



Information Exchange on HTGR and Nuclear Hydrogen Technology between JAEA and INET in 2008

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The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. Presently only two HTGR reactors are operational in the world, including the HTTR (High Temperature Engineering Test Reactor) in Japan Atomic Energy Agency (JAEA) and the HTR-10 in the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University in China. JAEA and INET have cooperated since 1986 in the field of HTGR development, particularly on the HTTR and HTR-10 projects. This report describes the cooperation activities on HTGR and nuclear hydrogen technology between JAEA and INET in 2008.

Keywords: HTGR, HTTR, HTR-10, International Cooperation

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日本原子力研究開発機構と中国清華大学核能及新能源技術研究院との
高温ガス炉及び原子力水素製造技術の情報交換に関する報告書（2008 年）

日本原子力研究開発機構大洗研究開発センター高温工学試験研究炉部

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高温ガス炉から取り出される高温の熱は、高効率発電のみならず、広範囲なプロセス熱利用、特に、熱化学水素製造に用いることができることから、高温ガス炉への関心が世界的に高まっている。現在、世界で運転されている高温ガス炉は 2 基のみで、1 つが独立行政法人日本原子力研究開発機構の HTTR（高温工学試験研究炉）であり、もう 1 つが、中国の清華大学核能及新能源技術研究院（INET）の HTR-10 である。原子力機構と INET は、1986 年の覚書締結以来、これまで高温ガス炉分野、特に、HTTR 計画及び HTR-10 計画について研究協力を進めてきた。本報は、2008 年の原子力機構と INET の高温ガス炉及び原子力水素製造技術開発に関する研究協力活動についてまとめたものである。

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1. Introduction

The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. National projects on HTGRs are ongoing in Japan, China, France, USA, South Africa, Korea, etc., and the VHTR (Very High-Temperature Reactor) is chosen as the most promising Generation IV nuclear reactor system in GIF (Generation IV International Forum). There are presently only two HTGRs operating in the world, HTTR, High Temperature Engineering Test Reactor, in JAEA (see Table 1.1 and Fig. 1.1) and HTR-10 in Institute of Nuclear and New Energy Technology of Tsinghua University (INET) (see Table 1.2 and Fig. 1.2).

Construction of the HTTR was started in 1991 and its first criticality was achieved on November 10, 1998. Then, power-up tests were carried out, and rated thermal power of 30MW at the reactor outlet coolant temperature of 850°C was attained in December 2001. Rated power operation and safety demonstration tests using the HTTR have been conducted since FY2002. After several operational cycles, high temperature test operation of the HTTR to achieve the coolant temperature of 950°C was conducted, and coolant temperature of 950°C at reactor outlet was reached on April 14, 2004.

First criticality of the HTR-10 was achieved at air condition on December 1, 2000, and re-criticality at helium condition was attained in July 2002. Then, power-up tests were conducted, and the first synchronization at 3MWt was achieved in January 2003, followed by full power operation at 10MWt with core outlet temperature of 700°C in February 2003. Safety demonstration tests including helium circulator trip without scram and reactivity insertion without scram were carried out in 2003 and 2005.

INET is also promoting development of Modular High-Temperature Gas-cooled Reactor (MHTGR) named as High Temperature Gas-Cooled Reactor – Pebble bed Module (HTR-PM) (see Table 1.2 and Fig. 1.2), based on the technology and experiences of the HTR-10. The HTR-PM project is under the standard design phase, and the HTR-PM demonstration plant is planned to finish construction by 2013.

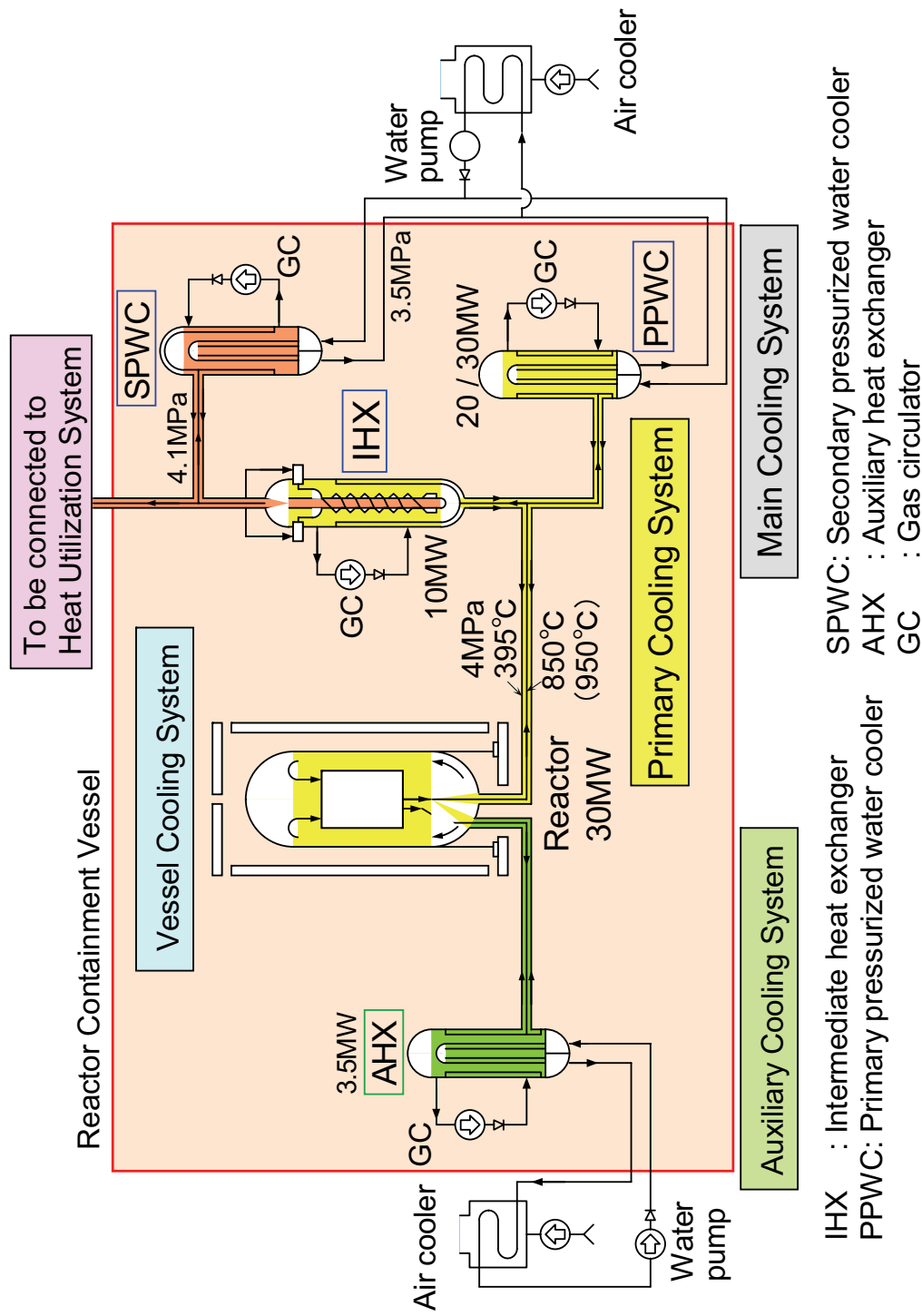
JAEA and INET have cooperated in the area of HTGR development, especially on HTTR and HTR-10 projects, since 1986 when a Memorandum of Understanding was exchanged between the two institutes. This report describes cooperation on HTGR development between JAEA and INET and major cooperation activities in 2008.

Table 1.1 Major specifications of HTTR

Thermal power	30MW
Outlet coolant temperature	850°C/950°C
Inlet coolant temperature	395°C
Fuel	Low enriched UO ₂
Fuel element type	Prismatic block
Direction of coolant flow	Downward
Pressure vessel	Steel
Number of cooling loop	1
Heat removal	IHX and PPWC (parallel loaded)
Primary coolant pressure	4MPa
Containment type	Steel containment
Plant lifetime	20 years

Table 1.2 Specifications of HTR-10 and HTR-PM

Parameters		HTR-10	HTR-PM
Reactor thermal power	MW	10	250
Net output power	MW	2.5	100
Primary helium pressure	MPa	3.0	7.0
Helium inlet temperature	°C	250	250
Helium outlet temperature	°C	700	750
Helium mass flow rate	kg/s	4.3	96
Main steam pressure	MPa	3.5	13.5
Main steam temperature	°C	435	543
Number of spherical fuel elements	-	27000	380000



IHX : Intermediate heat exchanger
PPWC: Primary pressurized water cooler
SPWC: Secondary pressurized water cooler
AHX : Auxiliary heat exchanger
GC : Gas circulator

Fig. 1.1 Cooling system of HTTR

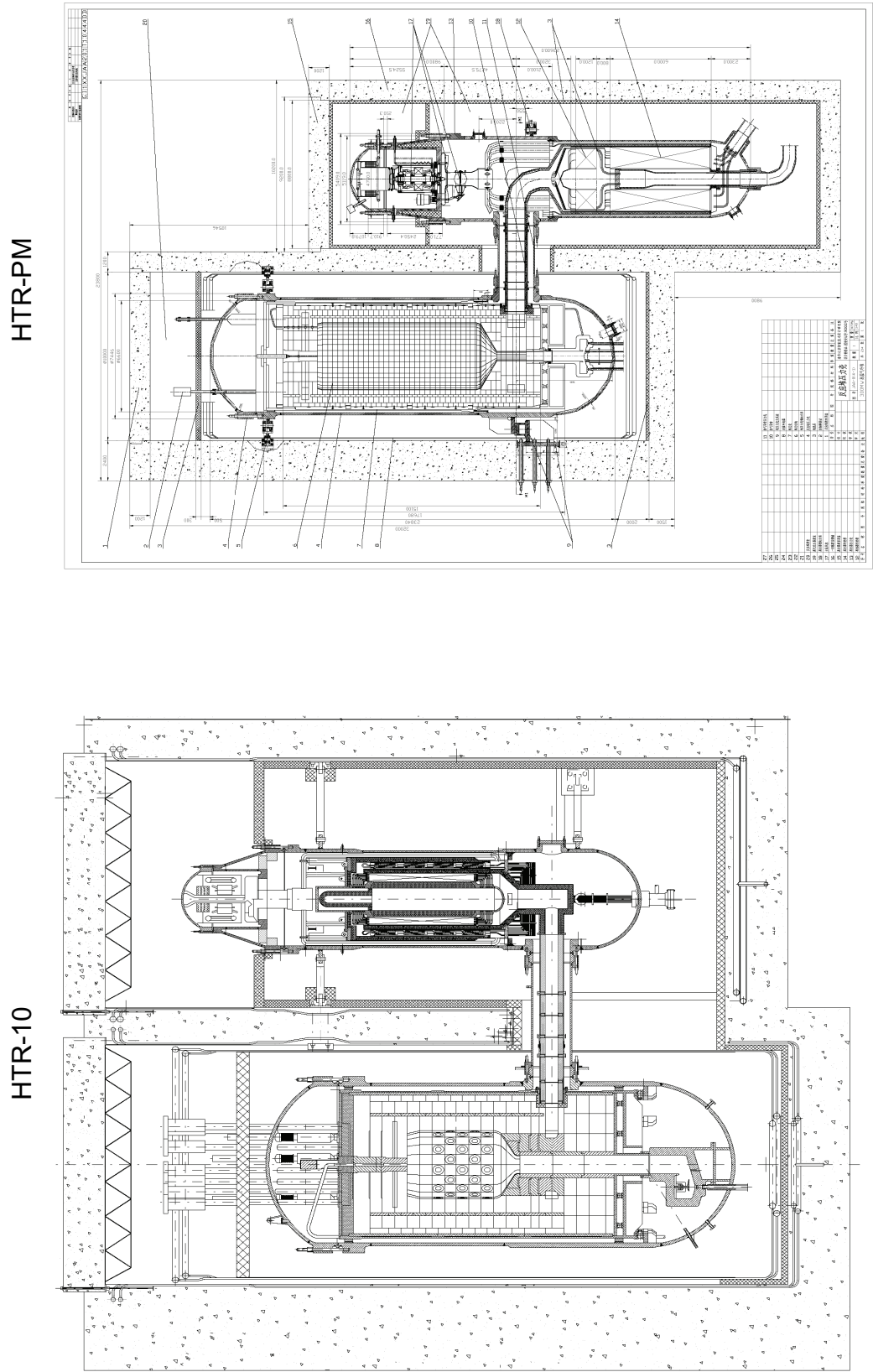


Fig. 1.2 Figures of HTR-10 and HTR-PM

2. Cooperation on HTGR Development between JAEA and INET

2.1 History of Cooperation

Vice chairman of Atomic Energy Commission of Japan, was requested for collaboration between China and Japan in the area of HTGR research and development during his visit to China in June 1985.

In September 1985, Director of Institute of Nuclear Energy Technology of Tsinghua University (INET) visited HTGR research and development facilities in Japan Atomic Energy Research Institute (JAERI), and discussed exchange of a Memorandum of Understanding (MOU) about cooperation on HTGR research and development.

In December 1985, A JAERI delegation visited INET and discussed exchange of a MOU.

In June 1986, JAERI and INET exchanged the initial MOU.

In June 1988, valid duration of the MOU was extended until June 1990.

In June 1990, the MOU was further extended until June 1995. In addition, Personnel Assignment Agreement was added to the memorandum of understanding.

In June 1995, valid duration of the MOU was extended until June 2000.

In June 2000, the MOU was further extended until June 2005.

In September 2003, Institute of Nuclear Energy Technology of Tsinghua University (INET) changed its full official name to Institute of Nuclear and New Energy Technology of Tsinghua University (INET) to further broaden academic disciplines of the institute.

In June 2005, valid duration of the MOU was once again extended until June 2010.

In October 2005, JAERI and Japan Nuclear Cycle Development Institute (JNC) merged to form Japan Atomic Energy Agency (JAEA).

Since June 1986 until today, information exchange meetings have been held almost every year as shown in Table 2.1, and general information exchange on research and development plan on HTTR and HTR-10 as well as on technologies in the area of HTGRs has been made.

Since the HTR-10 is the only pebble bed type HTGR and the HTTR the only prismatic block type HTGR being operated in the world at present, the information exchange has been beneficial for both JAEA and INET.

Since 1990 when the Personnel Assignment Agreement was added, JAEA has accepted researchers from INET in the field of HTGR safety, nuclear heat utilization, etc.

2.2 Area of Cooperation

The original MOU exchanged in 1986 stipulated the area of cooperation as follows. INET and

JAEA will provide to each other program status and technical outline information such as is generally available at each of their respective facilities relating to their respective programs for research and development of Gas-cooled Reactors. Each party will review the information provided by the other's programs as a basis for discussions on a future agreement. The subject matter of the information to be exchanged shall include, but not be limited to, the followings:

- A) The High-Temperature Gas-cooled Reactor (HTGR), for process heat and cogeneration, including both fuel technology and plant technology.
- B) The Very-High Temperature Gas-cooled Reactor (VHTR), for process heat, including both fuel technology and plant technology.
- C) (Note: The Very-High Temperature Gas-cooled Reactor (VHTR) here is similar to but not the same as the VHTR selected as a Generation IV nuclear system. The process heat application includes nuclear hydrogen production.)

In 1990, the MOU was amended by inserting that each party may assign its personnel into the facility of the other in accordance with the Personnel Assignment Agreement, and that for the purpose of carrying out the cooperative activities under the MOU, both parties may exchange samples when agreed by both of them. The MOU in 1990 also added a new paragraph: Each party shall make available, at least once a year to the other party reports written in English which have been published by each party.

2.3 Status of HTTR in 2008

The fourth periodic inspection of the HTTR was continued. The periodic inspection was started on May, 2007; however, in July 2007, one control rod was slightly deformed by mistake during maintenance work in the maintenance pit outside the reactor. It was decided to manufacture one control rod for replacement. The manufacture and replacement were carried out and new control rod was transported to the HTTR and the replacement work was finished in October 2008. Other maintenance and inspection have been continued. All maintenance works have been finished in December 2008. The HTTR will be start up in February 2009 to complete the fourth periodic inspection. On April 2009, HTTR will be started again to achieve 50 days full power operation with high temperature test operation mode (about 950°C of outlet coolant temperature).

After the 50 days full power operation, new safety demonstration tests such as loss of core flow tests (all primary gas circulator stop tests) and loss of core cooling tests (all primary gas circulator stop with vessel cooling system stop tests) will be started.

2.4 Status of HTR-10 in 2008

In the year of 2008, efforts involved in HTR-10 were made focusing on system enhancement and equipment maintenance (including corrective maintenance and preventive maintenance), regular check and experiment, training and re-training of operators, etc.. No power operation was carried out.

In the process of system enhancement and equipment maintenance, analysis and research were made concerning essentially with reducing potential equipment failures. Accordingly, design optimization, technical upgrading, and equipment maintenance were carried out to make sure that HTR-10 will run under stable, reliable and safe conditions to ensure important experiments to be carried out.

Regular check and tests were carried out to ensure the reliability and safety of operation of HTR-10, in accordance with the *Regulations for Periodical Tests and Examinations*, and in line with the frequency and requirements prescribed in *HTR-10 Technical Specifications*. Tests and examinations conducted during the shutdown period amounted to 49 items.

Technical upgrading and optimization and maintenance were made to the key systems and facilities of HTR-10. Equipment maintenance mainly includes preventive maintenance and corrective maintenance. Through the above efforts, it is proved that the performances and design features of HTR-10 will be assured for longtime power operation and meet the needs for important scientific experiments.

In 2008, the training program for HTR-10 operating staff is focused on the training and retraining of active operators and maintenance personnel, and the training for license renewal application.

Table 2.1 Number of people visiting INET from JAEA and JAEA from INET
for the purpose of exchanging information on HTGR

Year	Number of people visiting INET from JAEA	Number of people visiting JAEA from INET
1986	2	0
1987	2	0
1988	1	2
1989	0	1
1990	1	3
1991	3	0
1992	2	2
1993	1	4
1994	3	1
1995	2	2
1996	1	4
1997	2	2
1998	4	2
1999	0	3
2000	3	2
2001	0	2
2002	1	2
2003	1	3
2004	2	5
2005	5	3
2006	1	3
2007	2	5
2008	1	0

3. Major Cooperation Activities in 2008

3.1 Information Exchange Meeting

An information exchange meeting between JAEA and INET under the MOU was held in INET on February 26 to 28, 2008. An engineer of JAEA attended the meeting.

In the meeting, present status of HTR-PM project was presented by INET. The project was approved by the government on February 2008. The design of HTR-PM is almost finished. The construction of the HTR-PM will be started in June 2009 and finished in 2013.

Concerning the HTR-PM project, information exchange on core graphite components was carried out. JAEA presented the information about IG-110 which was used in the HTTR as core graphite components. IG-110 is also chosen as core graphite components of HTR-PM.

In the meeting, JAEA also presented the present status of HTTR.

3.2 Mutual Visits between JAEA and INET

(1) JAEA visit to INET

There is no visit except the information exchange meeting from JAEA to INET.

(2) INET visit to JAEA

No visit has been made to JAEA during the year 2008.

4. Concluding Remarks

This report summarized cooperation on HTGR development between JAEA and INET and major cooperation activities in 2008. An information exchange meeting was held at INET Beijing in February. Enhancing future collaboration between JAEA and INET is important, and continuous information exchange on HTGR-related technologies is beneficial for the both institutes.

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国際単位系 (SI)

表1. SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質質量	モル	mol
光度	カンデラ	cd

表2. 基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m ²
体積	立方メートル	m ³
速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s ²
波数	毎メートル	m ⁻¹
密度、質量密度	キログラム毎立方メートル	kg/m ³
面積密度	キログラム毎平方メートル	kg/m ²
比体積	立方メートル毎キログラム	m ³ /kg
電流密度	アンペア毎平方メートル	A/m ²
磁界の強さ	アンペア毎メートル	A/m
量濃度 ^(a) 、濃度	モル毎立方メートル	mol/m ³
質量濃度	キログラム毎立方メートル	kg/m ³
輝度	カンデラ毎平方メートル	cd/m ²
屈折率 ^(b)	(数字の) 1	1
比透磁率 ^(b)	(数字の) 1	1

- (a) 量濃度 (amount concentration) は臨床化学の分野では物質濃度 (substance concentration) とよばれる。
 (b) これらは無次元量あるいは次元1をもつ量であるが、そのことを表す単位記号である数字の1は通常は表記しない。

表3. 固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン ^(b)	rad	1 ^(b)	m/m
立体角	ステラジアン ^(b)	sr ^(c)	1 ^(b)	m ² /m ²
周波数	ヘルツ ^(d)	Hz	1	s ⁻¹
力	ニュートン	N		m kg s ⁻²
圧力、応力	パスカル	Pa	N/m ²	m ⁻¹ kg s ⁻²
エネルギー、仕事、熱量	ジュール	J	N m	m ² kg s ⁻²
仕事率、工率、放射束	ワット	W	J/s	m ² kg s ⁻³
電荷、電気量	クーロン	C		s A
電位差 (電圧)、起電力	ボルト	V	W/A	m ² kg s ⁻³ A ⁻¹
静電容量	ファラド	F	C/V	m ² kg ⁻¹ s ⁴ A ²
電気抵抗	オーム	Ω	V/A	m ² kg s ⁻³ A ⁻²
コンダクタンス	ジーメンズ	S	A/V	m ² kg ⁻¹ s ³ A ²
磁束	ウェーバ	Wb	Vs	m ² kg s ⁻² A ⁻¹
磁束密度	テスラ	T	Wb/m ²	kg s ⁻² A ⁻¹
インダクタンス	ヘンリー	H	Wb/A	m ² kg s ⁻² A ⁻²
セルシウス温度	セルシウス度 ^(e)	°C		K
光束密度	ルーメン	lm		cd sr
照射度	ルクス	lx	lm/m ²	m ⁻² cd
放射性核種の放射能 ^(f)	ベクレル ^(d)	Bq		s ⁻¹
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	m ² s ⁻²
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト ^(g)	Sv	J/kg	m ² s ⁻²
酵素活性濃度	カタール	kat		s ⁻¹ mol

- (a) SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
 (b) ラジアンとステラジアンは数字の1に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の1は明示されない。
 (c) 測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
 (d) ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計過程についてのみに使用される。
 (e) セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
 (f) 放射性核種の放射能 (activity referred to a radionuclide) は、しばしば誤った用語で"radioactivity"と記される。
 (g) 単位シーベルト (PV, 2002, 70, 205) についてはCIPM勧告2 (CI-2002) を参照。

表4. 単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘力のモーメント	パスカル秒	Pa s	m ⁻¹ kg s ⁻¹
表面張力	ニュートンメートル	N m	m ² kg s ⁻²
角速度	ニュートン毎メートル	N/m	kg s ⁻²
角加速度	ラジアン毎秒	rad/s	m m ⁻¹ s ⁻¹ =s ⁻¹
熱流密度、放射照度	ラジアン毎秒毎秒	rad/s ²	m m ⁻¹ s ⁻² =s ⁻²
熱容量、エントロピー	ワット毎平方メートル	W/m ²	kg s ⁻³
比熱容量、比エントロピー	ジュール毎ケルビン	J/K	m ² kg s ⁻² K ⁻¹
比エネルギー	ジュール毎キログラム毎ケルビン	J/(kg K)	m ² s ⁻² K ⁻¹
熱伝導率	ジュール毎キログラム	J/kg	m ² s ⁻²
体積エネルギー	ワット毎メートル毎ケルビン	W/(m K)	m kg s ⁻³ K ⁻¹
電界の強さ	ジュール毎立方メートル	J/m ³	m ⁻¹ kg s ⁻²
電荷密度	ボルト毎メートル	V/m	m kg s ⁻³ A ⁻¹
表面電荷密度	クーロン毎立方メートル	C/m ³	m ³ s A
電束密度、電気変位	クーロン毎平方メートル	C/m ²	m ² s A
誘電率	クーロン毎平方メートル	C/m ²	m ² s A
透磁率	ファラド毎メートル	F/m	m ³ kg ⁻¹ s ⁴ A ²
モルエネルギー	ヘンリー毎メートル	H/m	m kg s ⁻² A ⁻²
モルエントロピー、モル熱容量	ジュール毎モル	J/mol	m ² kg s ⁻² mol ⁻¹
照射線量 (X線及びγ線)	ジュール毎モル毎ケルビン	J/(mol K)	m ² kg s ⁻² K ⁻¹ mol ⁻¹
吸収線量率	クーロン毎キログラム	C/kg	kg ⁻¹ s A
放射強度	グレイ毎秒	Gy/s	m ² s ⁻³
放射輝度	ワット毎ステラジアン	W/sr	m ⁴ m ⁻² kg s ⁻³ =m ² kg s ⁻³
酵素活性濃度	ワット毎平方メートル毎ステラジアン	W/(m ² sr)	m ² m ⁻² kg s ⁻³ =kg s ⁻³
	カタール毎立方メートル	kat/m ³	m ³ s ⁻¹ mol

表5. SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10 ²⁴	ヨタ	Y	10 ⁻¹	デシ	d
10 ²¹	ゼタ	Z	10 ⁻²	センチ	c
10 ¹⁸	エクサ	E	10 ⁻³	ミリ	m
10 ¹⁵	ペタ	P	10 ⁻⁶	マイクロ	μ
10 ¹²	テラ	T	10 ⁻⁹	ナノ	n
10 ⁹	ギガ	G	10 ⁻¹²	ピコ	p
10 ⁶	メガ	M	10 ⁻¹⁵	フェムト	f
10 ³	キロ	k	10 ⁻¹⁸	アト	a
10 ²	ヘクト	h	10 ⁻²¹	ゼプト	z
10 ¹	デカ	da	10 ⁻²⁴	ヨクト	y

表6. SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60 s
時	h	1 h=60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	'	1'=(1/60)°=(π/10800) rad
秒	"	1"=(1/60)'=(π/648000) rad
ヘクタール	ha	1 ha=1 hm ² =10 ⁴ m ²
リットル	L, l	1 L=1 l=1 dm ³ =10 ³ cm ³ =10 ⁻³ m ³
トン	t	1 t=10 ³ kg

表7. SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	1 eV=1.602 176 53(14)×10 ⁻¹⁹ J
ダルトン	Da	1 Da=1.660 538 86(28)×10 ⁻²⁷ kg
統一原子質量単位	u	1 u=1 Da
天文単位	ua	1 ua=1.495 978 706 91(6)×10 ¹¹ m

表8. SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	1 bar=0.1 MPa=100 kPa=10 ⁵ Pa
水銀柱ミリメートル	mmHg	1 mmHg=133.322 Pa
オングストローム	Å	1 Å=0.1 nm=100 pm=10 ⁻¹⁰ m
海里	M	1 M=1852 m
バイン	b	1 b=100 fm ² =(10 ⁻¹² cm) ² =10 ⁻²⁸ m ²
ノット	kn	1 kn=(1852/3600) m/s
ネーパ	Np	SI単位との数値的な関係は、 対数量の定義に依存。
ベベル	B	
デジベル	dB	

表9. 固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	1 erg=10 ⁻⁷ J
ダイン	dyn	1 dyn=10 ⁻⁵ N
ポアズ	P	1 P=1 dyn s cm ⁻² =0.1 Pa s
ストークス	St	1 St=1 cm ² s ⁻¹ =10 ⁻⁴ m ² s ⁻¹
スチルブ	sb	1 sb=1 cd cm ⁻² =10 ⁻⁴ cd m ⁻²
フオト	ph	1 ph=1 cd sr cm ⁻² 10 ⁴ lx
ガリ	Gal	1 Gal=1 cm s ⁻² =10 ⁻² ms ⁻²
マクスウェル	Mx	1 Mx=1 G cm ² =10 ⁻⁸ Wb
ガウス	G	1 G=1 Mx cm ⁻² =10 ⁻⁴ T
エルステッド ^(c)	Oe	1 Oe ≐ (10 ³ /4π) A m ⁻¹

- (c) 3元系のCGS単位系とSIでは直接比較できないため、等号「≐」は対応関係を示すものである。

表10. SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	1 Ci=3.7×10 ¹⁰ Bq
レントゲン	R	1 R=2.58×10 ⁻⁴ C/kg
ラド	rad	1 rad=1 cGy=10 ⁻² Gy
レム	rem	1 rem=1 cSv=10 ⁻² Sv
ガンマ	γ	1 γ=1 nT=10 ⁻⁹ T
フェルミ		1 フェルミ=1 fm=10 ⁻¹⁵ m
メートル系カラット		1 メートル系カラット=200 mg=2×10 ⁻⁴ kg
トル	Torr	1 Torr=(101 325/760) Pa
標準大気圧	atm	1 atm=101 325 Pa
カロリ	cal	1 cal=4.1858 J (「15°C」カロリ), 4.1868 J (「IT」カロリ), 4.184 J (「熱化学」カロリ)
マイクロン	μ	1 μ=1 μm=10 ⁻⁶ m

