JAEA-Review
2009-072

JAEA-Review

Conceptual Study for New ^{99}Mo-Production Facility in JMTR

Akihiro KIMURA, Koichi IIMURA, Jinsaku HOSOKAWA, Hironobu IZUMO
Naohiko HORI, Tetsuya NAKAGAWA, Masaru KANNO, Masahiro ISHIHARA
and Hiroshi KAWAMURA

Department of JMTR Operation
Neutron Irradiation and Testing Reactor Center
Oarai Research and Development Center

March 2010

Japan Atomic Energy Agency 日本原子力研究開発機構

独立行政法人日本原子力研究開発機構　研究技術情報部　研究技術情報課
〒319-1195　茨城県那珂郡東海村白方白根 2 番地 4
電話 029-282-6387, Fax 029-282-5920, E-mail:ird-support@jaea.go.jp

Intellectual Resources Section, Intellectual Resources Department,
Japan Atomic Energy Agency
2-4 Shirakata Shirane, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195 Japan
Tel +81-29-282-6387, Fax +81-29-282-5920, E-mail:ird-support@jaea.go.jp

Conceptual Study for New ^{99}Mo-Production Facility in JMTR

Akihiro KIMURA, Koichi IIMURA, Jinsaku HOSOKAWA, Hironobu IZUMO
Naohiko HORI, Tetsuya NAKAGAWA, Masaru KANNO, Masahiro ISHIHARA
and Hiroshi KAWAMURA

Department of JMTR Operation
Neutron Irradiation and Testing Reactor Center
Oarai Research and Development Center
Japan Atomic Energy Agency
Oarai-machi, Higashiibaraki-gun, Ibaraki-ken

(Received December 18,2009)

Refurbishment of facilities and equipments for the JMTR is in progress in order to re-start at FY 2011. The refurbishment has been carried out since 2007, and new irradiation facilities will be installed in order to accomplish user's requirements. As one of the new irradiation facilities, JAEA has a plan to produce ^{99}Mo, a parent nuclide of ^{99m}Tc.

At present, radioisotopes are indispensable for a diagnosis and treatment in the medical field. Demand of ^{99m}Tc (half life 6h) used as a radiopharmaceutical increases up year by year. Moreover, the expansion of demand will be expected in future. However, the supply of ^{99}Mo in Japan depends fully on the import from foreign countries. Therefore, it is necessary to supply ^{99}Mo stably by the domestic production. There are two methods of ^{99}Mo (half life 65.9h) production; the one is the nuclear fission (n,fiss) method, and the other is the (n,γ) method using the ^{98}Mo target.

^{99}Mo production in the JMTR with the (n,γ) method was studied and evaluated. As a result, it was found that the partial amount of ^{99}Mo demand is possible to supply stably if a new hydraulic-rabbit-irradiation-facility (HR) is used.

In this paper, results of a conceptual study of the new facility for ^{99}Mo production was reviewed, and was presented at 2nd international symposium Material Test Reactors.

Keywords: ^{99}Mo, ^{99m}Tc, (n,γ) Method, JMTR, New Hydraulic-rabbit-irradiation-facility

JMTRを用いた新^{99}Mo製造設備の概念検討

日本原子力研究開発機構　大洗研究開発センター
照射試験炉センター　原子炉施設管理部

木村 明博、飯村 光一、細川 甚作、出雲 寛互、
堀 直彦、中川 哲也、菅野 勝、石原 正博、河村 弘

(2009年12月18日受理)

現在、JMTRは2011年度の再稼動に向けて機器・設備の改修を行っている。改修は2007年から行われている。新しい照射装置はユーザーの要望により設置される。その一つとして、JMTRは^{99m}Tcの親核種である^{99}Moの製造計画を立てている。

放射線や放射性同位元素は疾病の診断や治療に使われている。その中でも^{99m}Tcは放射性医薬品としての需要が年々増加しており、今後もさらなる増加が考えられる。しかし、日本では^{99m}Tcの唯一の親核種である^{99}Moを全て海外から輸入している。そのため、国内での安定供給が望まれる。^{99}Moは2つの方法で製造される。1つは核分裂を利用した(n,f)法でもう一つは^{98}Moを使用した(n, γ)法である。

JMTRでは、シンプルな(n, γ)法による^{99}Moの製造について検討を行った。その結果、新しい水力ラビット照射装置を使用することにより一定量の^{99}Moを安定的に供給できることが分かった。

本報告書は、新しい照射装置での^{99}Mo製造についての概念検討結果についてレビューしたものであり、このレビュー結果は第2回材料試験炉国際会議で発表した。

大洗研究開発センター：〒311-1393　茨城県東茨城郡大洗町成田町4002

Contents

目　　次

1. Introduction

At present, radiation and radioisotope (RI) are indispensable for a diagnosis and treatment in the medical field. Demand of ^{99m}Tc (half life 6h) used as a radiopharmaceutical increases up year by year. Moreover, the expansion of demand will be expected in future. However, the supply of ^{99}Mo in Japan depends fully on the import from foreign countries. Therefore, it is necessary to supply ^{99}Mo stably by the domestic production[1,2]. In this situation, Japan Atomic Energy Agency (JAEA) has investigated the ^{99}Mo production method using the JMTR[3,4].

As one of the new irradiation facilities after restart of the JMTR, the JAEA has a plan to produce ^{99}Mo, a parent nuclide of ^{99m}Tc.

Two methods are considered as the ^{99}Mo production by using the hydraulic-rabbit-irradiation-facility (HR) of the JMTR; the one is the nuclear fission (n,fiss) method and the other is ^{98}Mo target (n,γ) method [$^{98}Mo(n,\gamma)^{99}Mo(\beta^-)$ ---> ^{99m}Tc]. Comparison between two methods is shown in Table 1. The (n,fiss) method is high cost, has many impurities, high specific activity and difficult to handle U. The (n,γ) method is low cost and has few impurities and a low specific activity. Therefore, the ^{99}Mo production in the JMTR with simple (n, γ) method was studied.

In this paper, results of a conceptual study of the new facility for ^{99}Mo production was reviewed, and was presented at 2nd international symposium Material Test Reactors.

2. Irradiation method

The existing HR is a water loop system to transfer the small sized (φ32mm, 150mm length) capsule, so called rabbit, which can be injected into and ejected from the reactor core by water flow. Schematic diagram of the HR is shown Figure 1. Having the feature that the capsules are inserted and extracted without reactor shutdown, the system is very useful for producing ^{99}Mo, efficiently.

The ^{99}Mo is produced by irradiation of Molybdenum Trioxide (MoO_3) pellets inserted into the capsule. General properties of the MoO_3 are shown Table 2. The pellets are very convenient for handling and treatment both pre-irradiation and post-irradiation. From a viewpoint of higher ^{99}Mo production, higher density pellets should be used.

MoO_3-pellets are enclosed among the aluminum rabbit. Aluminum rabbit used in the HR is shown Figure 2. After irradiation during an appropriate irradiation time, the rabbit is ejected from reactor core. Irradiation capsules are transferred to the hot laboratory, which is connected to the reactor building through the water canal, for post irradiation treatments. Owing to the shielding capability of the water, irradiated radioactive capsules are safely transferred underwater through the canal. After that ^{99}Mo is dissolve and extraction. These processes can be efficiently carried out by using the JMTR hot laboratory. Finishing the necessary treatment, the ^{99}Mo is transferred from the hot laboratory to external facilities

3. Irradiation process

3.1 Pre-irradiation treatment

The high purity (99.9～99.9999%) Molybdenum trioxide (MoO_3) powder as the raw material is sintered. In the former manufacturing method using camphor as binder, the sintering density was about 70% of the theoretical density (T.D.). However, the pellet of a high sintering density of 90～95%T.D. can be manufactured by a new manufacturing method. Moreover, the new manufacturing method can greatly shorten the pellet manufacturing period from 4 days to 10 minutes compared with the former manufacturing method. Therefore, it will be possible to prepare many target pellets within a short period.

After preparation of the pellets, the dimension inspection, the weight measurement, the visual inspection, and the impurity analysis, etc. are performed. The pellets are enclosed with the inner tube and the rabbit holder, and then the irradiation rabbit is prepared.

3.2 Irradiation

The irradiation rabbits are set in the reactor core by water flow, and are irradiated at arbitrary time. After that, the irradiation rabbits are taken out from the reactor core by water the flow. Flow chart of ^{99}Mo production by the HR is shown Figure 3.

3.3 Post-irradiation treatment

After irradiation, the irradiated rabbits are moved to the JMTR hot laboratory through the canal. At there, the rabbit outer tube is opened, and after that, the inner tube is taken out. Then, the inner tube is opened, and the MoO_3 pellets are taken out. These processes will be commercialized as a chemical treatment process in the hot laboratory. Production flow in the JMTR Hot Laboratory is shown Figure 4.

The MoO_3 pellets taken out are dissolved with the sodium hydroxide (NaOH), and the ^{99}Mo is adsorbed by the PZC (Poly Zirconium Compound). The PZC is shown Figure 5. Impurities are analyzed with the product inspection (pH measurement, γ ray measurement, volume measurement, and weight measurement). After inspection, the Mo is moved into the product container, and the container is loaded to transfer cask. The surface contamination test and 1m dose rate measurement, etc. for the transfer cask are carried out for the transportation to the pharmaceutical manufactures. Since the half life time of ^{99}Mo is 65.9 h and ^{99m}Tc is 6.0 h, the working hours to treat ^{99}Mo from the irradiation to the shipment should be short. Therefore, it is necessary to study the shortening the process time in future.

4. Estimation of ^{99}Mo production

The JMTR core has a capability for installing three HRs. Now, there is one HR (D-5 hole) in the JMTR. There are two major factors to decide the amount of ^{99}Mo production. The one is a thermal neutron flux at the irradiation position in the reactor core, and the other is a number of rabbits that can be irradiated at the same time. Here studied are the irradiation capability of the M-9 hole. Because, thermal neutron flux at the M-9 hole is higher than the D-5 hole. The hole size of the reactor core grid plate is different according to the position of irradiation hole. Therefore, the structure of the hydraulic rabbit tube to be installed in the new position will be different. In the M-9 hole 5 rabbits can be installed at maximum. On the other hand, the D-5 hole can not install 5 rabbits. As a result of study, the M-9 hole was selected as a new HR position. The new HR will produce ^{99}Mo more than the existing HR. The structure of the hydraulic rabbit tube installed in the reactor core is shown Figure 6.

One operating cycle of the JMTR is about 30 days. Also one rabbit irradiation needs 6 days. Therefore, it is possible to irradiate 4 batches by one operating cycle. Moreover, necessary time from the irradiation to the shipment was evaluated as 2.5 days. Based on these assumptions, the amount of ^{99}Mo production was evaluated for the case of using the M-9 hole. As a result, it was found that ^{99}Mo of 37 TBq or less/week (1000 Ci/week) could be shipped. The amount of ^{99}Mo for the case is shown in Table 3.

5. Conclusion

For the purpose of the domestic stable supply the ^{99}Mo, production by the $^{98}Mo(n,\gamma)$ reaction method was studied. From this study followings are concluded;

- The irradiation capability of D-5 and M-9 irradiation holes was compared. As a result of comparison, the M-9 irradiation hole was selected for the new hydraulic rabbit position owing to the higher thermal neutron flux at the M-9 rather than that of the D-5 hole. The M-9 irradiation hole enables 5 rabbits irradiation at maximum.
- JAEA has a plan to manufacture pellets by the new manufacturing method, which can produce high sintering density (90-95% T.D.) pellets.
- From product estimation, it was found that the JMTR will be able to provide at about 20% amount (37TBq:1000Ci) of ^{99}Mo imported to Japan.

References

1) Japan Radioisotope Association, "Statistics of the use of radiation in Japan", (2005).

2) US-DOE, "Forecast future demand for medical Isotopes", (1999).

3) "Proceedings of 2008 KAERI/JAEA Joint Seminar on Advanced Irradiation and PIE Technologies", JAEA-Conf 2008-010, (2008).

4) K. Iimura et al., "Conceptual Study of ^{99}Mo Production Facility in JMTR", JAEA-Technology 2008-035, (2008).

Table 1: Comparison between two methods.

	(n,fiss) method	(n, γ) method
Production method	^{235}U (n,fiss) FP→ ^{99}Mo →^{99m}Tc	^{98}Mo (n, γ) ^{99}Mo →^{99m}Tc
Cost	High	Low
Nonproliferation	X	O
Specific activity	High	Low
Impurity	High	Low

Table 2: Properties of MoO_3.

Pellet type	Sintered type
Sublimation temp.	~750 ℃
MoO_3 Molecular weight	149.35 g/mol
MoO_3 Theoretical density	4.692 g/cm^3
MoO_3 Melting point	780 ℃

Table 3 : Estimation of ^{99}Mo production using the new HR

Items		
Hydraulic irradiation facility		New hydraulic irradiation facility
Rabbit Specification	**Irradiation hole**	M-9
	Thermal Neutron Flux (max.)	3.5×10^{18} ($m^{-2}\cdot s^{-1}$)
	Number of irradiation rabbit (max.)	5 rabbits
Amount of ^{99}Mo production		37 TBq/week (1,000 Ci/week)
Percentage for the amount of import		About 20%

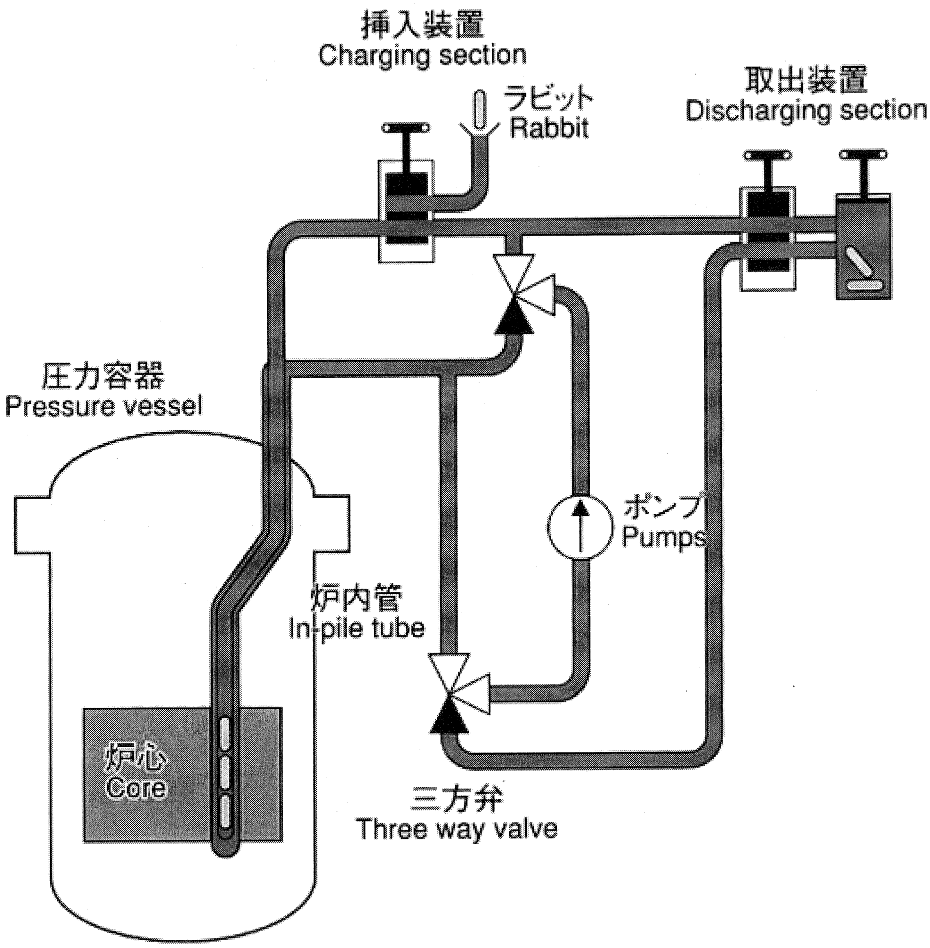


Figure 1 Schematic diagram of the HR

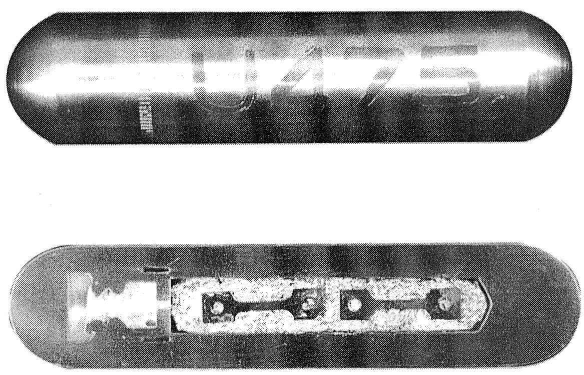


Figure 2 Aluminum rabbit used in the HR

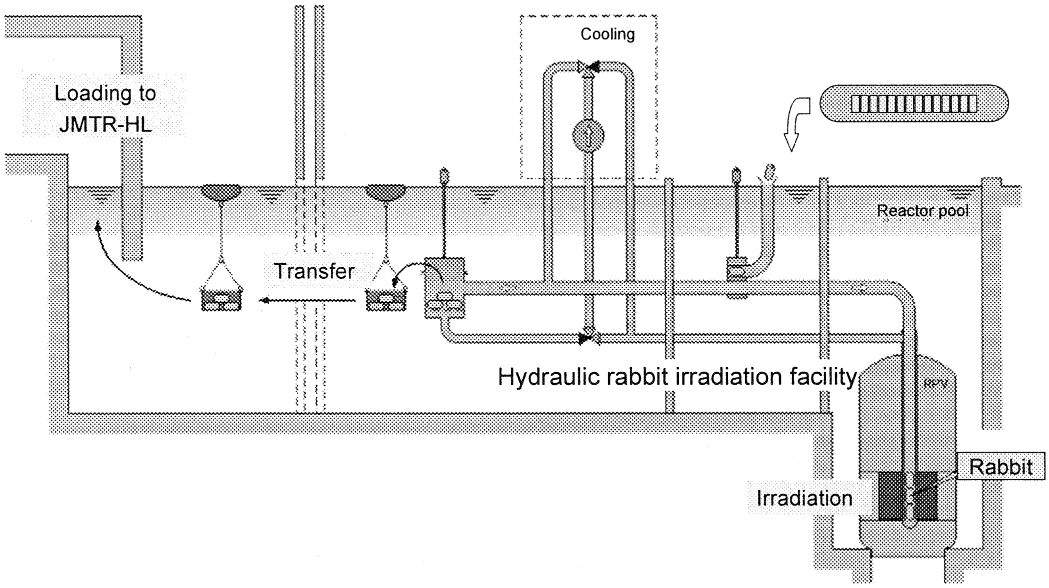


Figure 3 Flow chart of ^{99}Mo production by the HR in the JMTR.

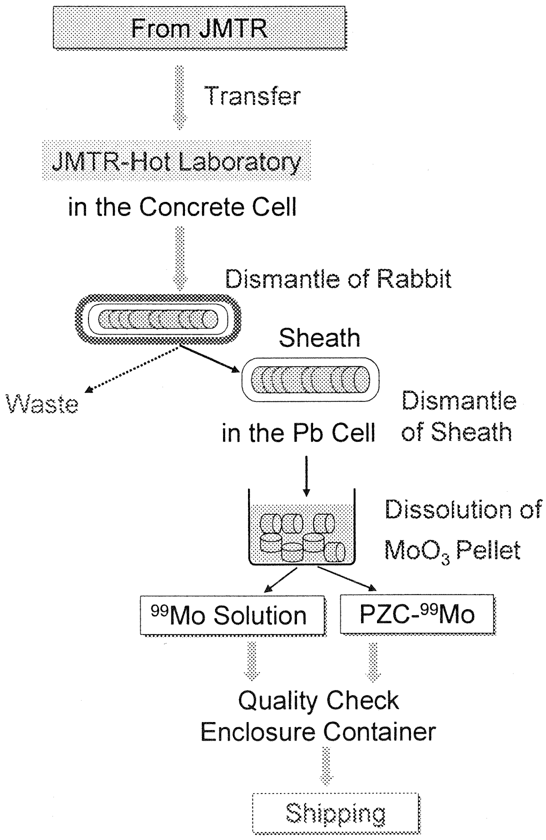
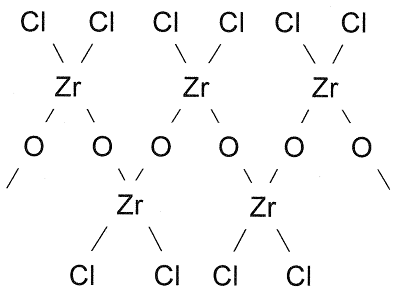
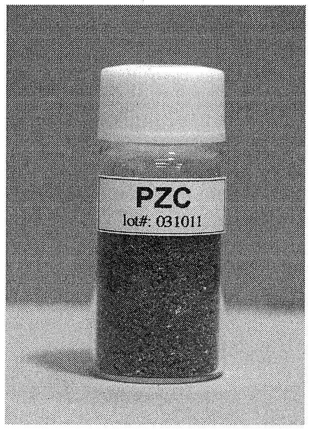


Figure 4 Production flow in the JMTR Hot Laboratory.



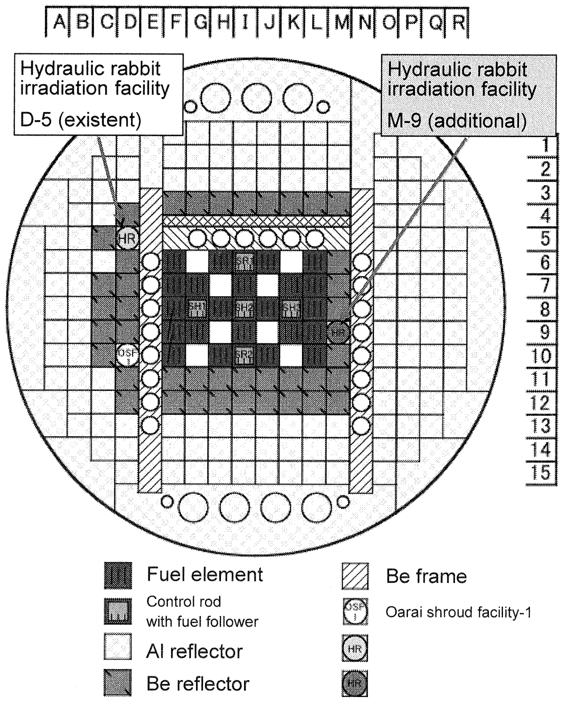
➢Selective adsorption of Mo, W
- Mo : 250mg(Mo)/g(PZC) in Na_2MoO_4
- W : 500mg(W)/g(PZC) in Na_2WO_4

As PZC generator of ^{99}Mo-^{99m}Tc, ^{188}W-^{188}Re



Poly-Zirconium Compound

Figure 5 PZC



JMTR Core arrangement

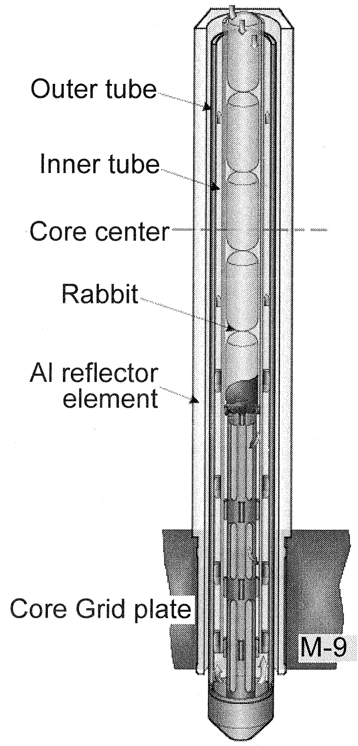


Figure 6 Structure of the hydraulic rabbit tube installed in the reactor core

APPENDIX

2nd International Symposium on Material Test Reactors
September 28-31, 2009

Conceptual Study for New ^{99}Mo-Production Facility IN JMTR

Akihiro Kimura, Koichi Iimura, Jinsaku Hosokawa,
Hironobu Izumo, Naohiko Hori, Tetsuya Nakagawa,
Masaru Kannno Masahiro Ishihara, and Hiroshi Kawamura

Neutron Irradiation and Testing Reactor Center
Japan Atomic Energy Agency

Contents

Introduction (1/2)

Why?

Background

- Demand of ^{99m}Tc (half life 6h) used as a radiopharmaceutical increases up year by year, and will be expected to expand in future.
- Supply of ^{99}Mo in Japan depends fully on the import from foreign countries.
- In addition, unexpected shutdown of production reactors, such as NRU in Canada etc., happened, and now the production crises is the serious problem all over the world.

To supply stably by domestic production is very important.

New irradiation facility

JAEA has a plan to produce ^{99}Mo (parent nuclide of ^{99m}Tc) to meet the user's requirements .

1

Introduction (2/2)

How?

^{99}Mo (half life 66.7h) production has two methods;

1. Nuclear fission method (n,f)
   Using high enriched U-target now. The target will be changed into low enriched one due to NTP reason.

2. ^{98}Mo target method (n,γ) [$^{98}Mo(n,\gamma)^{99}Mo \xrightarrow{\beta^-} {}^{99m}Tc$]
   Using ^{98}Mo target.

^{99}Mo production in JMTR is using a simple (n,γ) method taking account of advantages on low wastes production as well as low production cost.

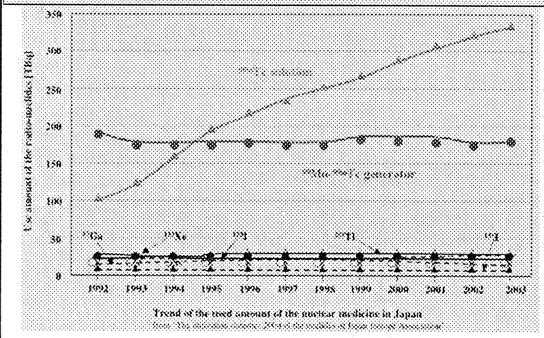
2

Contents

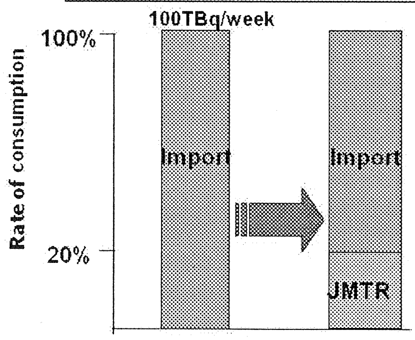
1. Introduction
2. ^{99}Mo Production Plan in JMTR
3. Conceptual study on irradiation facility in JMTR
4. Conceptual study on post irradiation process in JMTR/HL
5. Conclusion

^{99}Mo Production in JMTR

Demand of ^{99m}Tc is increasing rapidly



^{99}Mo 100% import

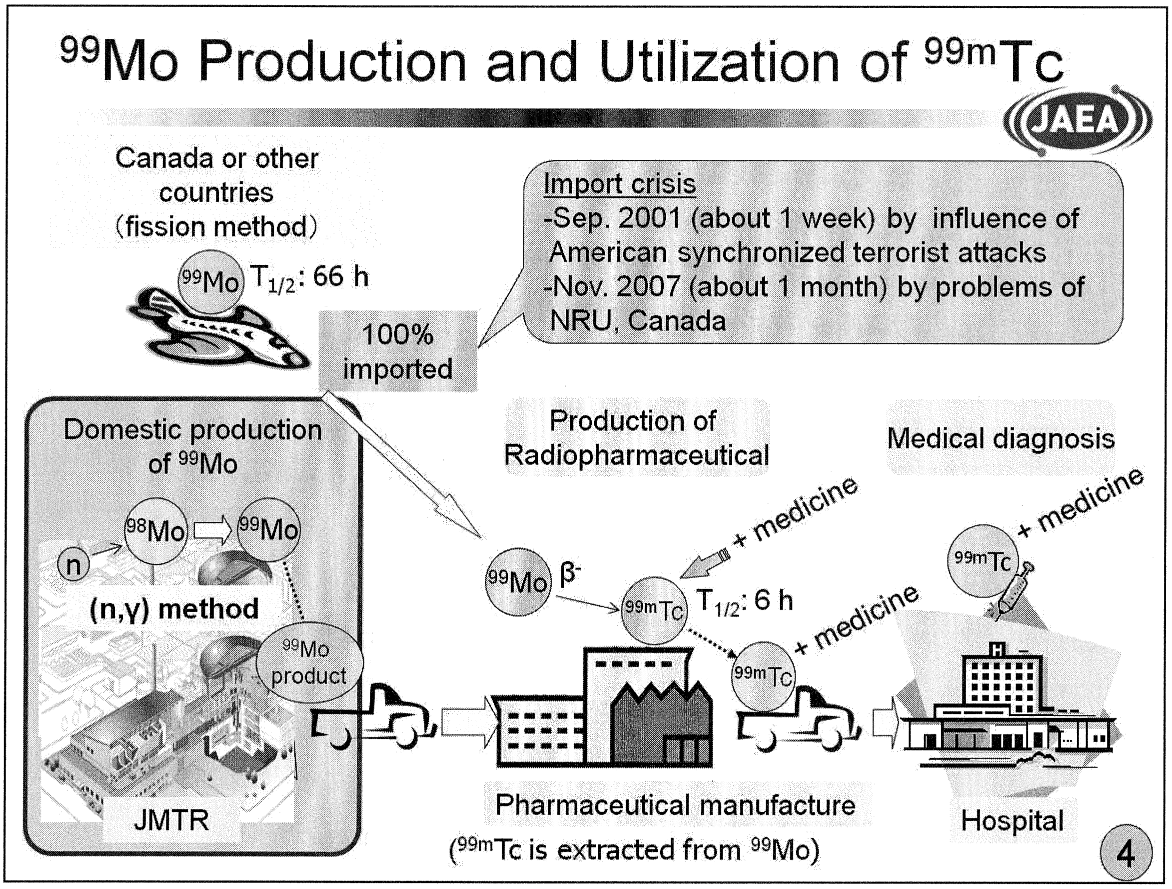


JMTR contribution to user's market

Comparison of two methods

	(n,fiss) method	(n,γ) method
Production method	^{235}U (n,fiss) FP → ^{99}Mo $\xrightarrow{\beta^-}$ ^{99m}Tc	^{98}Mo (n,γ) ^{99}Mo $\xrightarrow{\beta^-}$ ^{99m}Tc
Cost	High	Low
Nonproliferation	X	○
Specific activity	High	Low
Impurity	High	Low

3



Planning of New Irradiation Facilities

New Irradiation Facilities

[New irradiation facilities will be installed by the external budget from the industrial users etc.]

Work schedule for the installation of new irradiation facilities

No.	Item / Year	2006	2007	2008	2009 *1	2010	2011 Re-operation	2012
1	Fuel Tests Irradiation facility of LWR fuels for ramp test	Conceptual design	Detail design	Designing, Fabrication, Installation				
2	Material Tests Irradiation facility for LWR core materials		Detail design	Designing, Fabrication, Installation		2 units		1 unit
	New industrial use (1) ^{99}Mo production facility	Conceptual design, etc.				under planning		
4	New industrial use (2) Silicon semiconductor irradiation facility	Conceptual design, etc.				under consideration		
5	Fuel irradiation facility Irradiation facilities for LWR fuels	Conceptual design, etc.				under consideration		

*1 : In order to prepare necessary space for new material irradiation facilities installation, existing facilities are to be removed.

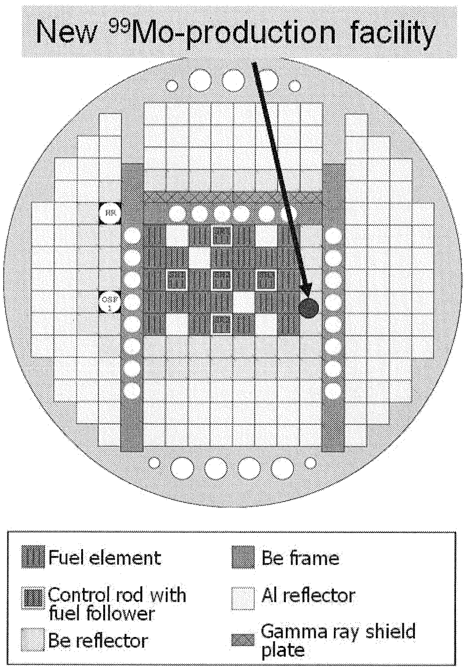
5

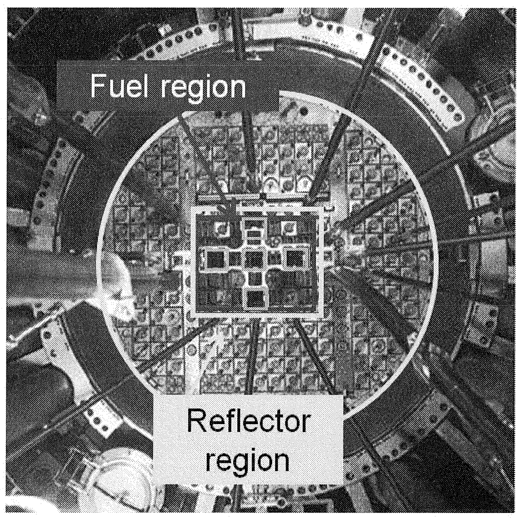
Contents

1. Introduction
2. ^{99}Mo Production Plan in JMTR
3. Conceptual study on irradiation facility in JMTR
4. Conceptual study on post irradiation process in JMTR/HL
5. Conclusion

JMTR Core and ^{99}Mo Production Facility

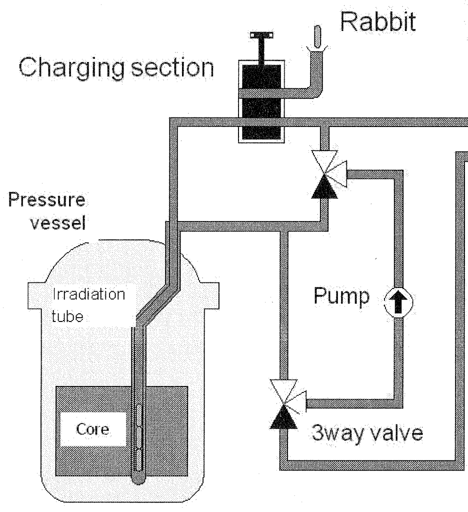
JAEA



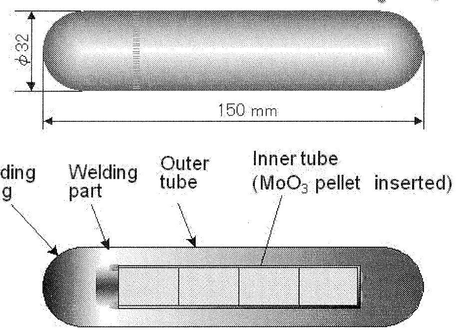


6

Hydraulic Rabbit Irradiation Facility and MoO_3



Hydraulic rabbit irradiation facility



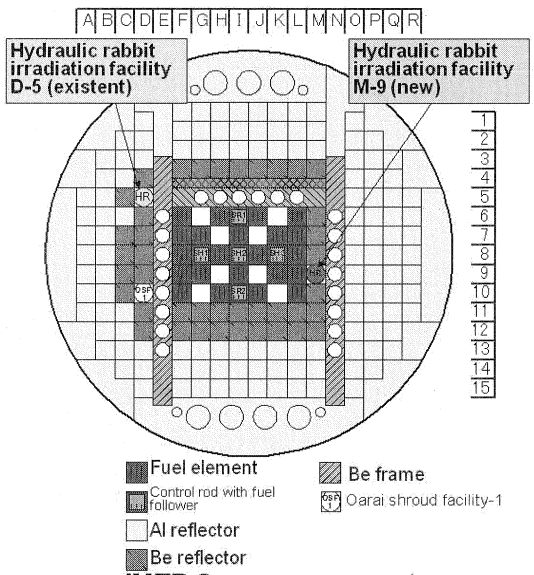
A typical rabbit and its cross section

Molybdenumtrioxide (MoO_3) properties

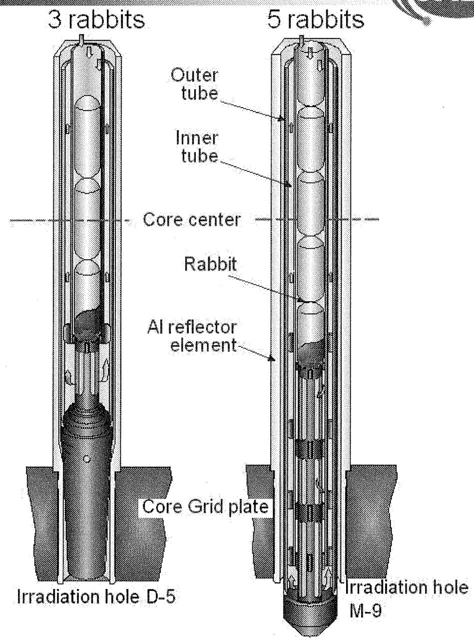
Pellet type	Sintered type
Sublimation temp.	~750℃
Mo-98 Isotopic abundance	24%
MoO_3 Molecular weight	143.95 (Mo:66.6% O:33.3%)
MoO_3 Theoretical Density	4.692g/cm^3
MoO_3 Melting point	780℃

7

Hydraulic Rabbit Irradiation Facility



JMTR Core arrangement



Structure of Hydraulic rabbit tube

8

Estimated ^{99}Mo Production using Hydraulic Rabbit Irradiation Facility

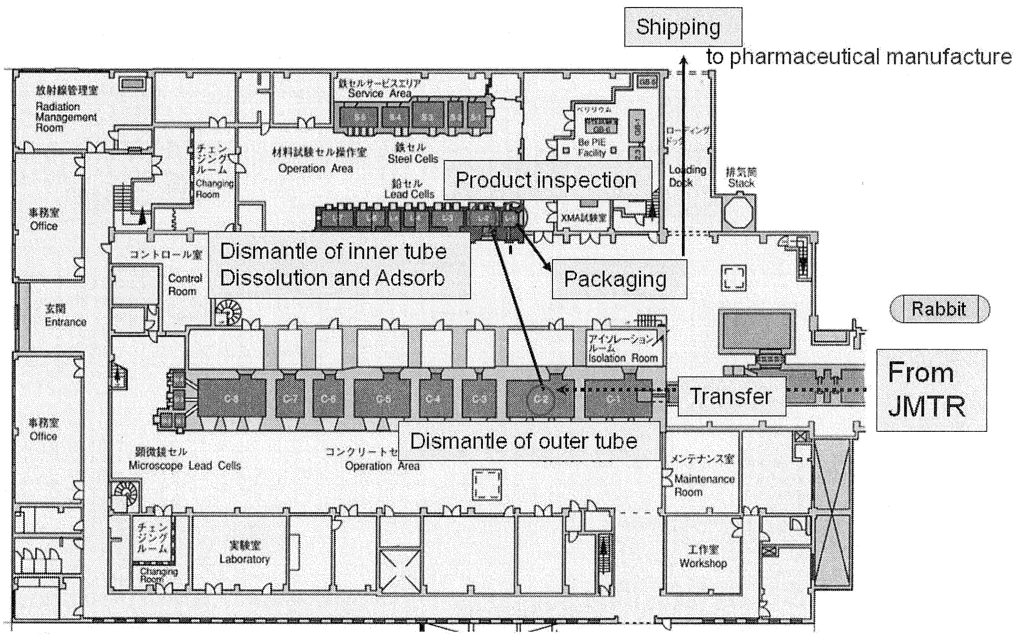
Items		Conceptual Study
Hydraulic rabbit irradiation facility		New hydraulic rabbit irradiation facility
Rabbit Specification	Irradiation hole	M-9
	Thermal Neutron Flux (max.)	$3.5\times10^{18}(m^{-2}/s)$
	Number of irradiation rabbit (max.)	5 rabbits
Amount of ^{99}Mo production		37 TBq/week (1000 Ci/week)
Percentage for the amount of import		About 20%

- Weekly production, 4 shipment/cycle
- 30days/cycle, 6cycle/year (180 days / year)

9

Contents

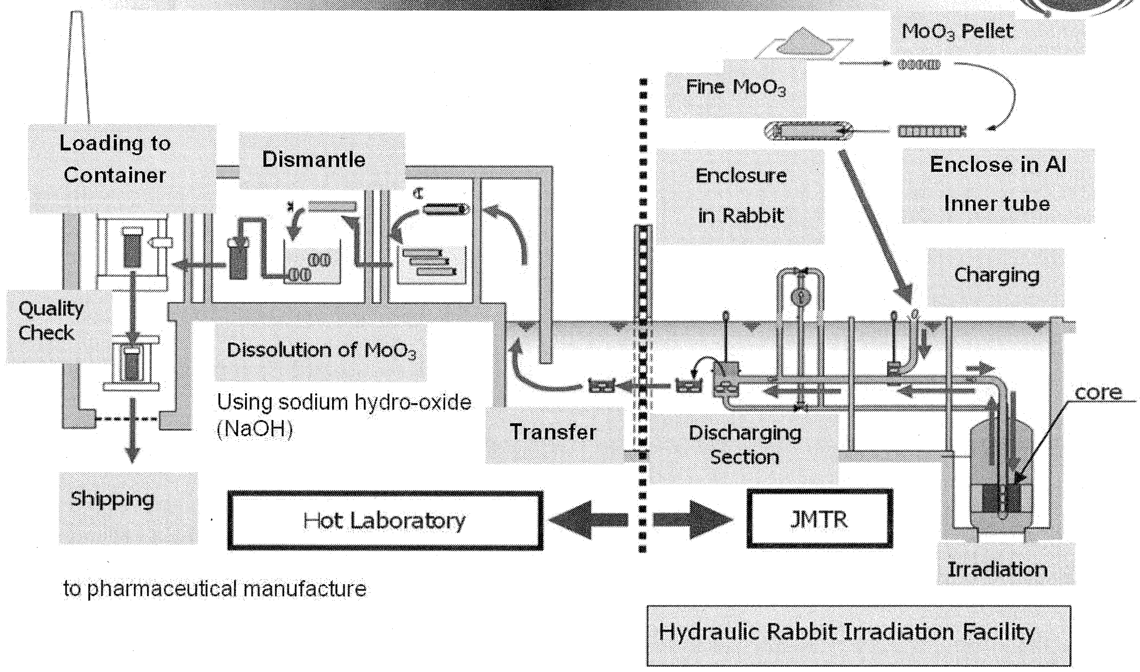
Post Irradiation Process in JMTR Hot Laboratory



*; ^{99}Mo is dissolved from MoO_3 pellets by easy chemical treatment using sodium hydro-oxide (NaOH)

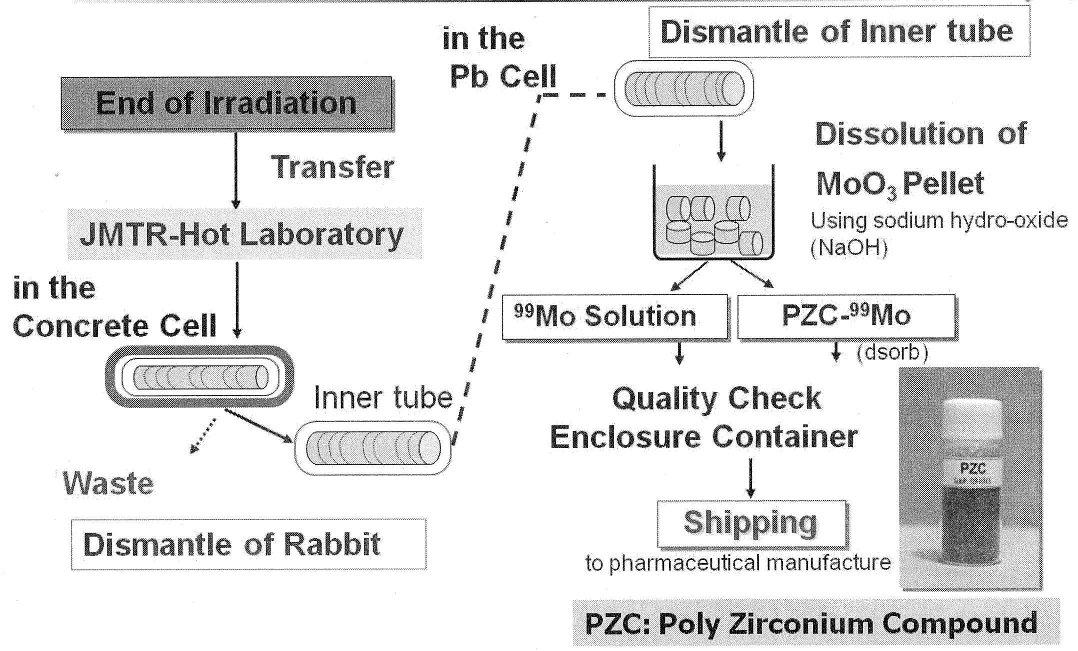
10

Outline of ^{99}Mo Production Process



11

Outline of ^{99}Mo Production Process



12

Contents

1. Introduction
2. ^{99}Mo Production Plan in JMTR
3. Conceptual study on irradiation facility in JMTR
4. Conceptual study on PIE process in JMTR/HL
5. Conclusion

Conclusion

- ^{99}Mo production method in JMTR is the ^{98}Mo(n,r)^{99}Mo reaction, where the sintering pellet of MoO_3 will be used as a target material.
- The hydraulic rabbit irradiation facility is selected as irradiation facility of ^{99}Mo production, because the facility is possible to irradiate the Mo target from short time to long time without reactor shutdown.
- JMTR will be able to provide ^{99}MO at about 20% amount of imported to Japan, by installing new hydraulic rabbit irradiation facility in the reflector region of the core.

13

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位 名称	SI 基本単位 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	SI 基本単位 記号
面積	平方メートル	m^{2}
体積	立法メートル	m^{3}
速さ，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	キログラム毎立法メートル	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）ともよばれる。
(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=60s
時	h	1h =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	1ha=1hm^{2}=10^{4}m^{2}
リットル	L，l	1L=11=1dm^{3}=10^{3}cm^{3}=10^{-3}m^{3}
トン	t	1t=10^{3} kg

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		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	ジーメンス	S	A/V	m^{-2} kg^{-1} s^{3} A^{2}
磁束	ウエーバ	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)	℃		K
光束	ルーメン	lm	cd sr (c)	cd
照度	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}
酸素活性	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的過程についてのみ使用される。
(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	1eV=1.602 176 53(14)×10^{-19}J
ダルトン	Da	1Da=1.660 538 86(28)×10^{-27}kg
統一原子質量単位	u	1u=1 Da
天文単位	ua	1ua=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=0.1MPa=100kPa=10^{5}Pa
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	1 Å=0.1nm=100pm=10^{-10}m
海里	M	1 M=1852m
バーン	b	1 b=100fm^{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。
ベル	B	
デジベル	dB	

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

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}=0.1Pa s
ストークス	St	1 St =1cm^{2} s^{-1}=10^{-4}m^{2} s^{-1}
スチルブ	sb	1 sb =1cd cm^{-2}=10^{4}cd m^{-2}
フォト	ph	1 ph=1cd sr cm^{-2} 10^{4}lx
ガル	Gal	1 Gal =1cm s^{-2}=10^{-2}ms^{-2}
マクスウェル	Mx	1 Mx = 1G cm^{2}=10^{-8}Wb
ガウス	G	1 G =1Mx 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=1cGy=10^{-2}Gy
レム	rem	1 rem=1 cSv=10^{-2}Sv
ガンマ	γ	1 γ =1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	µ	1 µ =1µm=10^{-6}m

（第8版，2006年改訂）