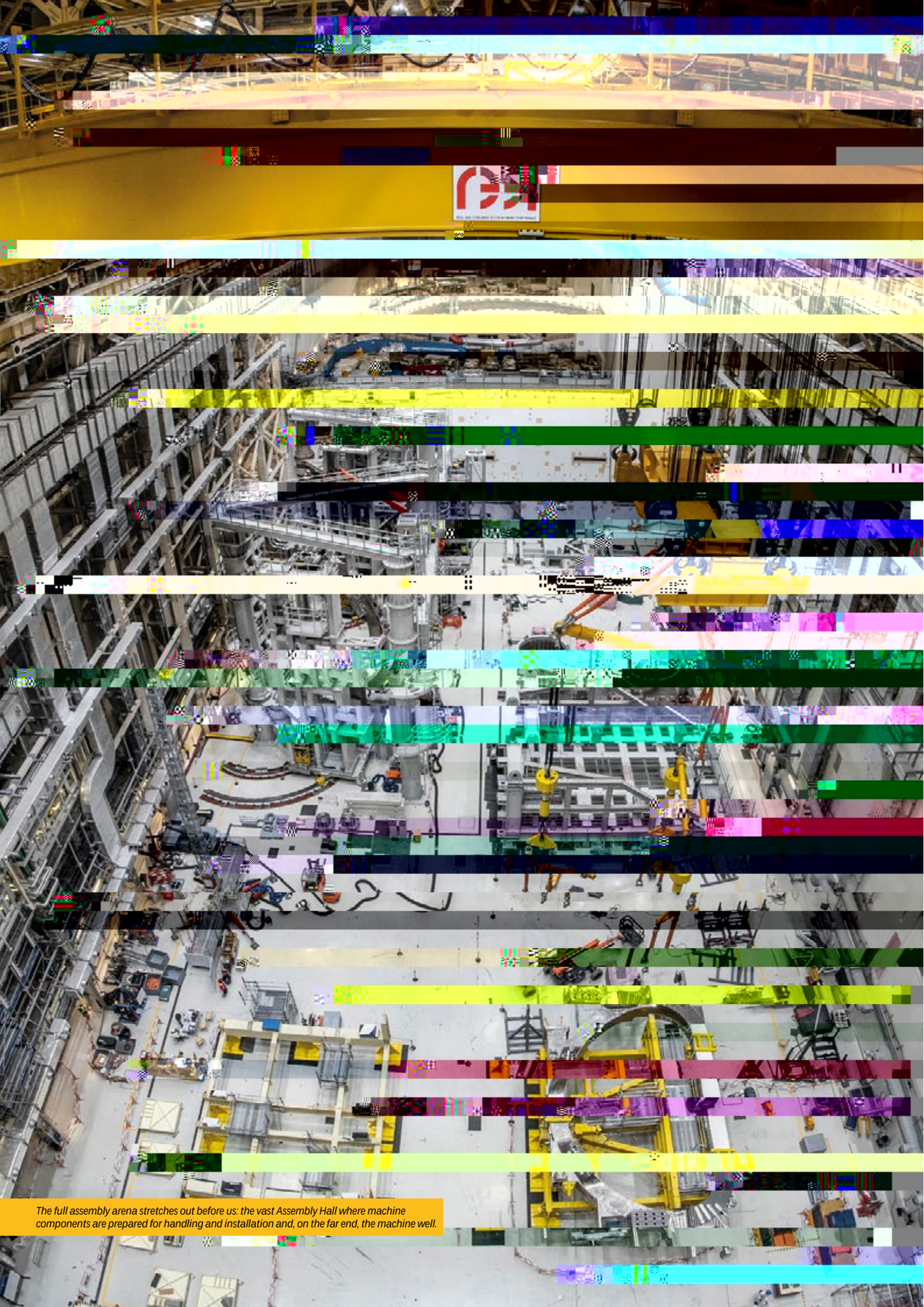
I salute the progress that was made over the past two years despite the challenges, and watch with pride (from afar) as the ITER machine and plant are assembled from contributions delivered by each of the Members. Thanks to the untiring e□ort of all who are committed to this project, the worst was avoided and the forward momentum was maintained. The challenges should never distract us from the sense of pride and partnership at what we are achieving together as the One-ITER team.

The ITER Project is progressing, but at a slower rate than planned. The coronavirus has created new delays and exacerbated some of those already present. In-kind contributions are still the key driver for assembly and installation to progress and the ITER Organization and the Domestic Agencies must continue to work in the most integrated way. I encourage all Members to meet their in-kind and in-cash commitments to enable the successful implementation of the project construction strategy.

As a Chinese proverb reads, "The going may be tough when one walks alone, but it gets easier when people walk together." While the survival of humankind is challenged by energy shortage and climate change, we should strengthen our belief in building a fusion community of shared future, we should stay more determined to realize fusion as a source of energy, and we should be con□dent in the innovative development of an alternative energy!

Finally, I must express my deepest sadness at the untimely passing of Director-General Bernard Bigot in May 2022. I can personally speak to his devotion and dedication to the project, and to the very positive legacy his seven years of strong leadership leave behind him. My sincerest condolences to all those who knew him well.

LUO DELONG
Beijing, China
June 2022



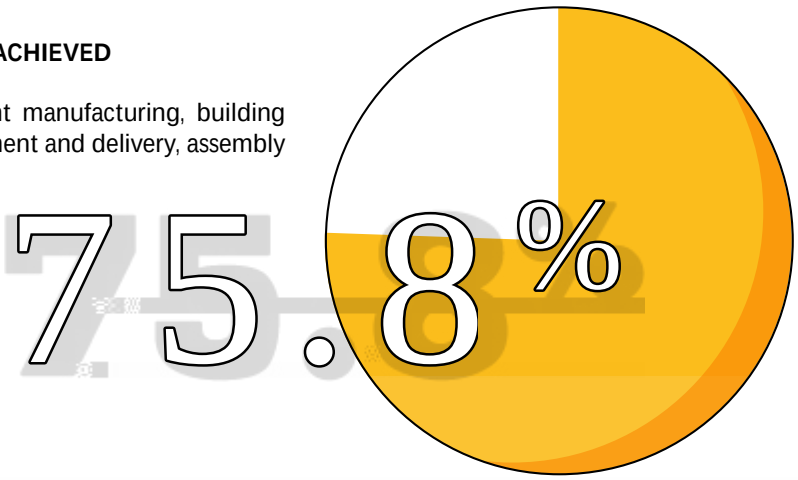
The full assembly arena stretches out before us: the vast Assembly Hall where machine components are prepared for handling and installation and, on the far end, the machine well.

FOREWORD FROM THE DIRECTOR-GENERAL

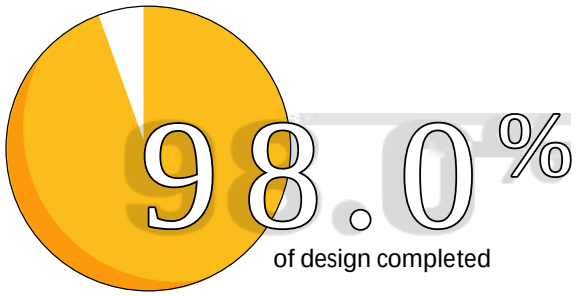
The global pandemic has lasted longer than any of us had hoped; at the same time, the resilience of the ITER community in the face of pandemic-induced challenges has

PROJECT STATUS 2021

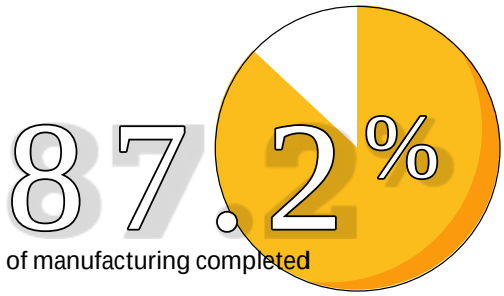
PHYSICAL WORK ACHIEVED TO FIRST PLASMA
(design, component manufacturing, building construction, shipment and delivery, assembly and installation)



PROGRESS TOWARD THE REALIZATION OF FIRST PLASMA SYSTEMS AND COMPONENTS

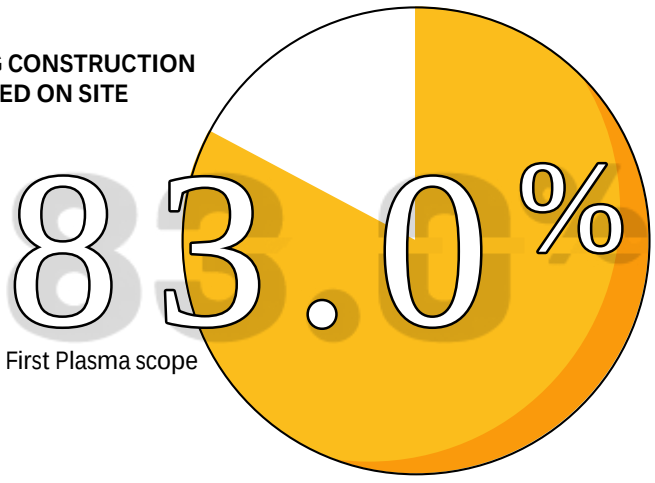


of design completed



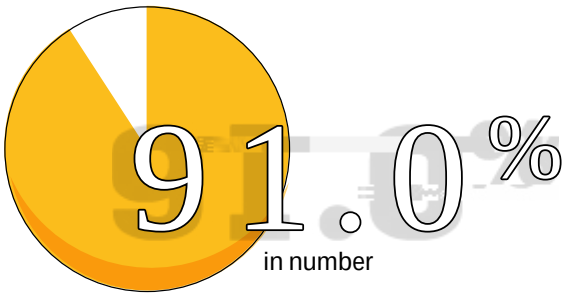
of manufacturing completed

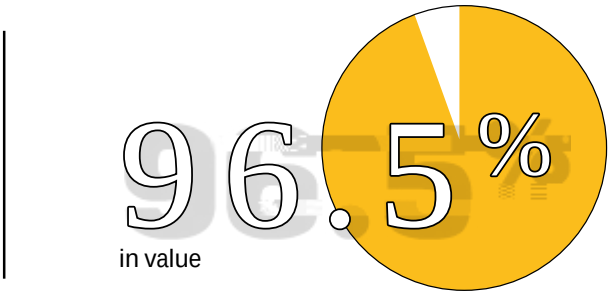
BUILDING CONSTRUCTION COMPLETED ON SITE



First Plasma scope

PROCUREMENT ARRANGEMENT* SIGNATURES

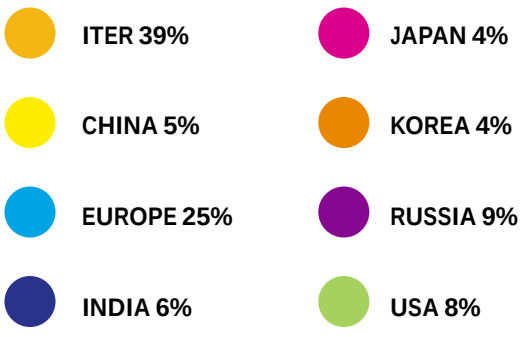




* A procurement Arrangement is an agreement that is signed between the ITER Organization and the Domestic Agencies, authorizing work for the development and manufacturing of the ITER installation.

INTELLECTUAL PROPERTY DECLARATIONS*

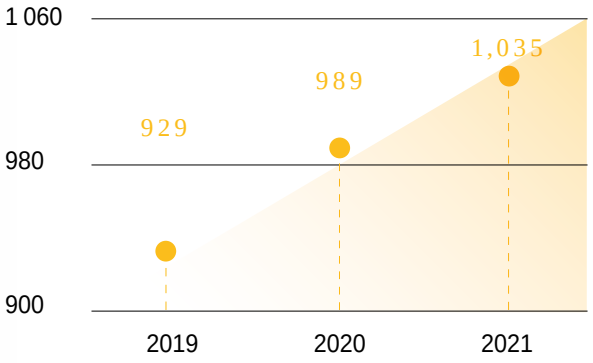
Declaration of "Generated Intellectual Property," cumulative



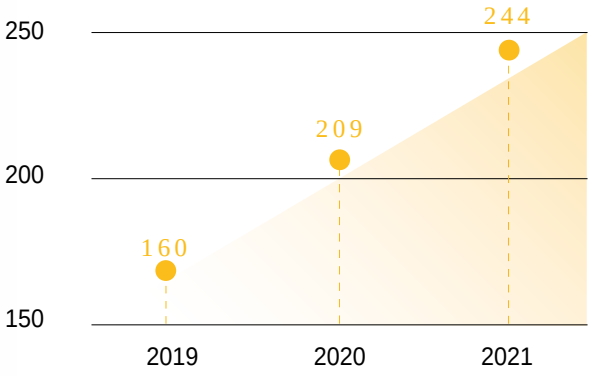
* The ITER Organization and the seven Members support the widest appropriate dissemination of intellectual property generated in the course of activities for ITER.

STAFF

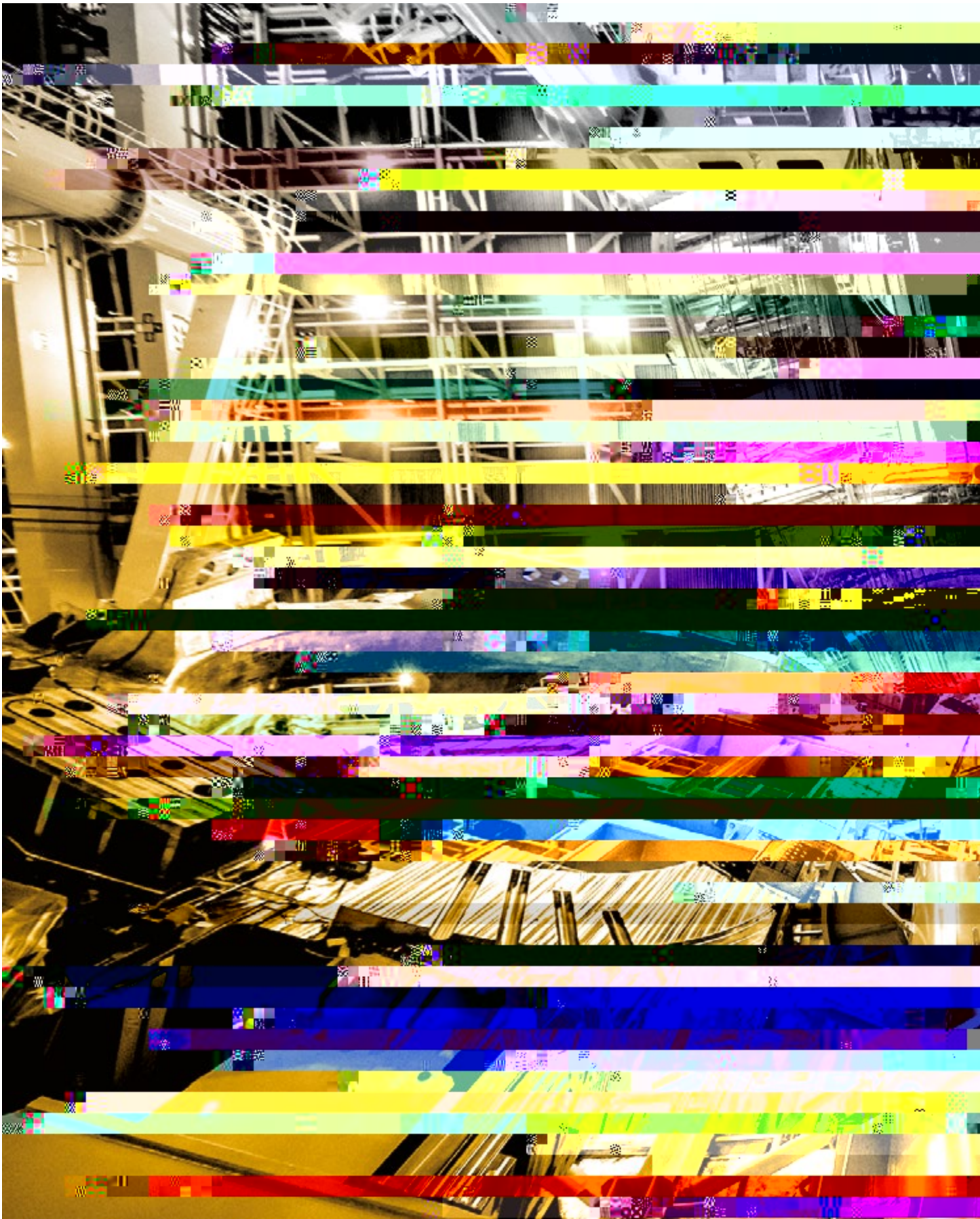
(see page 46)



ITER PROJECT ASSOCIATES*

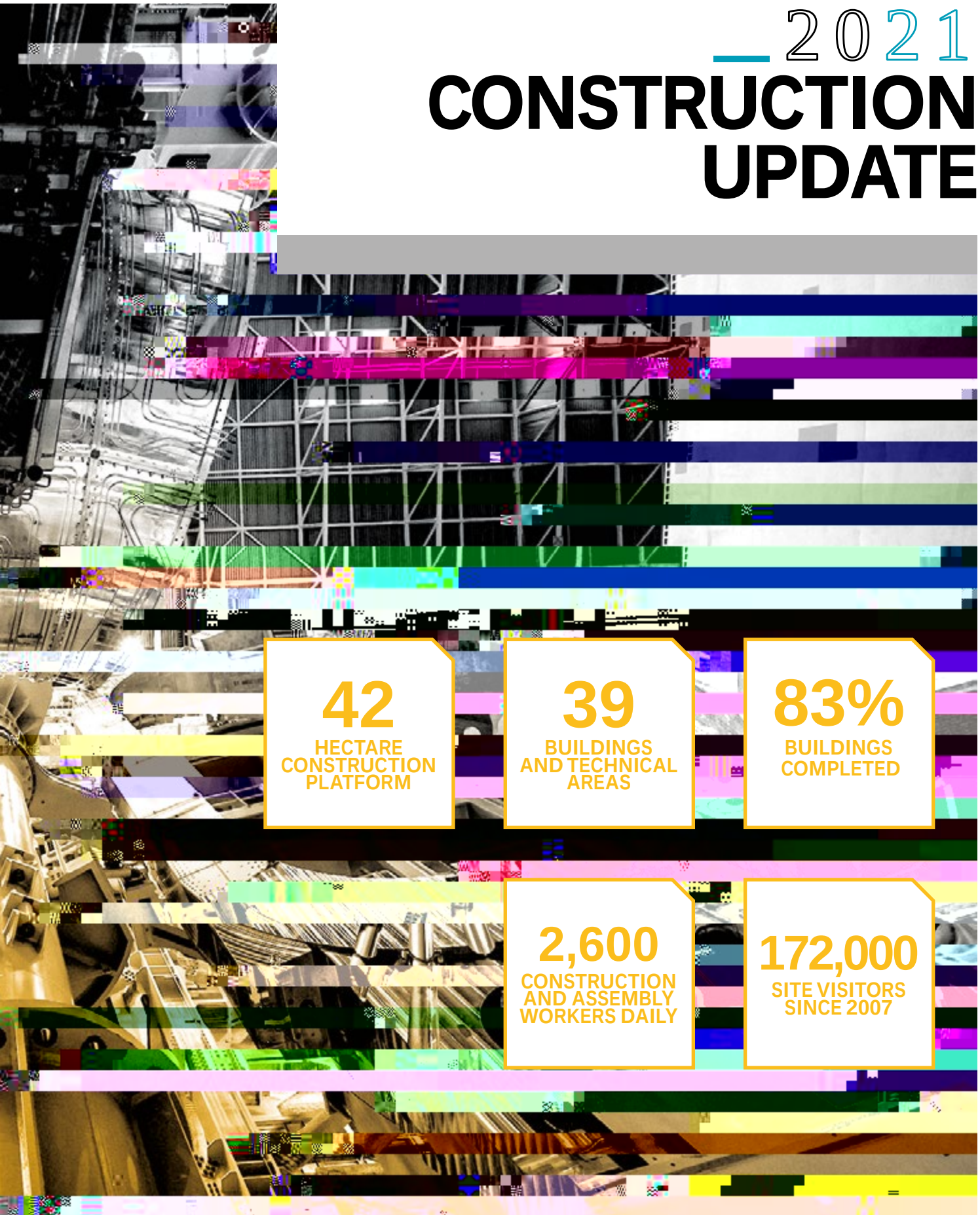


* Experts from the Members' scienti□c, technological and industrial communities who work at ITER while remaining employed by their home institute.



Vacuum vessel sector #6 has been dressed in its silver-coated thermal shield but not yet assembled with the two D-shaped vertical coils that are waiting on the wings. From this (unusual) perspective the giant sector sub-assembly tool seems particularly massive.

2021 CONSTRUCTION UPDATE



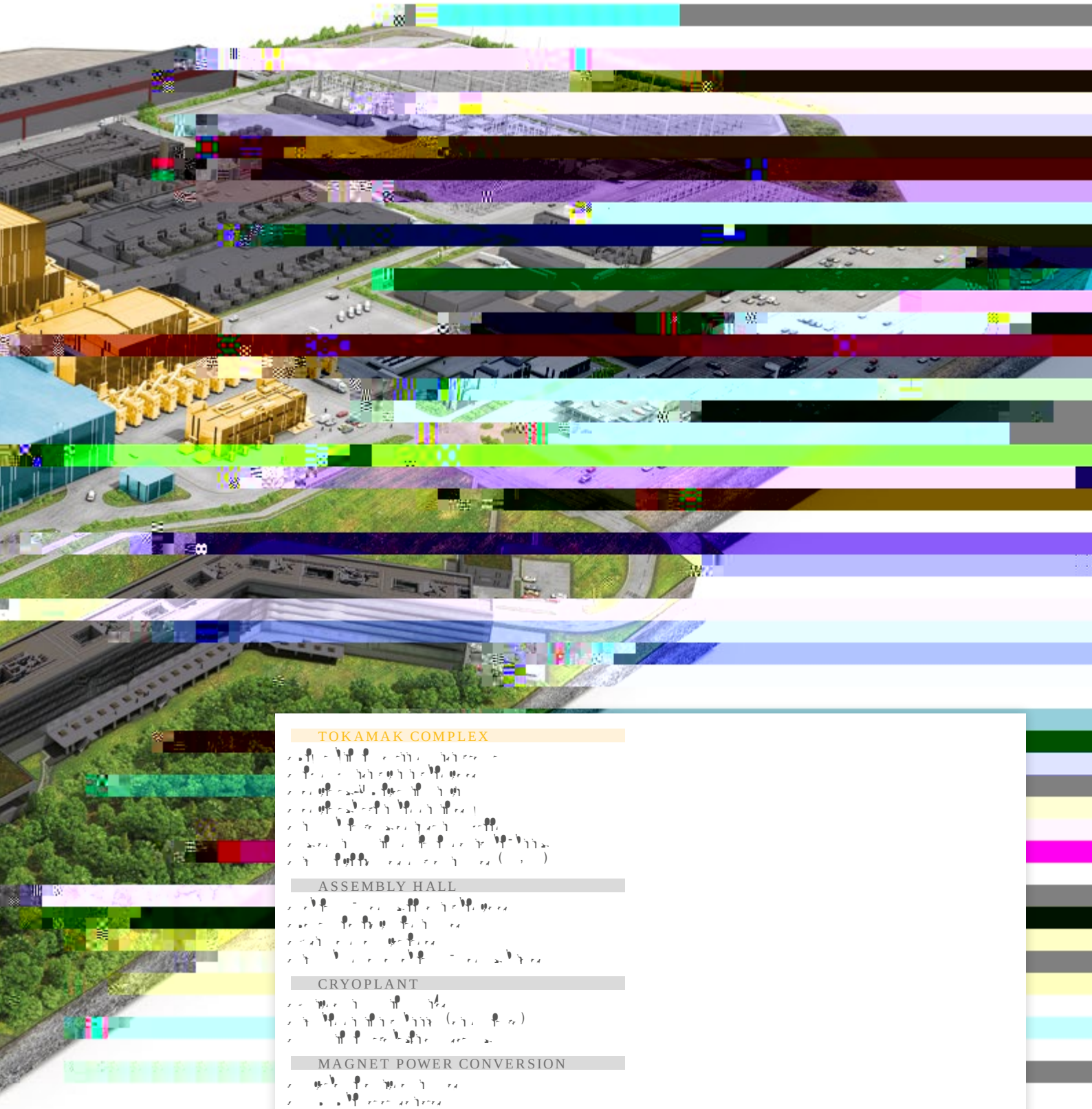
42
HECTARE CONSTRUCTION PLATFORM

39
BUILDINGS AND TECHNICAL AREAS

83%
BUILDINGS COMPLETED

2,600
CONSTRUCTION AND ASSEMBLY WORKERS DAILY

172,000
SITE VISITORS SINCE 2007



TOKAMAK COMPLEX

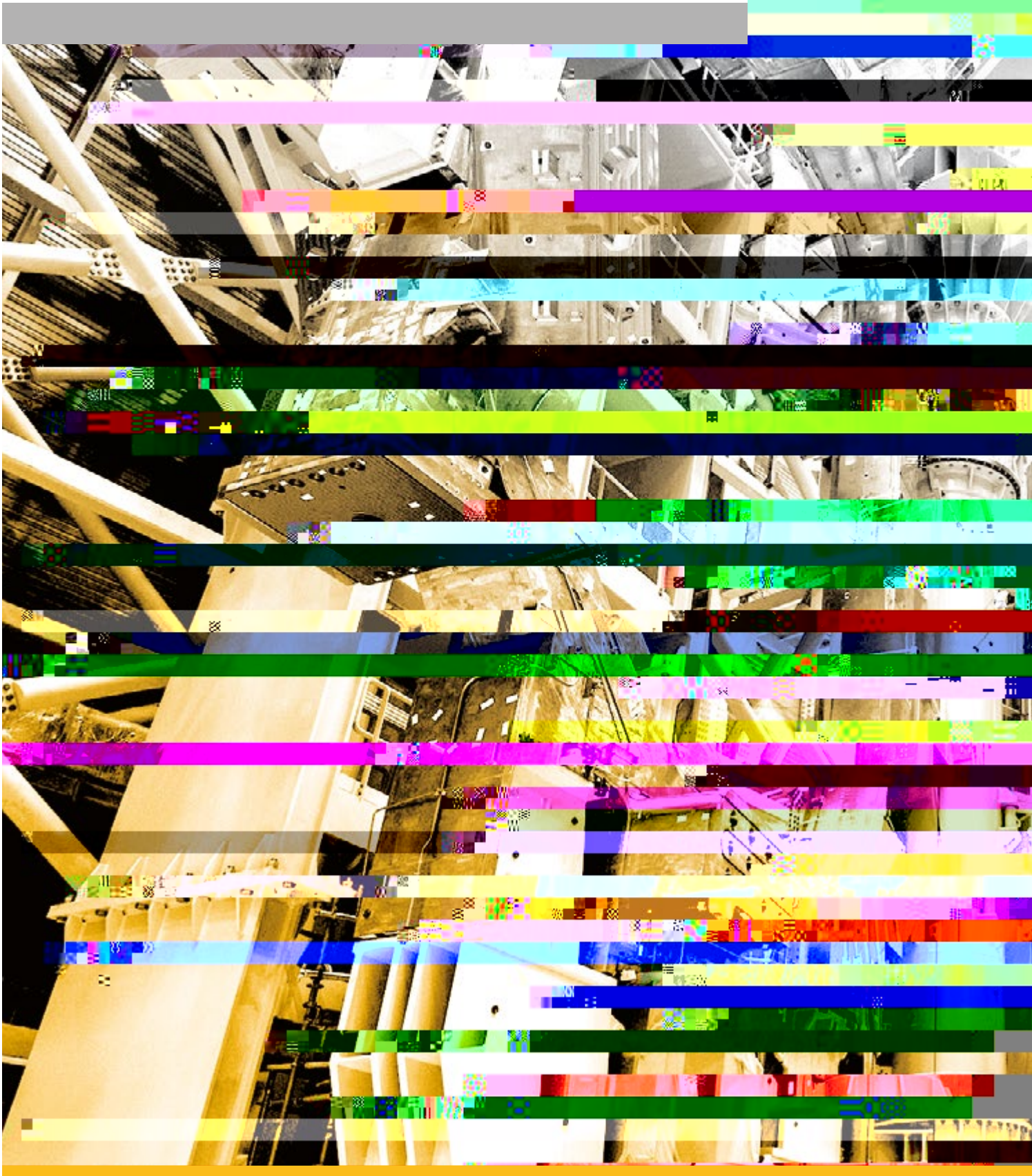
ASSEMBLY HALL

CRYOPLANT

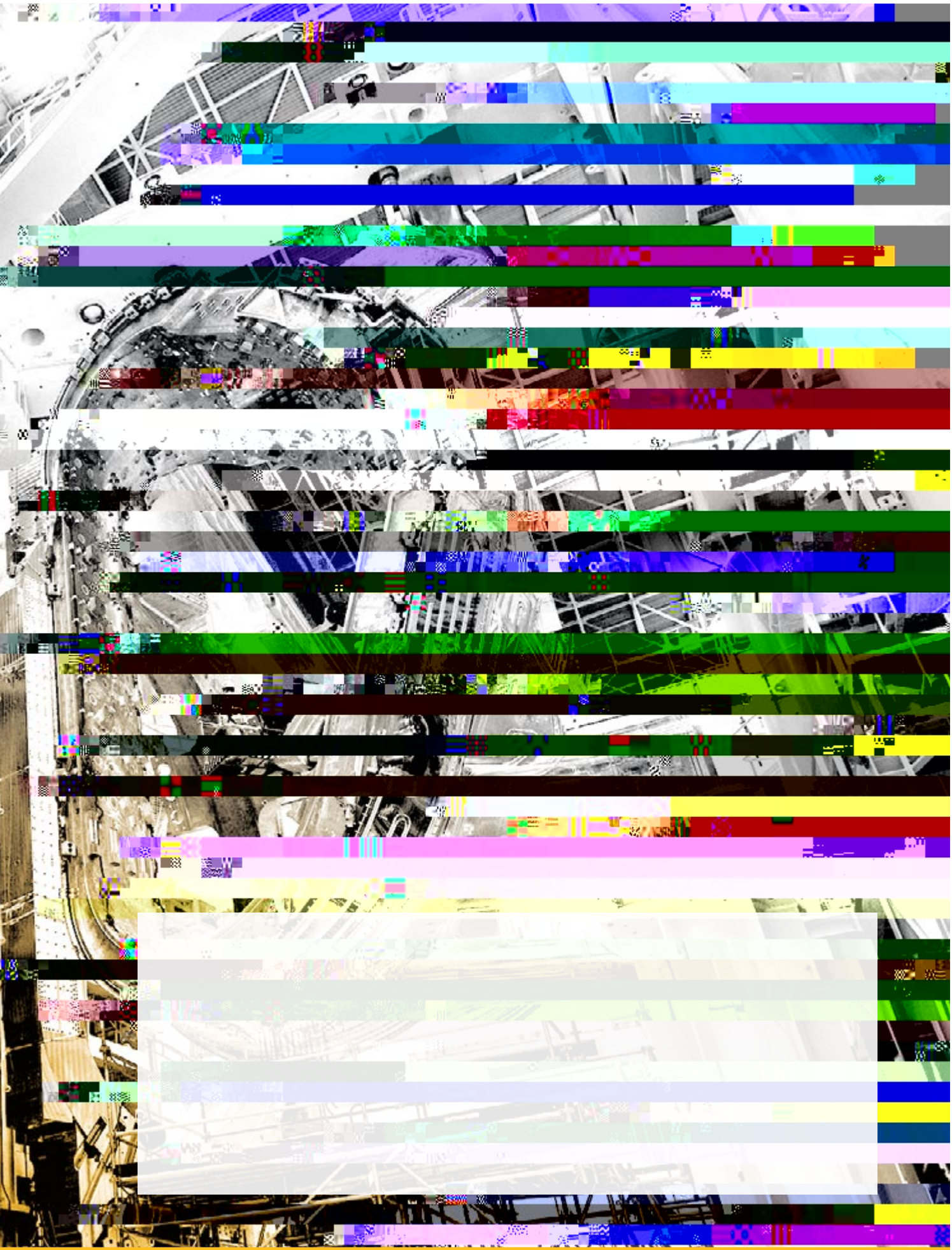
MAGNET POWER CONVERSION

CRYOSTAT WORKSHOP

ASSEMBLY AND INSTALLATION



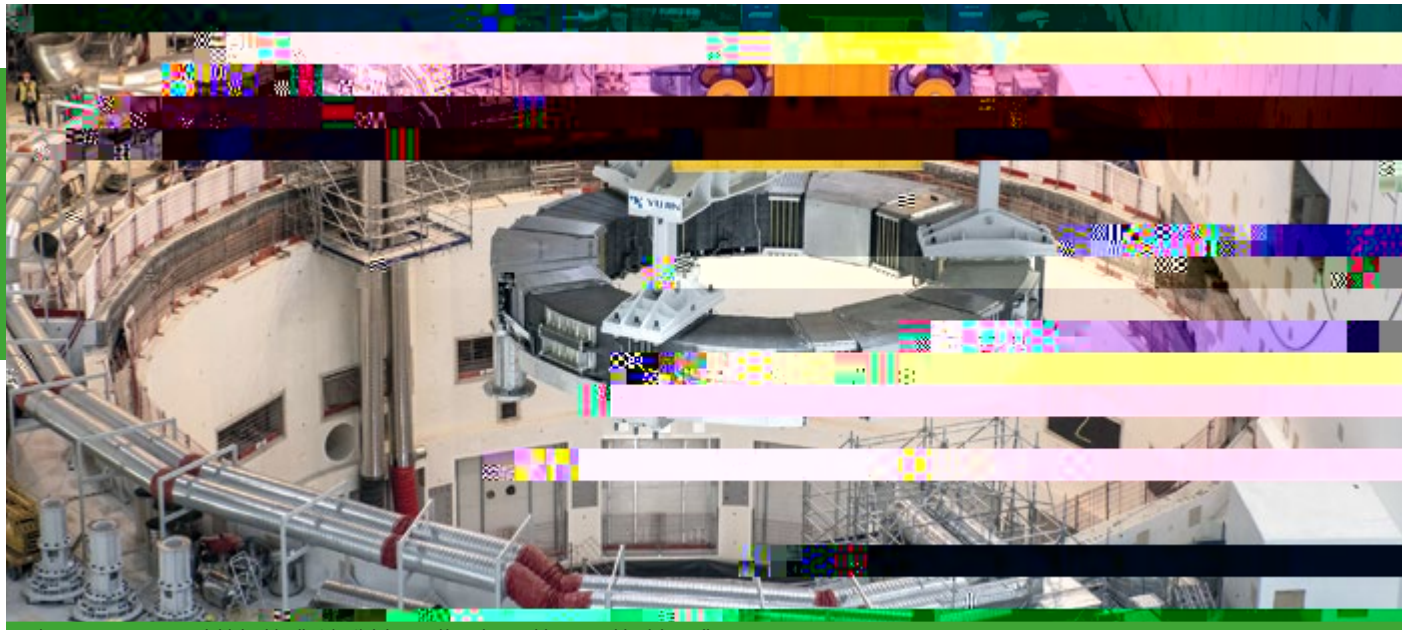
In 2021, the ITER assembly team successfully creates the rst vacuum vessel sub-assembly of the ITER machine. With sector #6 at the



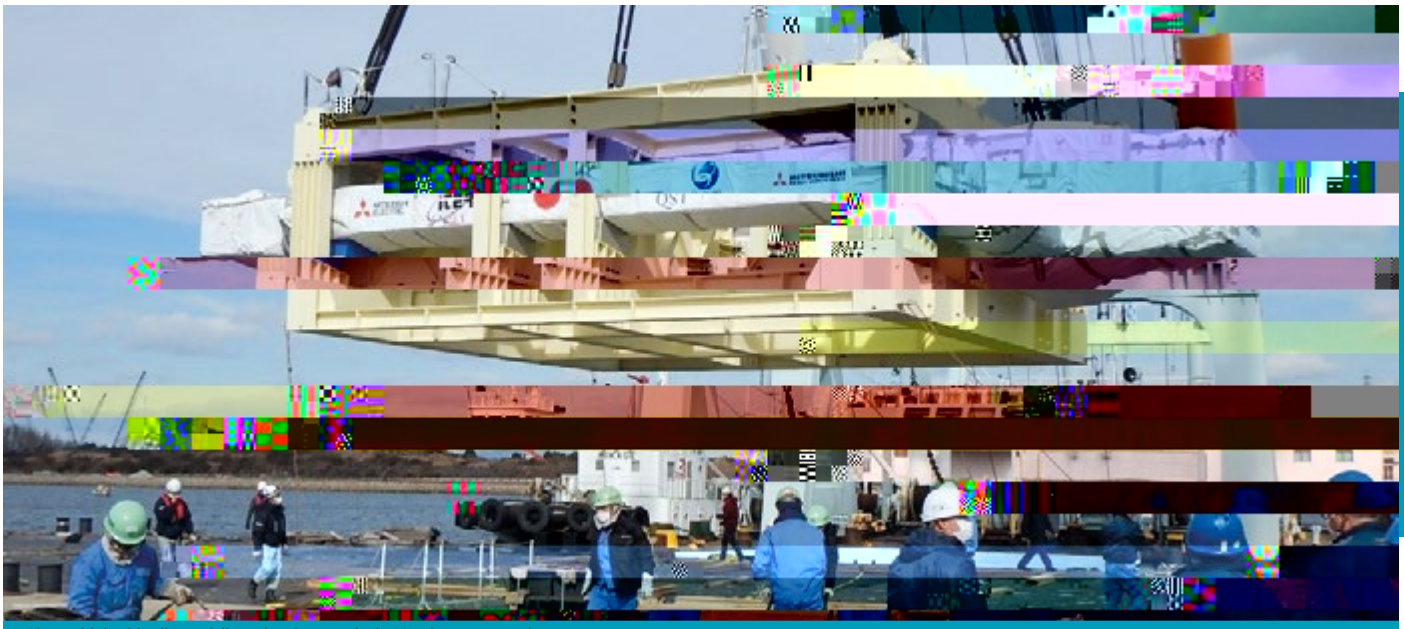
ASSEMBLING

JANUARY

FEBRUARY



The first ITER magnet, poloidal field coil #6 (PF6), is lowered into the machine assembly pit in April.



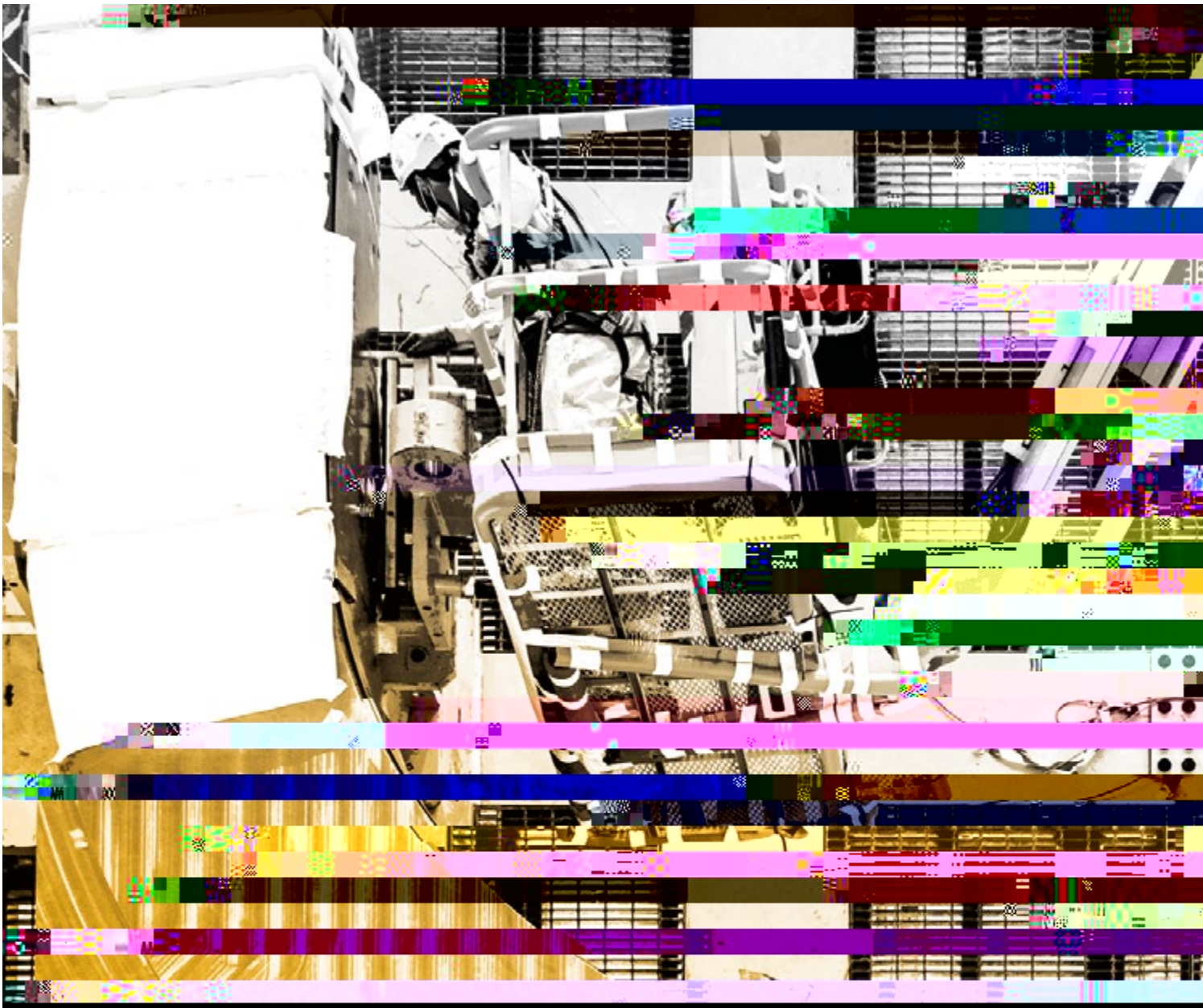
Six toroidal field coils are delivered to the ITER site in 2021 by Europe and Japan.

In November, the pit is declared ready for the first vacuum vessel sector after all captive components (like these magnet feeders) are installed.

ASSEMBLING
THE MACHINE

In-pit – In 2021, contractors to the Indian Domestic Agency nalized the welding of the cryostat lower cylinder to the cryostat base within

The Tokamak Complex – The installation of cryolines, cooling water lines, busbars, fast discharge units, cable trays and supports continues to progress level by level. Because the volume of installation work and contractor co-activity in the Tokamak Complex is high, the ITER construction teams are placing particular focus on the organization and optimization of installation sequences. The detailed sequences in the port cell shafts, for example, were optimized during the year through an in-depth constructability assessment that included the Holistic Integ onstrucooling tiv1ID 769 >>BDC ltR(HITBT9



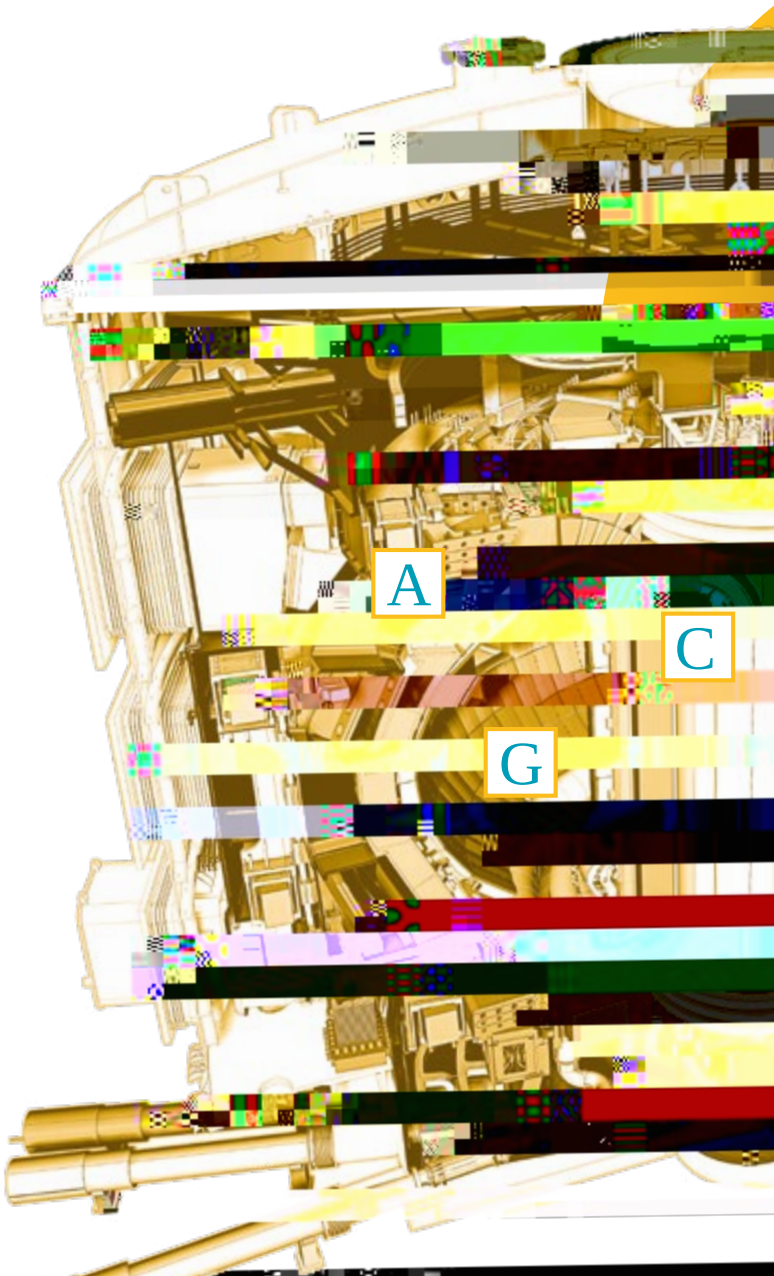
From its position on the wing of the giant sector sub-assembly tool, this D-shaped toroidal eld coil will be rotated inward and matched to vacuum vessel sector #6.

2021

ENGINEERING AND MANUFACTURING UPDATE

KEY COMPONENTS

The ITER Members are in the □nal stages of procuring the major components that will constitute the core machine. Ten superconducting magnets reached the site in 2021, joining the six that were delivered last year; globally, manufacturing completion is now above 97% for the central solenoid, poloidal and toroidal □eld magnet systems. Vacuum vessel sector manufacturing and delivery has continued steadily, but has been impacted by pandemic-related contractor delay, some



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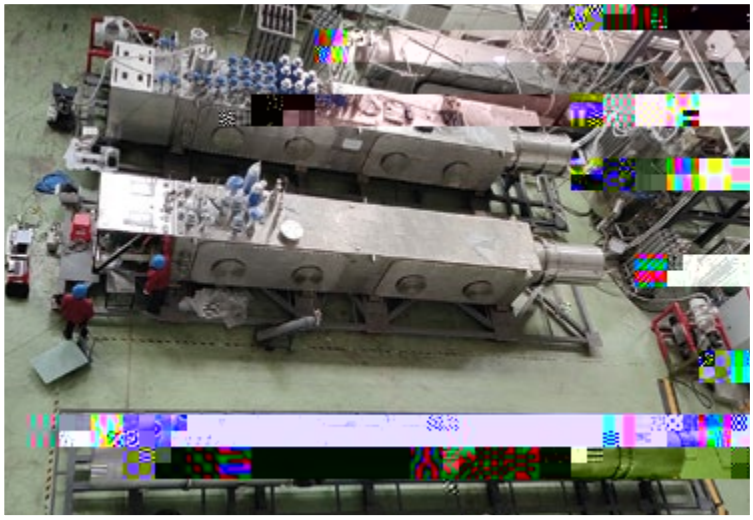
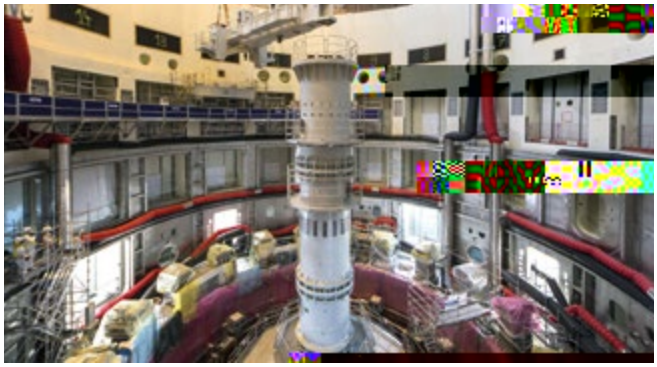
ENGINEERING AND

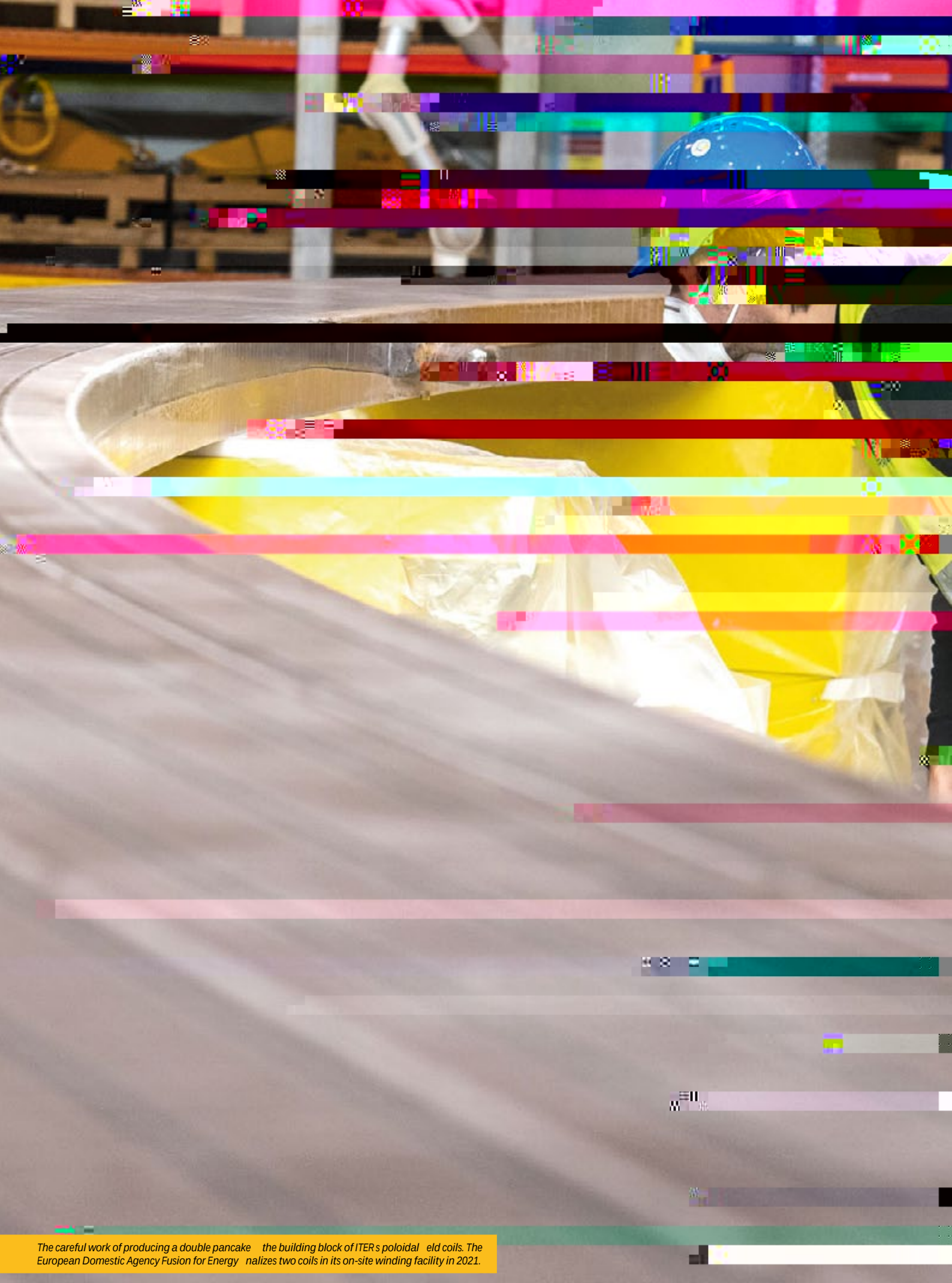


• Each of ITER's 31 magnet feeders is assembled on site fr three feeder segments shipped by China. Of approximatel 100 large components expected, 21 have arrived on site sinc 2018 and 9 have been installed in the Tokamak Building. I China, manufacturing completion has passed 60%.

• Russian specialists have successfully completed vacuu pressure impregnation of poloidal eld coil #1 (PF1). Nine metres in diameter, 200 tonnes, this ring coil will be the las ITER magnet installed in the Tokamak pit.

• A complex system of cryogenic lines produced in India will distribute the cooling power generated by the ITER cryoplant to clients throughout the installation. Four years after manufacturing was initiated, the last batch left





The careful work of producing a double pancake the building block of ITER s poloidal eld coils. The European Domestic Agency Fusion for Energy nalizes two coils in its on-site winding facility in 2021.

ENGINEERING AND MANUFACTURING HIGHLIGHTS 2021

• Fifty-four divertor cassettes form the backbone of a unique system designed to exhaust waste gas from the ITER machine and minimize impurities in the plasma. In Europe, the final contract for divertor cassette manufacturing has been signed and fabrication is underway, with delivery expected on this final group between 2025 and 2027. ' Walter Tosto [11]

• A set of spare pre-compression rings manufactured in Europe has been lowered into the Tokamak pit. Made of glass fibre/epoxy composite, six pre-compression rings in total will hold the toroidal field coils at top and bottom to help them resist electromagnetic forces.

• The ITER cryoplant has entered pre-commissioning, as tests are carried out to verify control-command systems, leak tightness, cleanliness, and safety. Over the last 3.5 years, the teams have assembled and installed 5,000 tonnes of equipment and many kilometres of piping (approximately one million work hours). [12]

• The heat rejection zone has been formally handed over by the construction teams to the operations/commissioning team. Commissioning activities have started. [13]

• The ITER magnet program advanced strongly in 2021—11/19 toroidal field coils, 3/6 poloidal field coils, and 2/7 central solenoid modules have now been delivered.

• A multiyear qualification program in Russia has concluded with the successful manufacturing and testing of a full-scale divertor dome prototype. It was shipped to ITER for divertor integration trials, where prototypes of all divertor components produced by Europe, Japan and Russia will be assembled for the first time. [14]

• China and Korea have completed the manufacturing of

11

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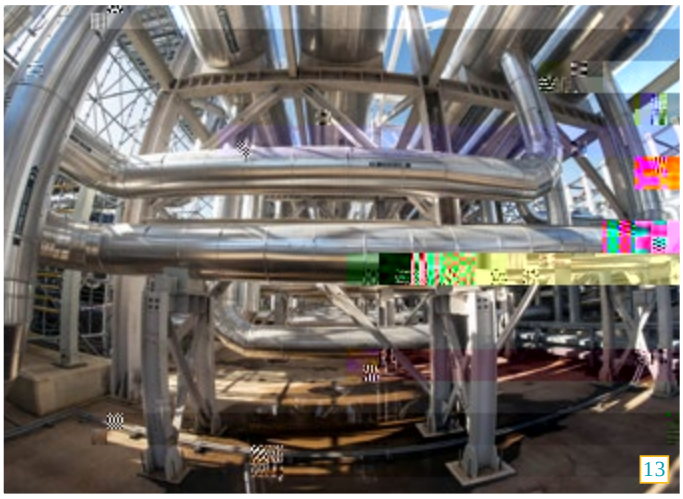
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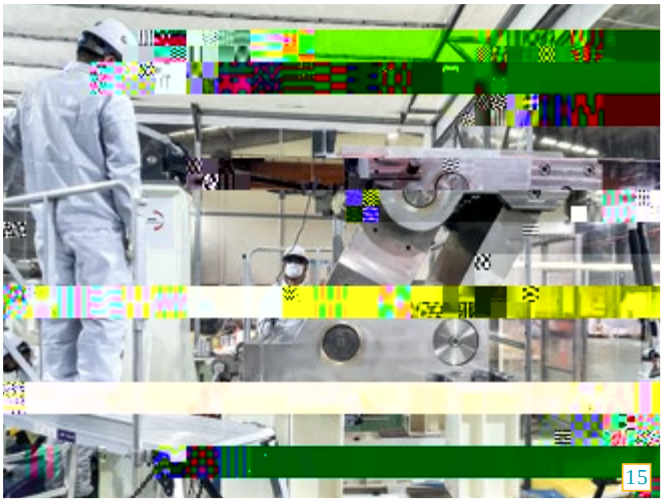
ENGINEERING AND MANUFACTURING HIGHLIGHTS 2021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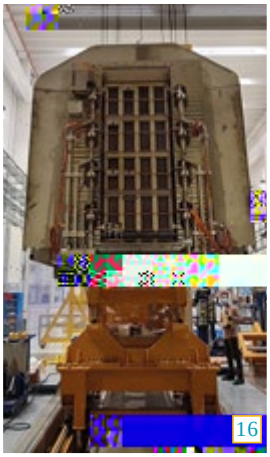
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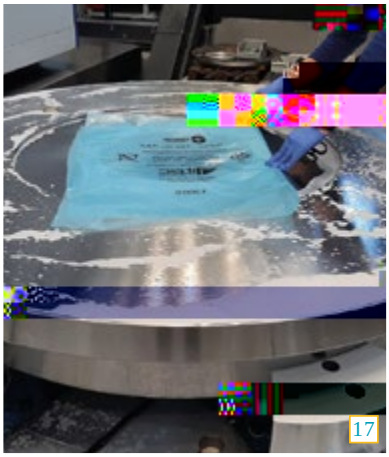
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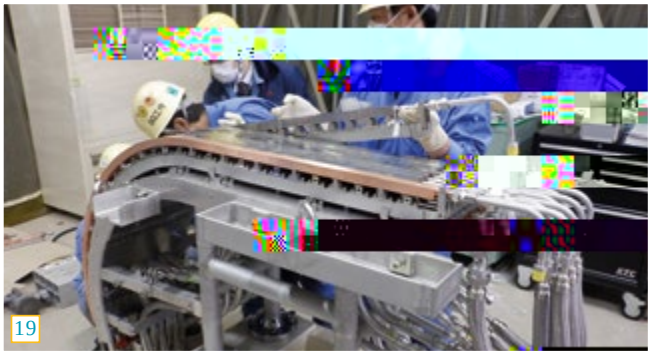
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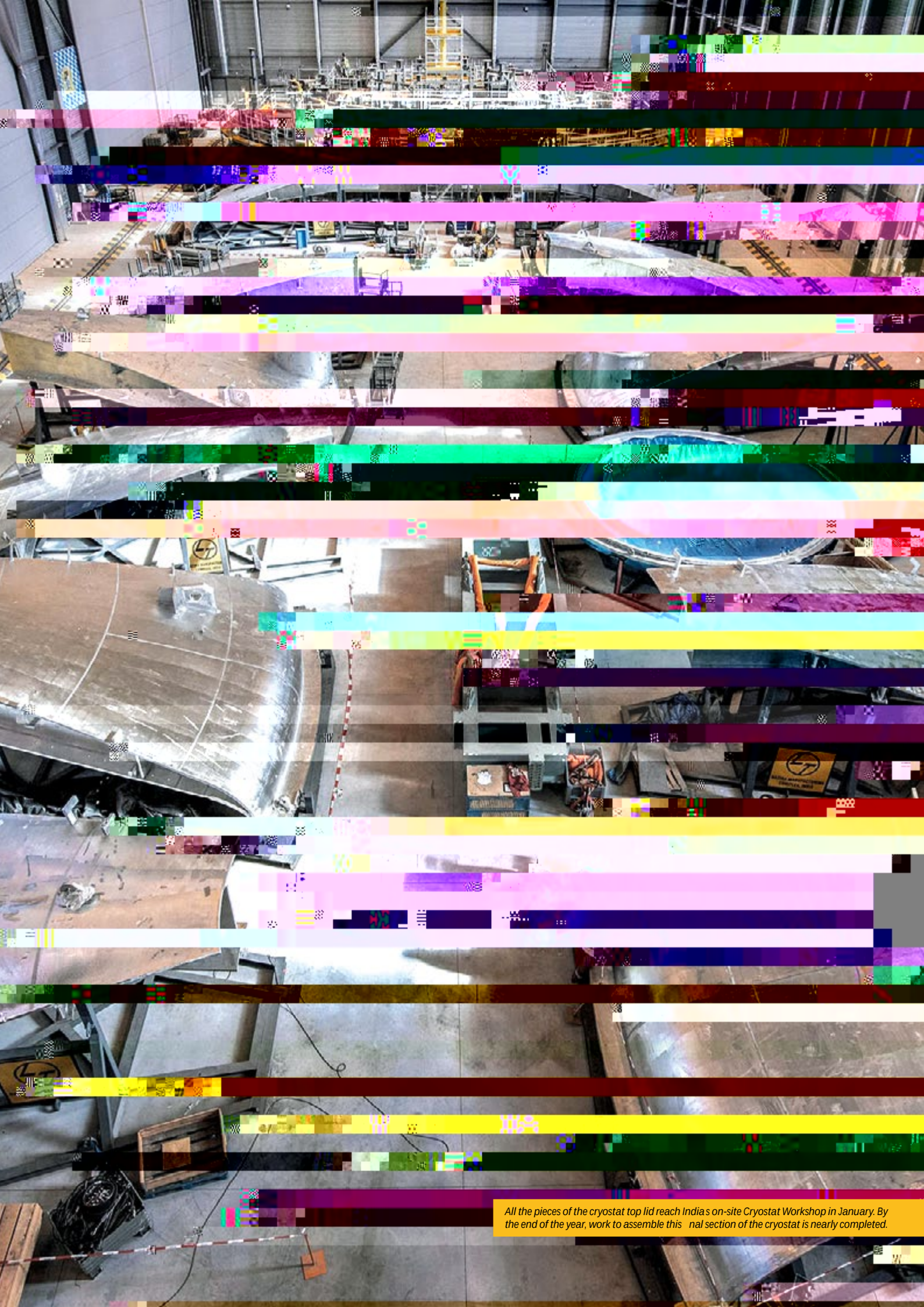
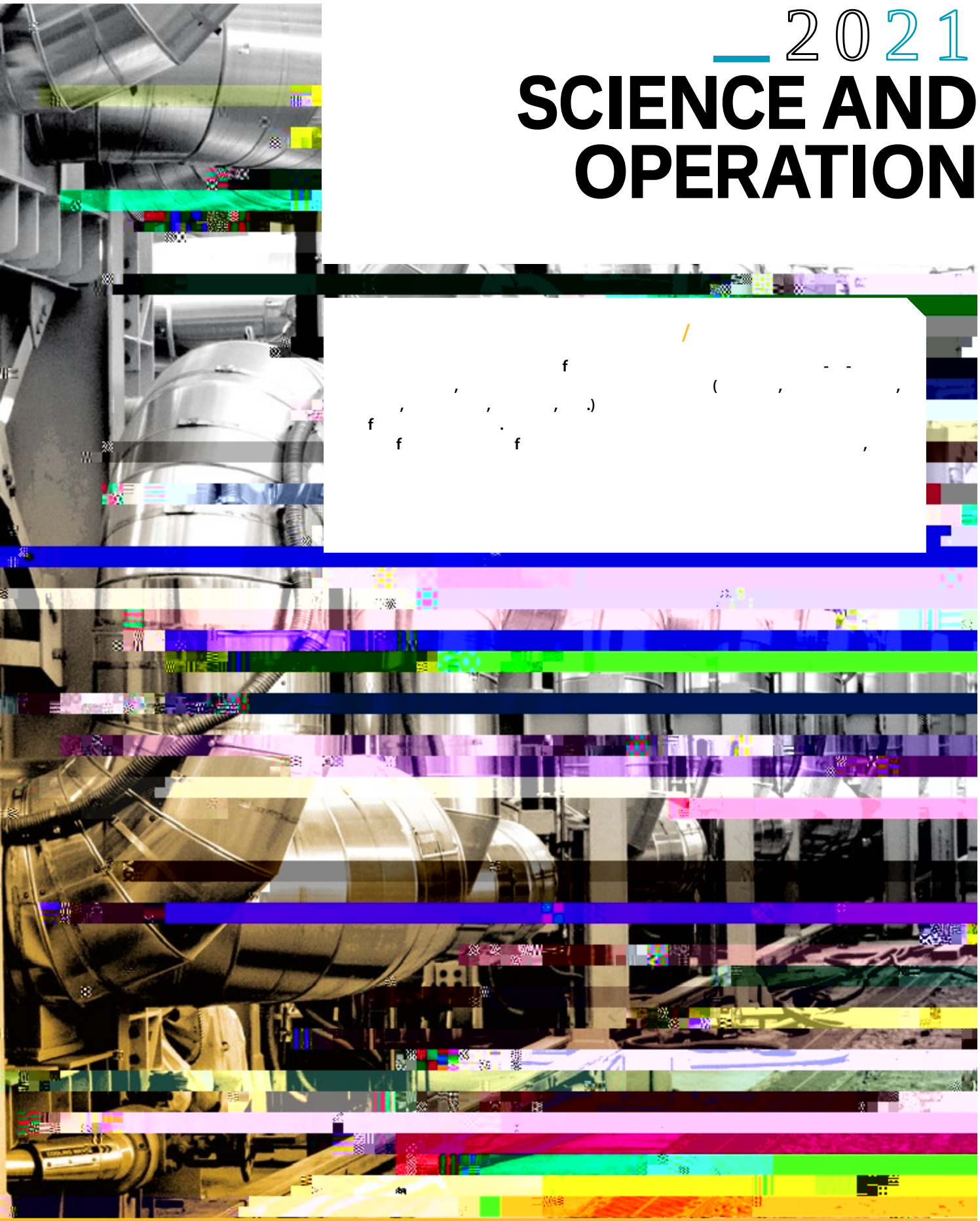


All the pieces of the cryostat top lid reach India's on-site Cryostat Workshop in January. By the end of the year, work to assemble this final section of the cryostat is nearly completed.



2021 SCIENCE AND OPERATION

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SCIENCE AND OPERATION

Disruption mitigation: Optimizing pellet shatter size and velocity

Even in the early phases of pre-fusion-power operation, ITER will need an e□ective method to mitigate the consequences of plasma disruptions—instabilities that may develop within the tokamak plasma. The ITER Organization is designing a disruption mitigation system based on shattered pellet injection. A shattered pellet injector is a device that pre-empts disruptions by releasing a spray of frozen hydrogen-neon pellets into a plasma. The frozen pellet fragments rapidly decrease the plasma temperature, thereby dissipating energy and minimizing potential damage to plasma-facing surfaces.

Under the coordination of the ITER Disruption Mitigation System Task Force, scientists and engineers are running shattered pellet injection experiments on operating tokamaks to optimize the performance of the technology and to provide the best possible basis for how to scale it to ITER. Following experiments initiated at JET (2019) and KSTAR (2020), the ITER Organization has launched a project together with the Max Planck Institute for Plasma Physics (IPP), in Garching, Germany, to install a shattered pellet injection system on the ASDEX Upgrade tokamak. The system is speci□cally designed to examine the impact of di□erent pellet shatter sizes and velocities on the mitigation process.

As part of the laboratory tests, the fragment plumes have been recorded and characterized for a large number of di□erent pellet types using high-speed cameras providing □rst-of-a-kind, high-resolution measurements of the shattering process, which will be used for future modelling of this key process for ITER. The shattered pellet injection system and upgraded diagnostics will be put to work in 2022 in a series of experiments conducted by the ITER Disruption Mitigation System Task Force together with IPP and the EUROfusion consortium.

Simulating measurements from ITER plasmas and actuators

Planning for ITER experimental exploitation requires the design of plasma simulation tools and control systems. Key ingredients for these tools are the models that simulate the measurements from the ITER plasmas, which will be used to control them as well as models to simulate the actuators to impact plasma behaviour and thus control.

Simulating the measurements that will be acquired from ITER plasmas requires the development of so-called synthetic diagnostics. These can be used to predict what will be seen on the real sensors, which will in turn help with the design of the diagnostic systems and in building the analysis tools that will interpret measurements.

This activity has seen a major development through the joint e□orts of the science and diagnostics divisions of the ITER Organization and the strong support of the Diagnostics Topical Group of the International Tokamak Physics Activity.

In addition, the systems that act on the plasma and their e□ects need to be simulated as well. To this purpose, work□ows to simulate the ITER heating and current drive systems (namely neutral beams, ion cyclotron and electron cyclotron radiofrequency heating) and the e□ects that the fast ions generated by these systems have on the plasma have been completed within the ITER Integrated Modelling and Analysis Suite (IMAS). These allow the simulation of the complex e□ects that take place when various heating systems are used simultaneously in ITER (e.g., the coupling

Re-evaluation of transient loads to plasma facing components in ITER scenarios

The high thermal and magnetic energies of ITER plasmas and the use of all-metal plasma-facing components mean that the transients resulting from uncontrolled edge-localized modes (ELMs) and unmitigated disruptions can lead to signi□cant damage and reduction in component lifetime in ITER. Runaway electron formation during the disruption current quench is also a signi□cant concern, given that the runaway beam may carry a large fraction of the plasma magnetic energy and deposit this energy in extremely localized areas, which can in turn cause large localized erosion in a single event and lead to in-vessel water leaks.

Given the importance of transient loads for ITER experimental availability, the ITER Council requested its Science and Technology Advisory Committee (STAC) to review progress on the evaluation of plasma-facing component behaviour under transient loads and their impact on the execution of the ITER Research Plan. The evaluation performed by the ITER Organization concluded that melting of the divertor tungsten monoblocks is expected to be ac-iunder

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SCIENCE AND

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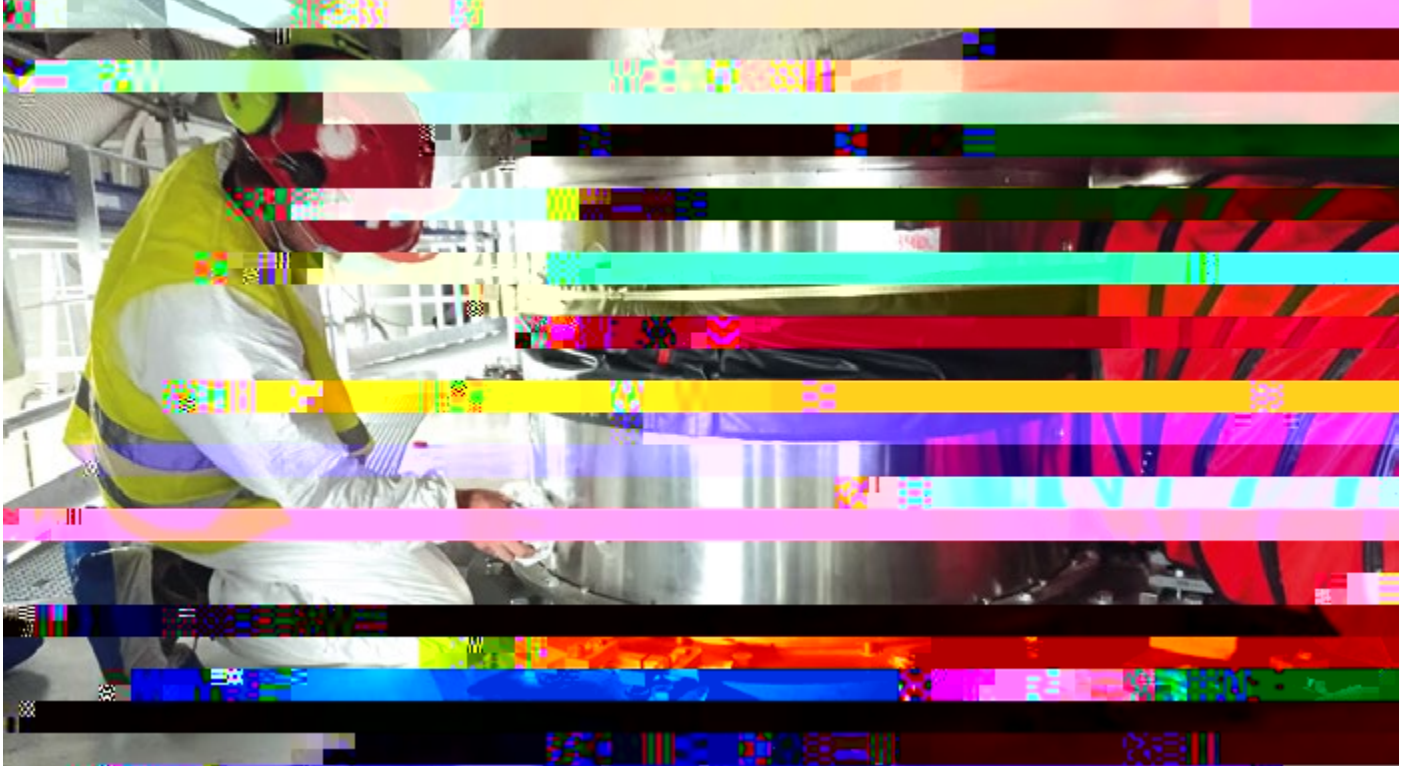


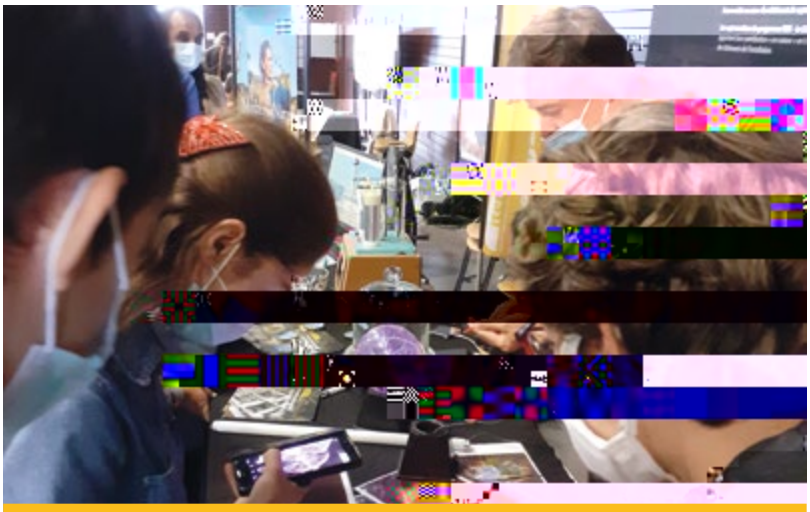
2021

CORPORATE HIGHLIGHTS

CORPORATE HIGHLIGHTS 2021

Against the backdrop of year two of the Covid-19 pandemic, the ITER Organization and the Domestic Agencies kept the project on its forward-moving trajectory—achieving key manufacturing and assembly milestones and gaining signi cant experience in the preparation of major components for installation in the machine pit. However, challenges reported in the manufacturing of some critical-path components, compounded by pandemic-related supply chain issues, are pushing back expected delivery dates and a ecting the schedule for machine assembly. In 2022, the ITER Organization will complete an assessment of these delays and present a Baseline Update to the ITER Council. To date, the project has executed 75.8% of the work scope to First Plasma and achieved 63 high-level ITER Council milestones.

Covid-19 – On site at ITER, the continuity plan in operation since the start of the pandemic in France has been e ective in maintaining critical-path assembly and installation work. For ITER manufacturing worldwide, the pandemic's e ect on the industry and transportation sectors has translated to periods of partial

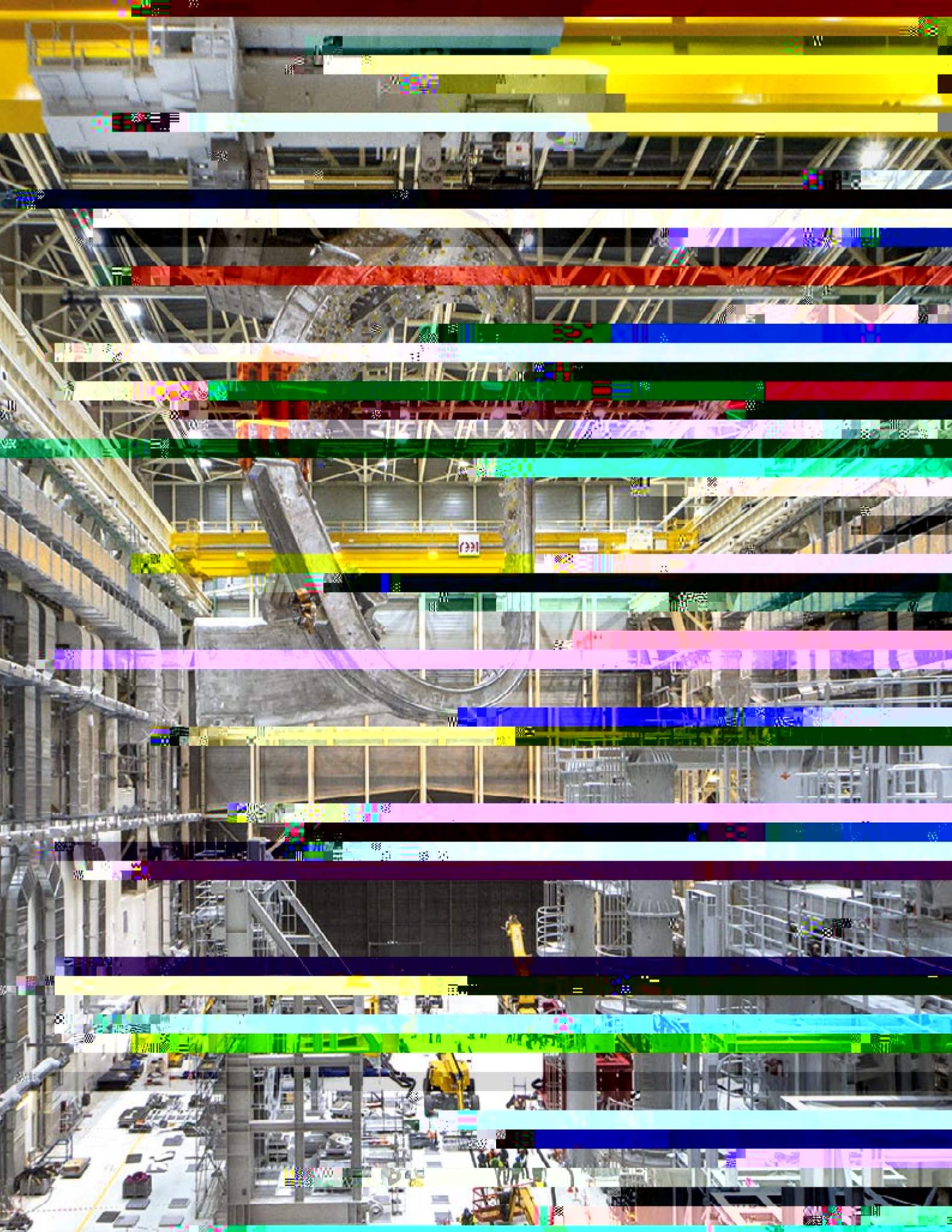


The outreach program picks up again in schools and local venues with masks.

Revised construction strategy – As requested by the ITER Council at it twenty-eighth meeting in June 2021, the ITER Organization is worvs

The ITER Organization innovates with a virtual Open Doors Day in 2021 due to pandemic restrictions.

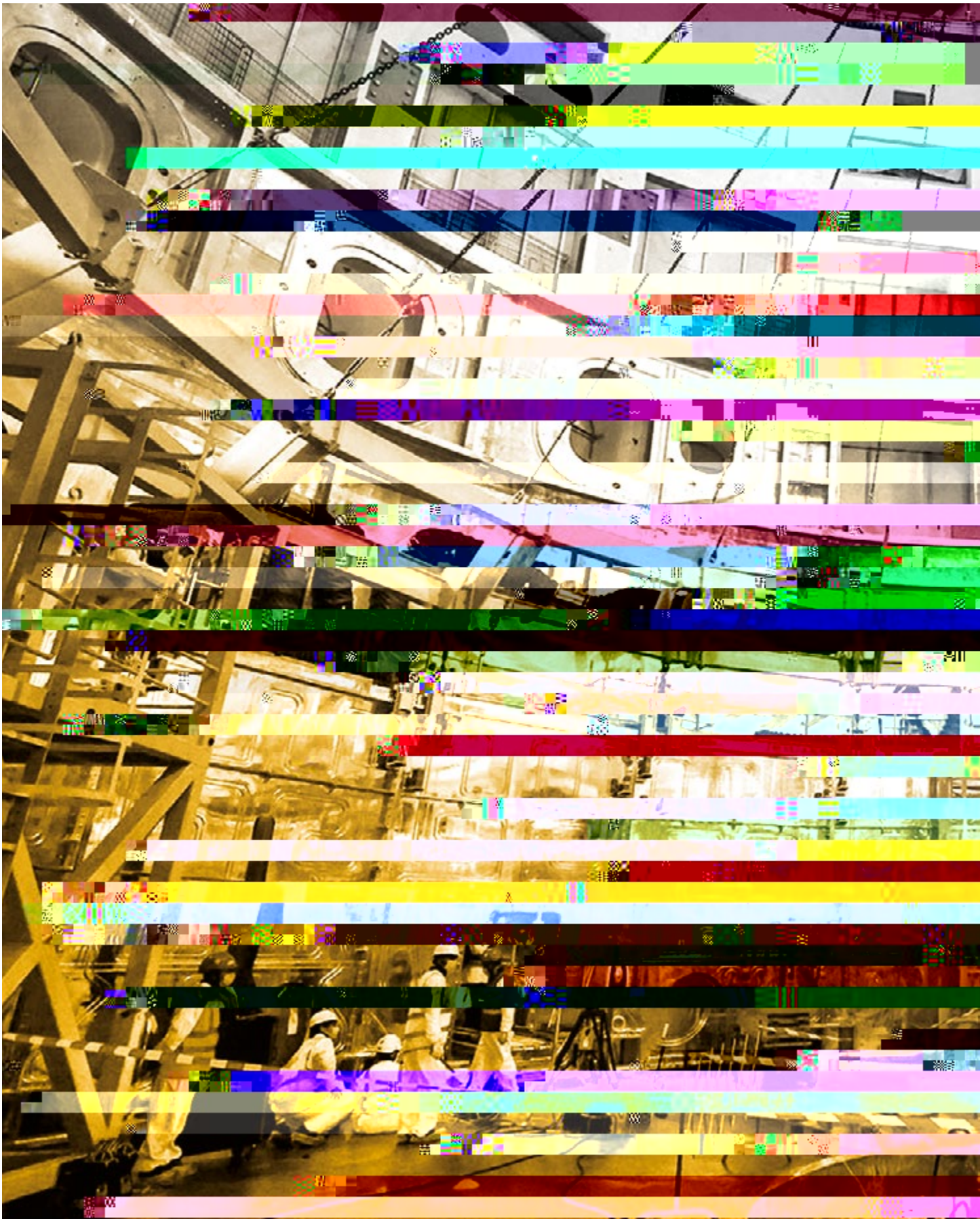
Poloidal eld coil #6 (PF6) may be the second smallest of the ITER ring magnets in terms of diameter (10 metres), but a higher number of stacked pancakes (nine instead of six or eight), a greater number of coil turns (twice as many as PF1) and exceptionally heavy clamps cause it to weigh an incredible 330 tonnes.



Vacuum vessel sector #6, from Korea, becomes the rst sector to be docked in tooling in April. A second sector (also from Korea) is received by the ITER teams in August.

Regulatory environment – As an Installation nucléaire de base (INB)—a nuclear installation under French nuclear safety regulations—the project is required at regular intervals to demonstrate that its safety-relevant buildings, civil structures, systems and components conform to the approved design and meet the safety case in the "as-built" or "as-installed" condition. To oversee these aspects of safety, soon after approving the project design the French nuclear safety authority, Autorité de sûreté nucléaire (ASN), put a series of hold points in place as part of the normal regulatory process. The next hold point for the ITER Project is the start of assembly authorization, which will be issued by ASN if the ITER team engages in a machine assembly activity “that would be di cult to reverse,” i.e., the welding together of the rst two vacuum vessel sectors in the tokamak pit. Exchanges between the ITER Organization and ASN on ITER’s safety le for the authorization of machine assembly have been frequent since the le was accepted as admissible for further

0 -7.5 Td /Span <</MCID 9 >>BDC BT -0.009 Tw 10 0 0 10 35.424376.2473 Tm /TT0 1 Tf [(assembly authorization \(ITER\))-9.9(has been submitted to ASN)] TJ 0 -1.2 Td [(1cbe assembly have been soon amr-F2021se asp5(t f6a)8 d alihe prET Eg (fr/P (r)10 (ojec)-1iD 1919 >>BDC BT -0.0



A large silver-plated component, the lower cryostat thermal shield, is lowered into the pit at the beginning of the year. Special rigging, with 18 points of interface, provides rigidity and stability.

2021

STAFFING AND FINANCIAL DATA

STAFF BY MEMBER

STAFF BY
ORGANIZATIONAL UNIT

MAMMOET

2021

DOMESTIC AGENCY PROCUREMENT HIGHLIGHTS

Chinese procurement highlights in 2021	% of ITER system procured by China
MAGNET SYSTEMS	
TOROIDAL FIELD CONDUCTOR	7.5%
POLOIDAL FIELD CONDUCTOR	65%
MAGNET SUPPORTS	100%
FEEDERS	80%
CORRECTION COILS	100%
CORRECTION COIL AND FEEDER CONDUCTORS	100%
POWER SYSTEMS	
PULSED POWER ELECTRICAL NETWORK (PPEN)	100%
AC/DC CONVERTERS	55%
(IC milestone)	
REACTIVE POWER COMPENSATION	100%
BLANKET	
BLANKET FIRST WALL	12.6%
BLANKET SHIELD BLOCK	50.2%
FUEL CYCLE	
GAS INJECTION SYSTEM	100%
GLOW DISCHARGE CLEANING	100%

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Korean procurement highlights in 2021

% of ITER system procured by Korea

VACUUM VESSEL

MAIN VESSEL (2 OF 9 SEGMENTS)

21.52%

EQUATORIAL PORTS AND LOWER PORTS

BLANK

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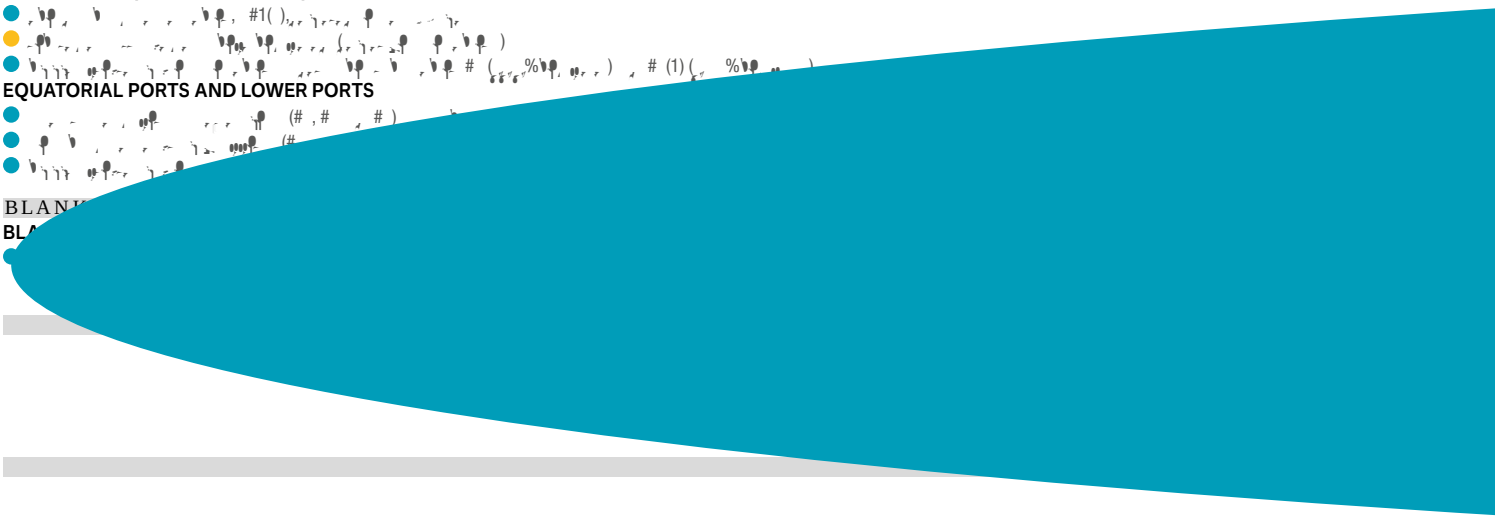
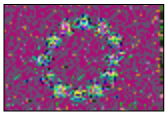


Russian procurement highlights in 2021	% of ITER system procured by Russia
POWER SYSTEMS	
SWITCHING NETWORK, FAST DISCHARGE UNITS, DC BUSBAR AND INSTRUMENTATION	100%
MAGNET SYSTEMS	
TOROIDAL FIELD CONDUCTOR	19.3%
POLOIDAL FIELD CONDUCTOR	20%
POLOIDAL FIELD MAGNET NO.1	100%
BLANKET	
BLANKET FIRST WALL	40%
BLANKET MODULE CONNECTORS	100%

US procurement highlights in 2021	% of ITER system procured by the US
COOLING WATER SYSTEM	
TOKAMAK COOLING WATER SYSTEM	100%



FUSION FOR ENERGY (EU-DA)

https://fusionforenergy.europa.eu/

PROCUREMENT ARRANGEMENTS*
Forty-one PAs signed since 2007 representing
85% in number **and**
96.5% of the total value **of**
EU in-kind contributions.

The EU-DA has awarded 725 design or fabrication contracts related to ITER procurement to universities, laboratories and industry since 2007.

EU procurement highlights in 2021	% of ITER system procured by the EU
VACUUM VESSEL	
MAIN VESSEL (5 OF 9 SEGMENTS)	56%
DIVERTOR	
INNER VERTICAL TARGETS	100%
CASSETTE BODY	100%
DIVERTOR RAIL	100%
BLANKET	
BLANKET FIRST WALL	47.4%
BLANKET COOLING MANIFOLDS	100%
REMOTE HANDLING	
IN-VESSEL DIVERTOR REMOTE HANDLING SYSTEM	100%
CASK AND PLUG REMOTE HANDLING SYSTEM	100%
NEUTRAL BEAM REMOTE HANDLING SYSTEM	100%
IN-VESSEL VIEWING SYSTEM (IVVS)	100%
COMMON TECHNOLOGIES	100%
POWER SYSTEMS	
STEADY STATE ELECTRICAL NETWORK (SSEN) AND PULSED POWER ELECTRICAL NETWORK (PPEN): DETAILED SYSTEM ENGINEERING DESIGN	100%
INSTALLATION AND COMMISSIONING	100%
EMERGENCY POWER SUPPLY	100%
SSEN COMPONENTS	25%
FUEL CYCLE	
FRONT END CRYO-DISTRIBUTION: WARM REGENERATION LINES	100%

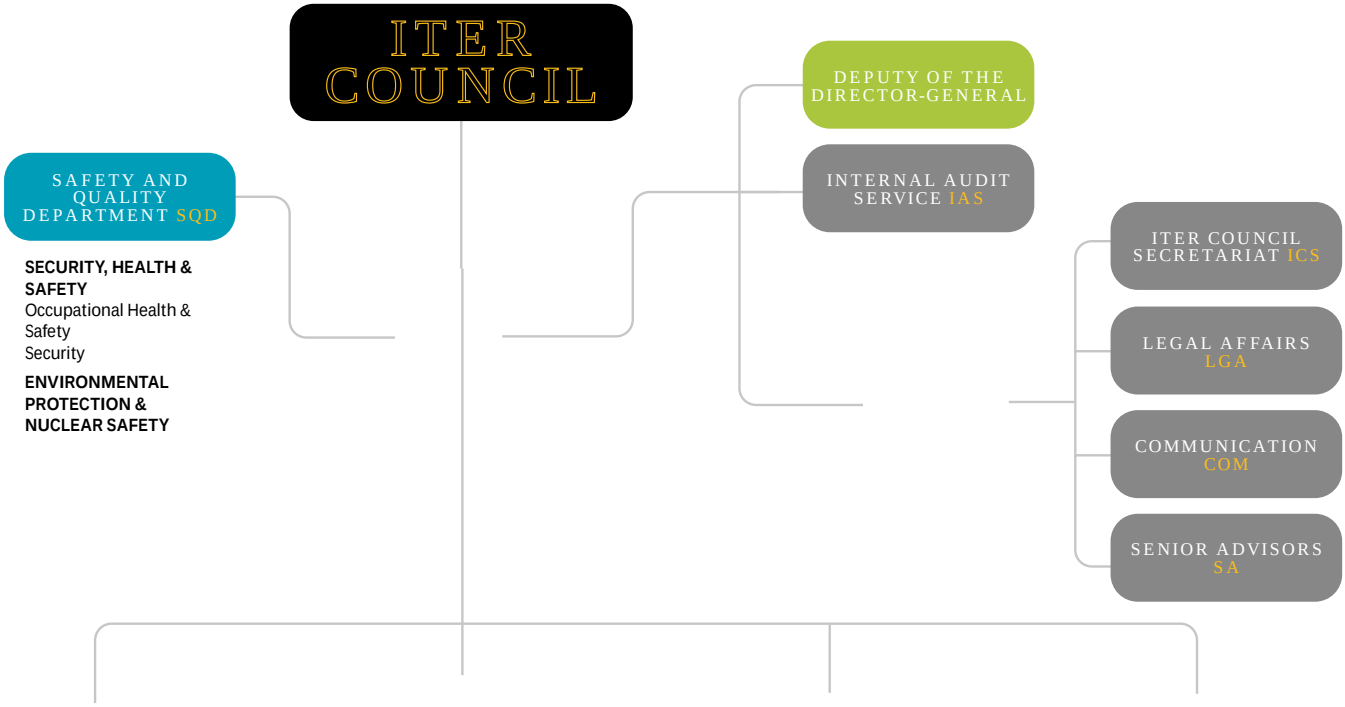
Abbreviations : CDR Conceptual Design Review ; DA Domestic Agency ; FDR Final Design Review ; I&C Instrumentation & Control ; IO ITER Organization ; IC ITER Council ; FAT Factory Acceptance Tests ; MIP Manufacturing & Inspection Plan ; MRR Manufacturing Readiness Review ; PA Procurement Arrangement ; PDR Preliminary Design Review ; SAT Site Acceptance Tests

INTERNATIONAL COOPERATION

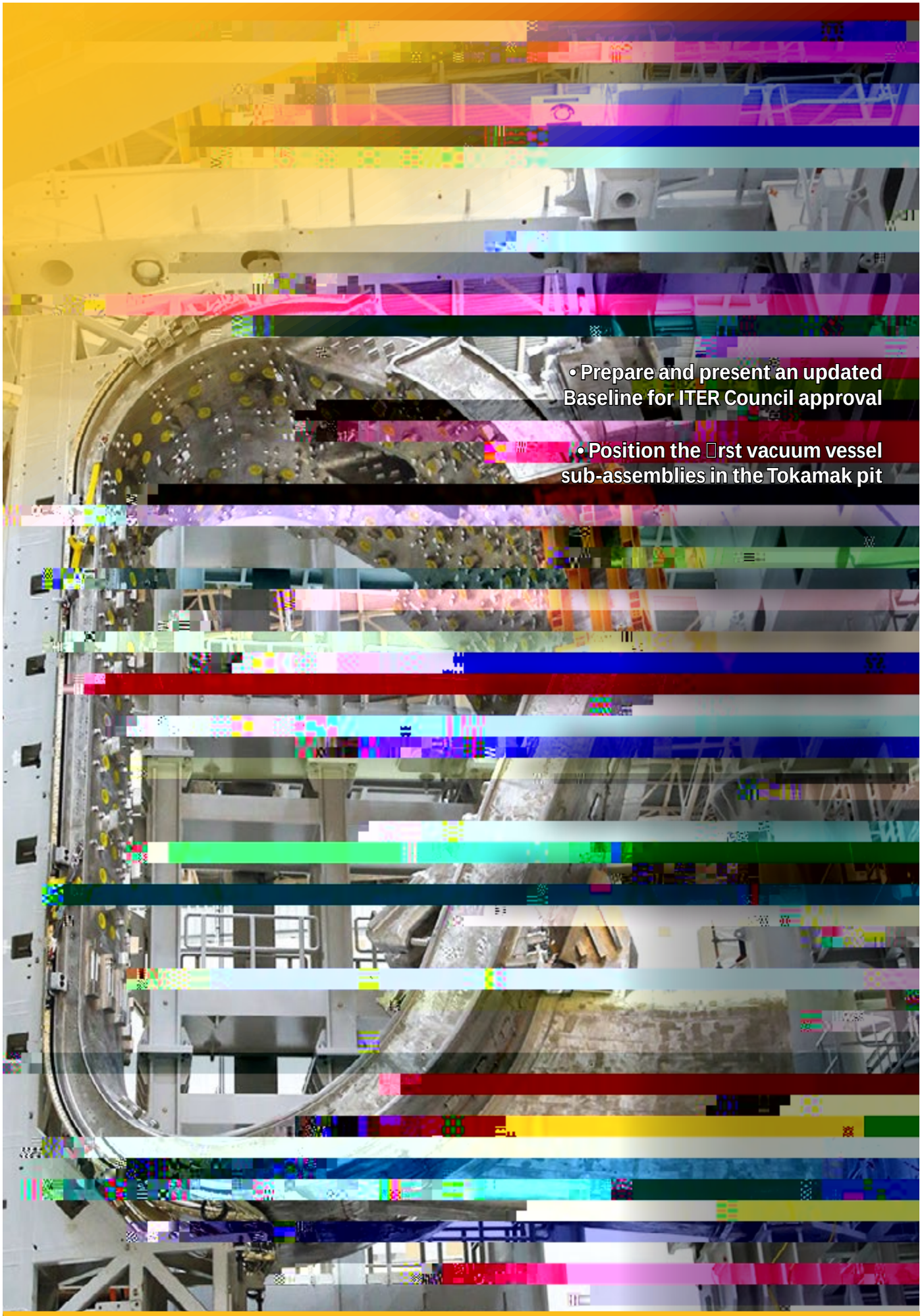
The following entities have signed Cooperation Agreements with the ITER Organization. (The list excludes agreements

UNIVERSITIES	
University of Leuven	Belgium
The Southwest Jiao Tong University	China
Huazhong University of Science and Technology	China
Dalian University of Technology (DLUT)	China
Anhui University of Science and Technology	China
Shanghai Jiao Tong University (SJTU)	China
Åland University of Applied Sciences	Finland
TOULOUSE INP - ENSEEIHT "N7"	France
Université Aixng (fr-FRTjEMC ETa)27 (OUL2rseillelTextREFF0009>>> BDC ( )TjEMC ETEMC /P /Lang (fr-FR)/MCID 3193 >>BDC BT/TT0 1 Tf8 0 0 8 532.3364 575.1079 Tm(Fra	

ORGANIZATION CHART



Caption cover image: A specially designed "cradle"—the upending tool—is used in the Assembly Hall to lift two categories of machine component to vertical: sectors of the vacuum vessel and D-shaped toroidal field coils. This bespoke took will be used 27 times during machine assembly.



The rst sub-assembly operation around vacuum vessel sector #6 is a success, as nal alignment is achieved to within 1 mm of tolerance in the radial, toroidal and vertical directions. This major achievement smooths the way for the similar assembly of eight other sub-assemblies in the months and years ahead.

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' ITER Organization, Juin 2022

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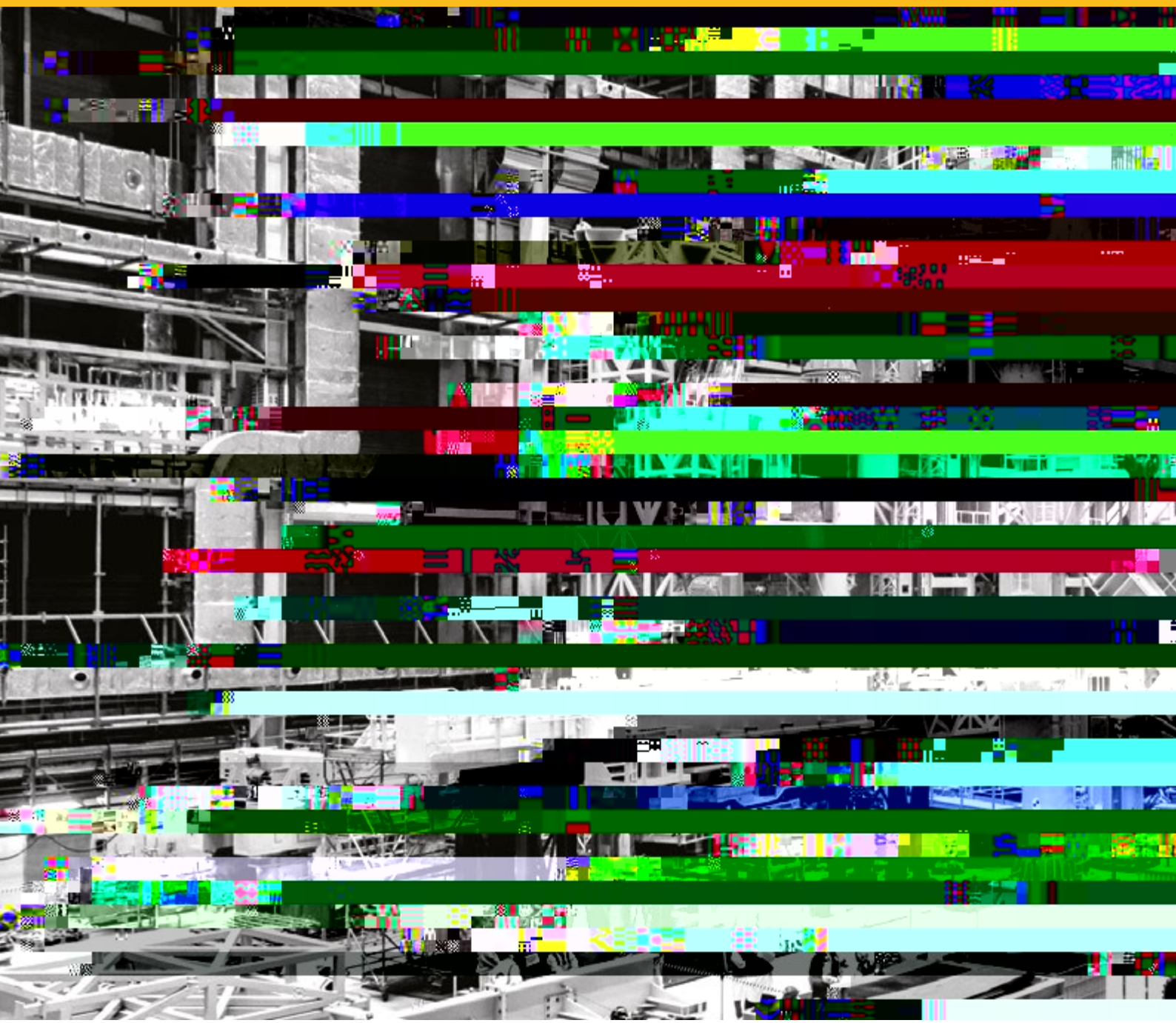

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