



**COCIR SELF-REGULATORY INITIATIVE
FOR MEDICAL IMAGING EQUIPMENT**

**MAGNETIC RESONANCE EQUIPMENT
MEASUREMENT OF ENERGY
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COCIR
SUSTAINABLE COMPETENCE IN ADVANCING HEALTHCARE

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1. INTRODUCTION

The Energy-related Products (Ecodesign) Directive, 2009/125/CE, enables the European Commission (EC) to set Ecodesign requirements through new regulations for any group of products which uses energy. In 2007, Medical Devices were identified as a “Priority A” product group by the European Commission for future regulation.

COCIR Companies presented in 2009 a Self-regulatory Initiative for Medical Imaging Equipment, committing to improve the environmental performances of their products.

The Steering Committee decided in 2010 to develop ecodesign targets for magnetic resonance and established a working group from the manufacturers of MRI systems.

The outcome of the group was an agreed upon procedure for measuring typical energy consumption of MRI equipment. This procedure defines specific states of system operation and instructions for determining a set of scanning protocols to be analysed. For each product in scope, the sum of sequence durations and the power draw are recorded.

COCIR Self-Regulatory Initiative

The Self-Regulatory Initiative requires only measurement of energy consumption in off and ready-to-scan mode. Therefore for the objective of the COCIR SRI, the sections on the measurement of the energy use during scan mode in the present methodology can be disregarded and the templates have to be filled in only with the following data:

- Power consumption in off mode and ready-to-scan mode
- Duration of scan sequences

In this MR test procedure, a low power mode is introduced which is selectable by the operator and not automatic. The duration of this mode estimated at 2 hours per day to represent time when the system is not off, and not ready-to-scan.



2. SCOPE

This methodology can be used to measure all whole-body MRI systems. Equipment and accessories beyond a basic MR product and not required for a basic scan, or customer-provided equipment, such as optional MR coils, patient vital signs accessories, facility-provided cooling water equipment and hardware for advanced medical applications, are outside the scope of this procedure.

The use of the present methodology to measure permanent magnet open MRI has not been evaluated.

The methodology is not suited for the measurement of technologies combining MRI with other Imaging systems, such as MRI/CT or MRI/PET.

3. DEFINITIONS

Energy: The capacity to do work. In this document, the unit of energy is kilowatt-hours (kW·h).

Off mode: The system functions into the minimum energy consumption state that the typical user can access, through selection of off or shutdown, at the operator console.

Power: The rate at which energy is generated or consumed. In this document, the unit of power is kilowatts (kW).

Procedure Type: An examination is a collection of scans for an individual patient. "Procedure Type" refers an exam for a specific anatomy or type of exam. (e.g. Abdomen or Vascular).

Ready-to-scan mode: This mode represents the state of the system between individual scans (e.g. during patient handling, data archiving, examination planning or contrast agent injection).

Scan mode: The MRI is actively scanning the patient to generate images by sending and receiving RF energy and switching the magnetic field gradients. The computing system interprets the data and generates the image.

Sequence Duration: Sequence duration is the time the system is actively scanning, during an exam. As the duration is determined by the details of the MRI scan prescription and product capabilities, each sequence's duration has to be determined on a per-product basis.

Low power mode: This operator selected mode represents a state of the system with power consumption lower than ready-to-scan and higher than off mode. (i.e., sleep mode, service/evaluation mode)

MRI water heat exchanger: MRI Equipment subsystem which transfers heat from the MR cooling water to the facility-provided cooling water. It is necessary that the cooling water in the MRI system is separated from the cooling water provided by the facility to protect MRI components that are water cooled.



4. SYSTEM POWER MODES

The operation modes are defined as “Off”, “Low power”, “Ready-to-scan”, and “Scan”. The energy consumption differs between the modes and that the transition between modes occurs by operator selection.

The anticipated power of these modes, from high to low, is:

Scan > Ready-to-scan > Low power > Off

The table below shows a possible state transition order, for an MRI system.

Initial State	Transition To	Method
Off	Ready-to-scan	Operator starts system
Ready-to-scan	Scan	Operator starts a scan
Scan	Ready-to-scan	Scanning completes
Ready-to-scan	Low power	Operator selection
Ready-to-scan/Low power	Off	Operator turns off system
Low power	Ready-to-scan	Operator selection

5. USE MODES OVERVIEW

Typical daily system operation is set as follows:

Mode	Duration
Off	12 hours
Low power	2 hours
Scanning and Ready-to-scan	10 hours

The typical daily energy consumption of a MRI system is the sum of the energy consumption for each of the three time periods.

OFF

During the 12 hours of off time, the system is assumed to be in the lowest operator selectable power mode.

LOW POWER

Duration is to be determined as a rest from Scan and ready-to-scan within 12 hours, or to be allocated as fixed hours.

SCAN AND READY-TO-SCAN

During the 10 hours of operation, the system is assumed to transition between the two modes: Ready-to-scan and scan.



MRI – Measurement of energy consumption

To describe operations, two sources were used. First, the IMV Medical Information Division 2007 MRI Market Summary Report, published May 2008, was used to determine the distribution of procedure types.

The 2007 MRI IMV Market Summary Report procedure distribution is:

Head	24%
Spine	25%
Abdomen	24%
Extremity	19%
Angio	9%

Second, within each procedure type, the specific sequences comprising the exam were selected based on the German "Guidelines of the Federal Medical Council for Quality Assurance of magnetic resonance imaging" (BÄK) and the "guidelines on criteria for quality assessment in nuclear magnetic resonance imaging pursuant to § 136 SGB V i.V.m. § 92 SGB V, Section 1 of the Federal Committee of Physicians and Sickness Funds (Quality assessment guidelines for magnetic resonance imaging).

The 27 clinically relevant sequences have been defined and listed in the template that can be downloaded with this document from the COCIR website.

The duration of each examination is unique per product and is the sum of:

- the total of "Sequence Duration" times
- the time for "Patient Handling and Administration Time",

Each manufacturer is responsible for determining the duration of each sequence (see chapter 11.4).

Significant variability in exam durations is introduced during patient handling and administration time, such as patient preparation, contrast agent injection, adjustments, etc. To reduce the variability, but to properly account for the energy used during these instances, fixed times were estimated and are added to the sequence duration to determine the total exam time. As a result, the following average values representing real examinations are to be used:

Examination	Average ready-to-scan time
Head:	00:14:21
Spine:	00:13:41
Abdomen:	00:22:43
Knee:	00:14:10
Angio:	00:16:07

The sum of sequence durations and administration time are combined with the procedure distribution percentages to determine the number of examinations per day and then the energy consumption for the 10 hour period of operation can be derived. These measurements are captured the template "MRI – template for data collection" (available for download at www.cocir.org).



6. RESOURCES

The following personnel are recommended:

- An engineer or technician familiar with the power distribution of the system and power electronics safety.
- An engineer or applications specialist familiar with scanner operation and the prescribing of clinical protocols.

7. UNIT UNDER TEST (UUT)

System Configuration: System configuration should be recorded and configured to perform the set of specified procedures with appropriate RF receiving coils.

Installation: The system shall be installed and calibrated according to its specification, including all system-critical items needed to perform a basic scan, e.g. gradient amplifiers, RF unit, MR coils needed for the specific measurements, reconstruction engine(s), required electronics such power supplies, controllers, console/computer, cryogen compressor, water heat exchanger, patient table, magnet and helium-conservation equipment.

Any equipment and accessories beyond basic product offering and not required for a basic scan, or customer-provided equipment, e.g. optional MR coils, patient vital signs accessories, facility-provided cooling water equipment and hardware for advanced medical applications shall not be included in the measurement.

Environmental Conditions: The measurements are to be taken at a steady-state operating temperature, and within manufacturer's specified ambient temperature and humidity limits.

Measurement: Prior to each mode's measurement, the equipment shall remain in that mode for sufficient time to allow temperature and other pertinent transient conditions to stabilize.

Emulated System: For sequence duration determination, it is permissible to use a device that emulates the hardware capabilities of the system, and uses the product software, to ensure the same prescription restrictions as a full system.

7.1. POWER MEASUREMENT DEVICE

A device capable of measuring 3-phase voltage and current and calculating the integral of power with respect to time (energy) or a power meter able to sample average power ratings.



8. COCIR MRI DATA COLLECTION SPREAD SHEET

The data obtained according to the present methodology have to be filled in the appropriate template that can be downloaded from the COCIR website www.cocir.org.

9. MEASURED RESULTS

The measured values resulting from this procedure are:

- Power measured in Off mode
- Power measured in Ready-to-scan mode
- Power measured in Low Power mode
- Power measured in Scan mode (average value) for each sequence
- Duration of each scan sequence
- Energy consumption per examination

10. INSTALLATION OF POWER MEASUREMENT DEVICE

The power measurement device shall be installed onto the input to the main disconnect panel of the system to ensure that all energy consumption of the MRI equipment is captured, including the cryogen compressor and the MRI water heat exchanger.

11. MEASUREMENT OF POWER AND ENERGY

11.1. OFF MODE POWER MEASUREMENT

- 1) Ensure that the power meter is on and functioning.
- 2) Shutdown the system to the minimum energy consumption state that the user can access.
- 3) Wait to ensure that all system elements have established low power operation.
- 4) Measure the average power draw (rate of energy consumption), for a period of at least 10 minutes. If the system has a variable power usage in this mode, the measurement duration shall be amended to at least one complete power usage cycle, which shall be taken to be the cycle from minimum to maximum usage.
- 5) Record this value, in kilowatts.

11.2. LOW POWER MODE POWER MEASUREMENT

- 1) Ensure that the power meter is on and functioning.
- 2) Wait to ensure that all applicable system elements have adapted to this mode.
- 3) Measure the average power draw (rate of energy consumption), for a period of at least 10 minutes. If the system has a variable power usage in this mode, the measurement duration shall be amended to one complete power usage cycle, which shall be taken to be the cycle from minimum to maximum usage.
- 4) Record this value, in kilowatts.

In case the MRI is not able to switch to a lower energy mode, the ready-to-scan power rate has to be used.



11.3. READY-TO-SCAN MODE POWER MEASUREMENT

- 1) Ensure that the power meter is on and functioning.
- 2) Prescribe a patient and execute any scan to ensure that the system is functioning.
- 3) After the scan completes, record the average power draw (rate of energy consumption), for a period of 12 minutes. Record this value, in kilowatts.

11.4. SCAN MODE ENERGY MEASUREMENT

Setting up Scan Programs

Prepare a scan program for each exam type according to the user manual using the parameters defined in Appendix I. If it is not possible for the MRI system under test to use a certain sequence specified in the Appendix I, use a sequence as close as possible to the sequence specified given the same contrast and diagnostic results. Store the scan programs for later usage on the same MRI system or MRI system type.

Measurement during scan with equipment actively scanning

Procedure for Power Determination using exam type average:

- 1) Set the equipment to Ready-to-Scan mode (according to 11.3).
- 2) For each exam type e_t :
- 3) Take time " t_s " and energy reading " E_s " and start scan program
- 4) After completion of scan program: take time " t_e " and energy reading " E_e "
- 5) Calculate average power $P_{et} = (E_e - E_s) / (t_e - t_s)$.
- 6) Transfer average power " P_{et} " to the evaluation sheet (row "sum scan time", column "Power / kW").
Transfer sequence durations " d_s " for all sequences used to the evaluation sheet (column "Sequence duration")
- 7) Consistency check: $t_e - t_s$ shall not deviate more than a few seconds from the sum of sequences' durations " d_s ".

Procedure for Power Determination using power sampling:

1. Set the equipment to Ready-to-Scan mode (according to 11.3).
2. For each exam type e_t :
3. Start scan program and sample the average power consumption within short intervals of time dt (e.g. every second). P_t is the sample at time t .
4. After completion of scan program:

For each sequence s :

- a. Calculate total energy consumption E_s for the sequence:
$$E_s = \sum_{t=t_s}^{t_e} (dt * P_t)$$

 t_s : Start time of sequence; t_e : End time of sequence
 - b. Calculate average power consumption P_s :
$$P_s = E_s / (t_e - t_s)$$
 - c. Consistency check: $t_e - t_s$ shall not deviate from the sequence duration d_s .
5. Transfer sequence durations d_s (column "Sequence duration") and average power P_s (column "Power / kW") for all sequences used to the evaluation sheet.



11.5. SEQUENCE DURATION DETERMINATION

The exact prescription of each sequence is to be determined by the individual manufacturers. Three criteria should be considered, when determining the prescription parameters:

- 1) Parameters defined in Appendix I must be met.
- 2) SAR and dB/dt limits should not exceed IEC60601-2-33 First Control Mode restrictions using a patient weight between 50 and 100kg.
- 3) The listed contrast type must be preserved (i.e. PD, T1, or T2-weighted)
- 4) Clinical considerations (i.e. reducing breath hold time for abdominal scans, or a minor adjustment in default TR to obtain the minimum required number of slices within one acquisition).

Record the duration of each sequence, as calculated by the system's software and displayed in the system's user interface.



12. HOW TO USE TEMPLATES

The methodology is complemented by an excel spread sheet where the measured data has to be filled in. The spread excel sheet is already equipped with formulas that provides the results.

The following data need to be filled in the template:

Measured data	Estimated data common to all Companies
1. Power consumption in off mode 2. Power consumption in ready-to-scan mode 3. Power absorption for each sequence 4. Duration of each sequence	Ready-to-scan time for each examination (times in-between-scans) reported at page 6

Template for Head examination

Orange cells: to be filled with measured data

Grey cells: data derived by formulas.

Please fill in orange cells					hours per day
Test measurements					24
Typical head measurement	Sequence duration				
Action	Endtime	Sequence duration	Power / kW	Time / h	Energy / kWh/sequenc
localizer				0,0000	0,00
slice planning / adjustments					
t2_tirm_tra_dark-fluid				0,0000	0,00
slice planning					
t2_tse_sag_512				0,0000	0,00
ep2d_diff_3scan_trace_p2				0,0000	0,00
slice planning					
t1_f12d_tra				0,0000	0,00
contrast agent injection					
t1_f12d_tra				0,0000	0,00
slice planning					
t1_f12d_cor				0,0000	0,00
Action	Total time				
average head examination total	0:14:21	kW	Time	kWh	
sum scan time	0:00:00	#DIV/0!	0,00	0,00	
sum ready to measure time	0:14:21	21,30	0,24	5,09	
		21,30	Total	5,09	

Sum of sequence durations

Average ready-to-scan time (see pg. 6), different for each examination

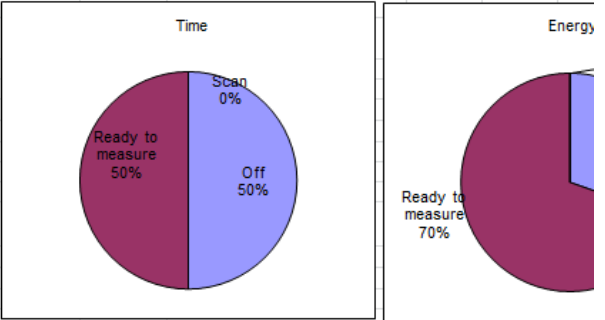
Ready-to-scan power consumption – measured. Same for all examinations



MRI – Measurement of energy consumption

The calculation sheet requires the following information to be filled in with power consumption in off, ready-to-scan and Low power mode

Summary to calculate patients per day in given mix		Please fill in orange cells	
	Minutes		
Potential exam time per day (12h)	720	Product	
minus Non-Availability (equals to 2h fixed ready to measure time)	120	Product category	
Available potential scanning time	600		
			Time per patient / h
Action	Duration	Distribution	Normalized
average head examination total	0:14:21	25	24%
typical spine measurement (lumbar spine)	0:13:41	26	25%
typical abdomen measurement	0:22:43	25	24%
typical knee measurement	0:14:10	20	19%
typical angio measurement	0:16:07	9	9%
		105	1,0000
			600
			38,360
			optimized patients that can be treated within this timeshare
			scan
			ready to measure
			total
	Time in Min	kW	kWh
Energy for non-availability (2h for service, reliability etc. in which system is ready to measure) fixed	120	21,30	42,60
Off-time (12h) fixed	120	9,30	111,6
Per day:	Time min	Energy kWh	
Off	720,00	9,30	111,60
Ready to measure	720,00	21,30	255,60
Scan	0,00	#DIV/0!	0,00
Sum of Energy per day for max. exams in given distribution	1440,00	15,30	367,20
Average kWh/Patient			9,57



Power consumption in off, ready-to-scan and low power mode



APPENDIX I

MRI CONFIGURATION

List of parameters¹ to be used to configure the MRI for each specific sequence.

	Number of Slices		FOV (mm ²)	Slc Thk (mm)	Resolution	Bandwidth (Hz/Px, Range)		Sequence Duration (For Reference Only)
	Minimum	Max	Max	Max	Max	Min	Max	BÄK
HEAD								
localizer	1	280	8	1,1	290	655	N/A	
t2_tirm_tra_dark-fluid_320	28	220	5	0,7	191,0	200	< 00:05:00	
t2_tse_sag_512	27	250 x 225	5	0,5	122,0	195	< 00:05:00	
ep2d_diff_3scan_trace_p2	23	240	5	1,9	1132,0	4000	< 00:05:00	
t1_se_tra_320	28	230	5	0,8	150	160	< 00:05:00	
t1_se_tra_320	28	230	5	0,8	150	160	< 00:05:00	
t1_se_cor_320	32	230	5	0,8	150	200	< 00:05:00	
SPINE								
localizer	5	450	8	1,8	290	655	N/A	
t2_tse_sag_512	16	300	3	0,6	160	165	< 00:05:00	
t1_tse_sag_512	15	300	4	0,6	240	250	< 00:05:00	
t2_tse_tra_512	20	230	4	0,5	95	195	< 00:05:00	
t1_tse_tra_448	20	230	4	0,6	110	230	< 00:05:00	
ABDOMEN								
localizer	5	450	8	1,8	450	655	N/A	
t1_fi2d_opp-in_tra_p2_mbh	30	380	6,0	1,5	240	525	< 00:00:45	
t2_trufi_cor_p2_bh	25	400	6,0	1,4	500	655	< 00:05:00	
t2_tse_tra_p2_mbh_320	30	380	6,0	1,2	260	395	< 00:05:00	
t1_vibe_fs_tra_p2_320_bh_pre	64	400	4	1,3	400	785	< 00:00:45	
t1_vibe_fs_tra_p2_320_bh_arterial	64	400	4	1,3	400	785	< 00:00:45	
t1_vibe_fs_tra_p2_320_bh_venous	64	400	4	1,3	400	785	< 00:00:45	
t1_vibe_fs_tra_p2_320_bh_delayed	64	400	4	1,3	400	785	< 00:00:45	
t1_vibe_fs_cor_p2_bh_288_post	128	400 x 360	4	1,4	600	870	< 00:00:45	
KNEE								
localizer_tra	3	450	8	1,8	250	656	N/A	
localizer_sag+cor+tra	3	300	5,0	1,0	250	435	N/A	
t1_se_sag_512	32	160	4	0,4	120	150	< 00:07:00	
t2_tse_fs_sag_320	30	160	4	0,5	115	265	< 00:07:00	
pd_tse_fs_cor_p2_512	30	140	4,0	0,3	120	165	< 00:07:00	
ANGIO								
I_Localizer_feet	7	400	8,0	1,6	240	558	N/A	
II_Localizer_legs	7	400	8,0	1,6	240	558	N/A	
III_Localizer_upper_legs	7	400	8,0	1,6	240	558	N/A	
IV_Localizer_abdomen	7	400	8,0	1,6	240	558	N/A	
IV_Angio3D_abdomen_pre	96	400 x 360	2	1,3	520	680	< 00:05:00	
III_Angio3D_upper_legs_pre	96	400 x 360	2	1,3	520	680	< 00:05:00	
II_Angio3D_legs_pre	88	400 x 360	2	1,3	520	690	< 00:05:00	
I_Angio3D_feet_pre	96	400 x 360	2	1,3	490	525	< 00:05:00	
IV_Care_bolus	1	N/A	20,0	1,8	400	400	N/A	
IV_Angio3D_abdomen	96	400 x 360	2	1,3	520	680	< 00:01:00	
III_Angio3D_upper_legs	96	400 x 360	2	1,3	520	680	< 00:01:00	
II_Angio3D_legs	88	400 x 360	2	1,3	690	525	< 00:01:00	
I_Angio3D_feet	96	400 x 360	2	1,3	490	525	< 00:01:00	

¹ The parameters have been defined according to the German "Guidelines of the Federal Medical Council for Quality Assurance of magnetic resonance imaging" (BAK) and the "guidelines on criteria for quality assessment in nuclear magnetic resonance imaging pursuant to § 136 SGB V i.V.m. § 92 SGB V, Section 1 of the Federal Committee of Physicians and Sickness Funds (Quality assessment guidelines for magnetic resonance imaging).



“Self-regulatory Initiative for medical imaging equipment”

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