International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

K.130

(01/2022)

SERIES K: PROTECTION AGAINST INTERFERENCE

Neutron irradiation test methods for telecommunication equipment

Recommendation ITU-T K.130

ITU-T

Recommendation ITU-T K.130

Neutron irradiation test methods for telecommunication equipment

Summary

Recommendation ITU-T K.130 describes soft error test methods for the telecommunication equipment that composes carrier telecommunications networks. The objective of soft error tests of the telecommunication equipment using an accelerator-driven neutron source is described first. An overview of the soft error tests and operating principles of an accelerator-driven neutron source are then introduced. The requirements of the accelerator-driven neutron sources and test sites are specified. The test conditions including test set-up, operational conditions and error monitoring and test procedures for the telecommunication equipment are specified. Notes for determining specific detailed test methods, such as the neutron flux to be used for irradiation and conditions for counting as failures in estimation of the reliability are also described.

History

Edition	Recommendation	Approval	Study Group	Unique ID[*]
1.0	ITU-T K.130	2018-01-13	5	11.1002/1000/13453
2.0	ITU-T K.130	2022-01-13	5	11.1002/1000/14934

Keywords

Irradiation test, neutron, soft error.

---

[*] To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Page

1 Scope ... 1

2 References ... 1

3 Definitions ... 1

  3.1 Terms defined elsewhere ... 1

  3.2 Terms defined in this Recommendation ... 1

4 Abbreviations and acronyms ... 1

5 Conventions ... 2

6 Advantages and objectives of neutron irradiation tests ... 2

7 Overview of neutron irradiation test system for telecommunication equipment using an accelerator-driven neutron source ... 2

  7.1 Configuration of neutron irradiation test facility ... 2

  7.2 Target assembly requirements ... 3

  7.3 Requirements for accelerator-driven neutron source ... 4

  7.4 Elimination of unnecessary irradiation ... 6

  7.5 Simultaneous neutron irradiation of EUTs ... 7

  7.6 Irradiation area ... 7

  7.7 Uniformity of neutron flux ... 7

  7.8 Miscellaneous notes ... 9

8 Test set-up ... 9

  8.1 Outline of test set-up ... 9

  8.2 Configuration ... 9

  8.3 Control terminals ... 10

  8.4 Positioning of EUT ... 10

  8.5 Control terminal and AEs installation ... 10

  8.6 Signal measurement equipment ... 10

9 Operation of EUT and test procedure ... 10

  9.1 Operation of EUT ... 10

  9.2 Test procedures ... 11

  9.3 Test report ... 14

Appendix I – Method of calculation for neutron fluence ... 15

Bibliography ... 16

Introduction

The implementation of measures to mitigate faults caused by soft errors is essential to meet the reliability requirements for telecommunication equipment, which is composed of highly integrated, miniaturized semiconductor devices. However, since soft errors occur very infrequently in telecommunication equipment, at a frequency as low as once every few years or decades, the reliability cannot be checked under normal environmental conditions, which makes it difficult to verify the effects of the measures designed to reduce failures and to check conformity to requirements. Therefore, it is necessary to test by irradiating equipment with an intense flux of high energy neutrons produced by an accelerator-driven neutron source at a very high rate, such as several million to several tens of million times that which exists in the natural environment. This enables soft errors to be generated quickly and allows verification of conformity to reliability requirements and the effects of mitigation measures against failures caused by soft errors.

However, to evaluate the reliability of the equipment using a neutron irradiation installation, it is necessary to appropriately determine the irradiation site, the irradiation intensity of the neutron beam, the set-up of the equipment under test (EUT) and the method used to validate operation of the EUT at the time of the test.

This Recommendation describes the outline of the neutron irradiation test and requirements for accelerator-driven neutron sources, test sites, test set-ups and test procedures for testing telecommunication equipment regarding failures caused by soft errors.

Recommendation ITU-T K.130

Neutron irradiation test methods for telecommunication equipment

1 Scope

This Recommendation provides guidance on soft error test methods using an accelerator-driven neutron source for confirming the validity of soft error mitigation measures. It also describes the requirements for test conditions, such as the neutron generator, test site, test set-up and test procedure for testing conformity to the reliability requirements of the equipment. This Recommendation is applicable to telecommunication equipment installed at telecommunications centres for carrier networks, including core network equipment (link and node equipment) and access network equipment.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.124]	Recommendation ITU-T K.124 (2022), *Overview of particle radiation effects on telecommunication systems*.
[ITU-T K.131]	Recommendation ITU-T K.131 (2022), *Design methodologies for telecommunication systems applying soft error measures*.

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 soft error: A phenomenon in which one or more bits within the data on the device have their values reversed. A soft error does not constitute damage to the actual semiconductor device.

3.2.2 neutron flux: Number of neutrons passing through a unit area per unit time.

3.2.3 neutron fluence: Number of neutrons per unit area.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AE	Associated Equipment
AR	Alert Reliability
CPU	Central Processing Unit
EUT	Equipment Under Test

MR	Maintenance Reliability
SR	Service Reliability

5 Conventions

None.

6 Advantages and objectives of neutron irradiation tests

Soft errors are caused by both high energy neutrons coming from outside of the equipment and alpha particles emitted from radioactive materials contained in semiconductor device packages. The occurrence rates of soft errors in semiconductor devices depend on their causes, i.e., the two kinds of particles; however, the phenomena and impact on the equipment do not vary regardless of the different causes. The failure modes after a soft error occurrence and the effects of the countermeasures do not vary regardless of the kind of particle causing the soft error in the telecommunication equipment. Since alpha particles do not penetrate deeply into solid material, it is difficult to test using alpha particles as it is necessary to remove the plastic packaging around the semiconductor devices to expose them to alpha particles. Thus, it is recommended to use neutrons for reliability tests for telecommunication equipment since their intensity is easily controlled during the test.

Neutrons are classified here into high energy neutrons and thermal neutrons and both types of neutron cause soft errors. The probability of the occurrence of soft errors caused by either type of neutron depends on the device type and feature size. However, considering the actual environment of telecommunication equipment, thermal neutrons are less likely to cause soft errors since cosmic-ray neutrons are mainly composed of high energy neutrons and thermal neutrons are shielded by the walls of telecommunications centres made of concrete, etc. In addition, since soft errors generated by either type of neutron have the same effect on system operation, this Recommendation applies tests using high energy neutrons. The necessity for soft error tests using thermal neutrons is a subject for future study.

The purpose of this test using an accelerator-driven neutron source is to confirm the following by soft error tests:

- Conformity to the soft error reliability requirements
- Normal operation of soft error detection and correction functions
- Normal operation of alerts and event notification functions when soft errors occur
- Normal operation of functions (e.g., switching controls of redundant components, circuit pack reset start-up functions) in case of a failure caused by soft errors.

7 Overview of neutron irradiation test system for telecommunication equipment using an accelerator-driven neutron source

7.1 Configuration of neutron irradiation test facility

By using an accelerator, it is possible to generate a neutron flux which causes a soft error in a relatively short period of time. As shown in Figure 7-1, a particle accelerator facility that can be used for soft error tests consists of a cyclotron/linear accelerator chamber, a target chamber, a neutron irradiation chamber (some facilities do not have a separate one) and an accelerator control chamber. The cyclotron/linear accelerator chamber, target chamber and neutron irradiation chamber are designated as radiation controlled areas. The neutron flux is generated by a nuclear reaction by irradiating the target in the target chamber with protons / electrons accelerated by the accelerator in the cyclotron/linear accelerator chamber. The neutron beam generated from the target directly irradiates the equipment under test (EUT) in the same room or is guided through the neutron flight tube in the shielding wall between rooms to irradiate the EUT in the next neutron irradiation chamber.

The soft errors produced by the neutron irradiation are observed from the safely shielded accelerator control chamber by a control terminal to check the status of the EUT.

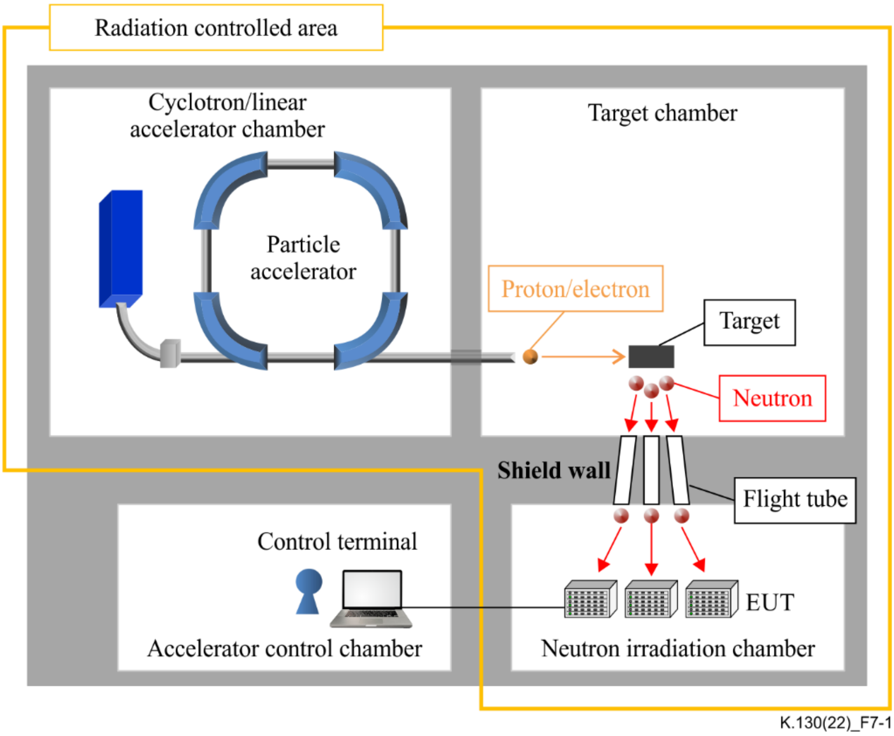


Figure 7-1 – Neutron irradiation test facility using an accelerator-driven neutron source

7.2 Target assembly requirements

When the target is irradiated with accelerated protons or electrons, high energy neutrons are produced through corresponding types of nuclear reactions. High energy neutrons are produced directly by a proton nuclear reaction, whereas electrons first produce gamma rays by reacting with the static electric field in the heavy metal atom and produce high energy neutrons through a photonuclear reaction.

In many facilities, as shown in Figure 7-2, thermal neutrons are generated by lowering the energy of high energy neutrons using a moderator (hydrogen-rich material), which is often employed in material research or neutron transmission imaging.

When performing a soft error test using an accelerator to which a moderator is usually attached for other purposes, the moderator, as shown in Figure 7-3, shall be removed and the EUT shall be directly irradiated with high energy neutrons emitted from the target without deceleration.

There is also a method to increase the neutron flux to the EUT by reflecting neutrons travelling outside the path to the EUT by placing a reflector such as lead around the target.

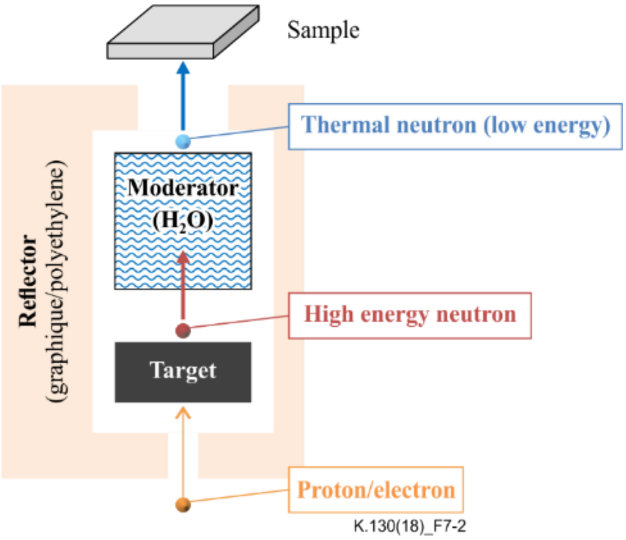


Figure 7-2 – Target assembly for thermal neutrons

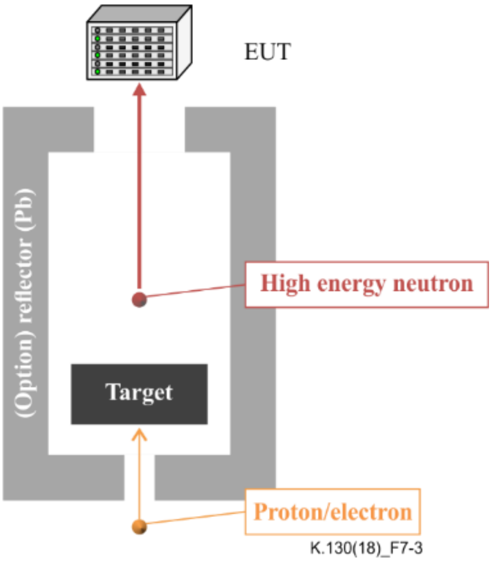


Figure 7-3 – Target assembly for soft error test

7.3 Requirements for accelerator-driven neutron source

Soft errors are caused by nuclear reactions between high-energy neutrons and the silicon nuclei in semiconductors. The stable composition ratios of silicon isotopes in the natural environment are ^{28}Si at 92.23%, ^{29}Si at 4.67% and ^{30}Si at 3.1%. Table 7-1 shows the nuclear reactions between each silicon isotope and neutrons, together with their threshold energies (the minimum energies required to cause a nuclear reaction). Since the majority of silicon is ^{28}Si, energy of about 4 MeV or more is required for tests in order to generate a specified number of soft errors.

A neutron in nature is caused by ultra-high energy particles travelling around the galaxy and includes ultra-high energy neutrons with energies up to several TeV. For this reason, a very large-scale accelerator is required, which can generate high energy neutrons to obtain a precise error rate in the natural environment very accurately; however, the numbers of and available time in this kind of facility are limited and the variable range of the irradiation area and beam intensity on such a very large-scale accelerator are narrow. Nevertheless, in telecommunication equipment installed at terrestrial telecommunication centres, soft errors due to neutrons having energy in the 4 to 10 MeV range and soft errors due to higher energy neutrons have been observed as nearly identical phenomena (memory bit inversion). Although there are some events with a very low probability that cause permanent damage from high energy neutrons, such events are excluded from the scope of the neutron irradiation test since it is extremely rare for these specific situations to occur in telecommunication equipment.

It is recommended to use a relatively small accelerator facility capable of generating neutron energy of about 4 to 10 MeV, because the error rate of the natural environment can be reproduced with sufficient accuracy, the validity of the soft error measures can be confirmed and conformity to the reliability requirements regarding soft errors can be checked. An accelerator facility which has sufficient neutron energy to reproduce soft errors should be selected based on the information of the neutron energy spectrum released by the accelerator facility, or calculation of the neutron energy spectrum from the configuration of an acceleration-driven neutron source. Figure 7-4 shows the neutron energy spectrum for accelerator facilities.

Table 7-1 – Si neutron reactions and threshold energies reaction with Si

Si - neutron reactions	E$_{threshold}$
^{28}Si + n --> ^{28}Al + p	3.999[MeV]
^{28}Si + n --> ^{25}Mg + α	2.749[MeV]
^{29}Si + n --> ^{29}Al + p	3.009[MeV]
^{29}Si + n --> ^{26}Mg + α	35[KeV]
^{30}Si + n --> ^{30}Al + p	8.040[MeV]
^{30}Si + n --> ^{27}Mg + α	4.341[MeV]

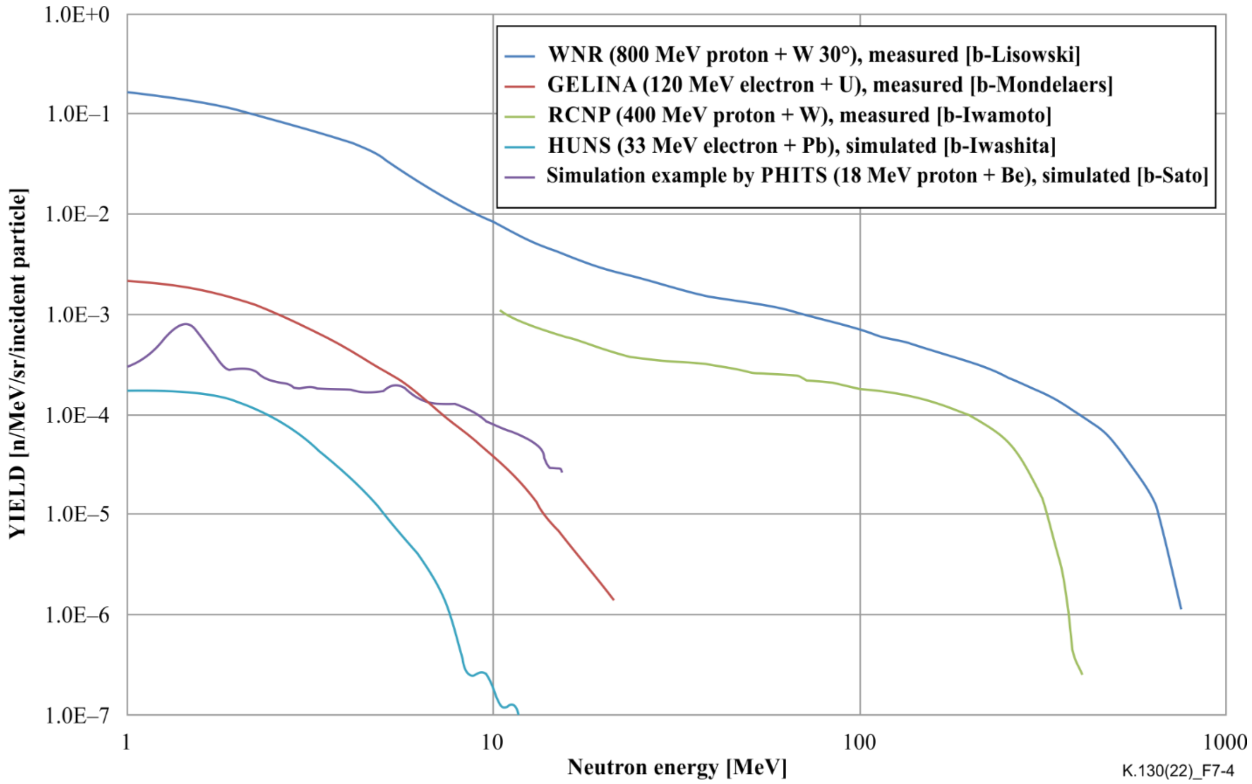


Figure 7-4 – Neutron energy spectrum for accelerator facilities

7.4 Elimination of unnecessary irradiation

In the neutron irradiation test, since only high energy neutrons, which are the major cause of soft errors, are to be irradiated, it is necessary to remove thermal neutrons and gamma rays that can cause permanent damage to semiconductors by shielding this unnecessary radiation. Also, from the viewpoint of improving test feasibility, the neutron irradiation area should be separated from the target chamber by appropriate shielding to reduce the induction of radioactivity in the neutron irradiation chamber.

This clause lists the key issues for the shielding required to eliminate unnecessary irradiation to the EUT and outside of the irradiation field.

7.4.1 Shielding against thermal neutrons

In order to reduce the irradiation from thermal neutrons, shielding materials such as cadmium or boron, by which thermal neutrons are efficiently shielded but high energy neutrons are less affected, should be installed so that the EUT is not irradiated with thermal neutrons as shown in Figure 7-5.

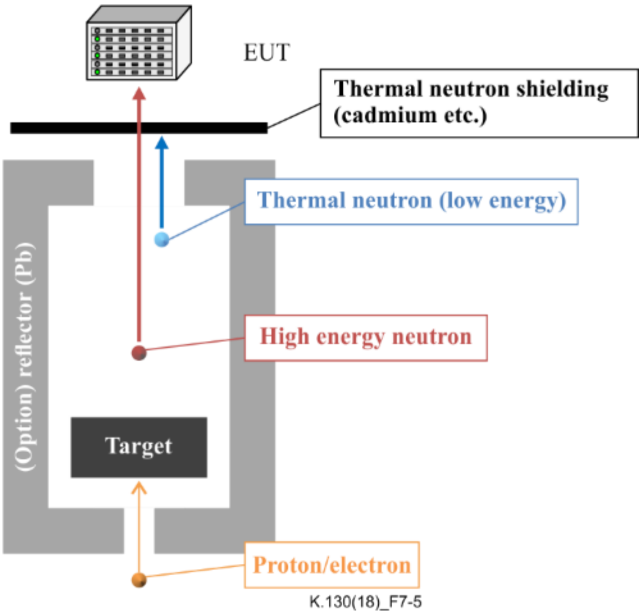


Figure 7-5 – Thermal neutron shielding

7.4.2 Shielding against gamma rays

When neutrons are generated by an electron accelerator, the target produces large amounts of gamma rays (greater than 10 Gy) [b-Eid]. Because gamma rays can physically damage semiconductors, lead blocks that shield gamma rays and easily transmit high-energy neutrons shall be installed. When using a proton accelerator, a shield for gamma rays is not necessarily due to the minimal amount of gamma rays produced.

7.4.3 Separation between target chamber and neutron irradiation chamber

Even after the irradiation of protons or electrons to the target is stopped, the target, surrounding structures and air are radioactive, so nobody can approach immediately. On the other hand, during the neutron irradiation test of telecommunication equipment, the irradiation room frequently needs to be entered in order to confirm a failure situation that cannot be checked remotely, to reset the device manually and to replace a circuit pack, etc.

Therefore, the target and the neutron irradiation field should be in separate chambers and appropriate shielding should be installed between them. If a separate neutron irradiation chamber cannot be obtained, it is recommended to install appropriate shielding material around the target to reduce the number of neutrons other than to the EUT.

7.5 Simultaneous neutron irradiation of EUTs

In order to improve test efficiency, it is preferable to have facilities that can simultaneously irradiate multiple units of telecommunication equipment. It is possible to test multiple units simultaneously by placing them in front of multiple neutron beams emitted from a single target as shown in Figure 7-6.

In this case, it is preferable to have at least three neutron beam lines. Also, when multiple beam lines are used, each beam should be controlled independently. This can be achieved by installing shutters on the beam lines or by using remote-controlled lifts to move the EUTs up and down. When testing an EUT mounted on a lift, it is necessary to confirm the lift elevation accuracy.

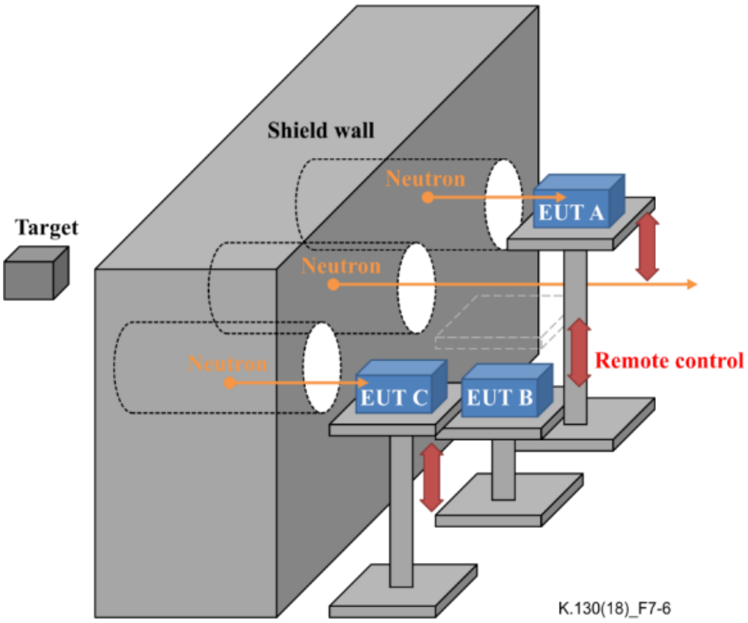


Figure 7-6 – An example of simultaneous irradiation to multiple EUTs using remote-controlled lifts

7.6 Irradiation area

If the irradiation area is small, it is necessary to change the irradiation position on the EUT and scan it to cover the necessary irradiation area, which increases the test time significantly. Hence, the irradiation area should be able to cover the entire EUT. As a result, it is possible to improve testing efficiency by irradiating neutron beams simultaneously to all the semiconductor devices in the EUT and thereby generating a soft error.

Taking into consideration the fact that ordinary telecommunication equipment is designed to be mounted on 19-inch racks and the height of modern units, it is recommended that the irradiation area is about 45 cm or more in width and height.

7.7 Uniformity of neutron flux

Since neutrons emit isotropically from the target, the neutron flux decreases in inverse proportion to the square of the distance. Figure 7-7 shows the neutron flux compared to distance from the target (the flux is normalized by the value at 1.0 m from the target). The flux can be increased in locations closer to the target, but flux change due to distance is also greater; for example, the flux reduces 30% when the separation increases by 20 cm from 1 m.

The position of the EUT should be 3.0 m away from the target in order to achieve a flux variation of less than 20% in the volume of an EUT whose depth is 30 cm. If a separation of 3.0 m cannot be achieved, the flux at the positions of components in the equipment shall be calculated carefully and compensation should be applied to the reliability estimation since the difference in the flux within the EUT is too large.

Table 7-2 shows options of neutron intensity determination for reliability evaluation considering the difference in the neutron intensity among the places in the enclosure of a EUT. By Method 1, reliability is evaluated based on the weakest neutron intensity, usually at the farthest component in the EUT enclosure from the target. If the component insensitive to the neutron soft error is clearly known, the intensity at that component can be ignored when minimum neutron intensity is determined.

By Methods 2 or 3, reliability can be evaluated more precisely than with Method 1, and the evaluation can give more realistic value approximating that in the natural environment. The method applied for the reliability evaluation shall be described in the test report.

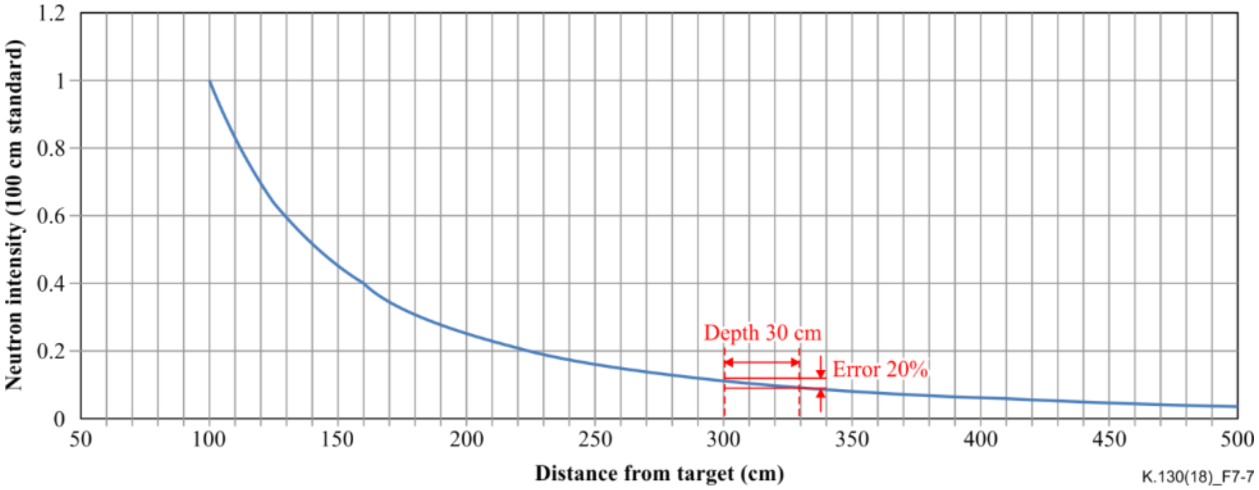


Figure 7-7 – Neutron intensity in relation to distance from the target

Table 7-2 – Test methods considering the difference of neutron intensity in a EUT

Method	Reliability evaluation method	Characteristics
1	The reliability is evaluated based on the weakest one among the neutron intensity at components in the EUT enclosure.	It gives the lowest and safest reliability evaluation. EUT may fail the test if it does not have sufficient margin of reliability.
2	Reliability is evaluated based on the number of failures originated by errors at each component in the EUT and neutron intensity relevant to that component.	Most accurate evaluation is possible. However, it is necessary to determine which component originates each failure. Therefore, the procedure may be complicated, and it takes time to analyse the failure and evaluate reliability.
3	Reliability is evaluated based on the middle value of neutron intensity in the EUT enclosure. The number of failures shall be obtained turning over the front and back of EUT so that each irradiation time to front and back is half of the total irradiation.	It gives a more accurate evaluation than Method 1 even though the calculation is easy. Alert reliability (AR) evaluation can be accomplished in the shortest time by this method.

7.8 Miscellaneous notes

1) Power source for EUT

A power source is required in the neutron irradiation chamber in order to operate the EUT. Sufficient power capacity must be available to operate the EUT.

For example, modern high-performance telecommunication equipment requires about 8000 W or more of power in the neutron irradiation chamber. In addition, electric power of about 1500 W should be available for measurement equipment and control terminals in the accelerator control chamber.

2) Floor space for neutron irradiation chamber

Enough space must be provided within the neutron irradiation chamber to place a rack or other housing so that the EUT can be set up at the irradiation position. A floor space of about 80 cm × 80 cm is necessary for the test including the space for the DC power and associated equipment (AE).

8 Test set-up

8.1 Outline of test set-up

The test system consists of the EUT, terminals for monitoring and control of the EUT and AE.

The EUT is installed in the neutron irradiation chamber with all the installed circuit packs to enable a comprehensive check of all the functions. The control terminal of the EUT is connected from the accelerator control chamber to the EUT and all functions which are used in normal operation should be installed. The following AE is installed: equipment to be normally connected to the EUT, signal measurement equipment for generating client signals and confirming signal normality and equipment for replicating the operational environment. It is desirable that the AE is installed outside the neutron irradiation chamber because it is out of the scope of the test, but in the case of installation in the neutron irradiation chamber due to cable and power supply restrictions, it is necessary to shield it from the neutrons with a concrete block, etc.

8.2 Configuration

The purpose of this test is to assess the reliability of the EUT in a manner that is consistent with its typical arrangement and use. Other arrangements may be used to check the entire area of the EUT and/or to reduce test time, provided these arrangements can be shown not to have a significant effect on the performance of the EUT.

An EUT should include all types of circuit packs, so that all functions can be comprehensively checked. The number of circuit packs should depend on operating conditions. However, when there are many types of circuit packs and it is not possible to mount all types of circuit packs at once, it is also possible to install a part of them. In this case, the process is to change the circuit pack to be mounted, test multiple times, and test all the circuit packs in turn. In addition, when the physical size is large or the irradiation area is narrow and the entire circuit pack cannot be irradiated at once, it is also possible to irradiate a part of the EUT at a time. In this case, the entire EUT is covered by sequentially conducting the test while changing the irradiation position of the neutron beam.

Units and circuit packs that do not irradiate in large systems (such as systems composed of multiple units) may be tested while they are in the irradiation room, or parts that are not irradiated may be placed in the accelerator control chamber and tested. The selection of these methods is based on whether the signal transmission and reception of the interface between the separated devices can be performed normally between the irradiation room and the accelerator control chamber.

If the EUT is a part of a system or can be connected to the AE, it should be connected to the necessary systems and AEs for testing compliance with all the types of reliability requirements.

The numbers of each circuit pack to be mounted, the configuration of the EUT including the neutron irradiation chamber and the accelerator control chamber and the type and number of the AEs are decided from the range in which the error state propagates and the operating conditions.

8.3 Control terminals

The control terminal employed for this test should have all functions which are used in normal operation, e.g., receipt of all alarms and notifications from the EUT, confirmation of EUT status under test, execution of control functions and restoration of failures remotely.

Since these functions are subject to the soft error test, it is necessary to ensure that there is as little variation from normal operation as possible.

8.4 Positioning of EUT

The EUT should be mounted on a support base or rack and its position adjusted so that the neutron flux of interest is irradiated to the target area of the EUT. The material for the racks where the EUT are installed is selected so that neutrons are not shielded or reflected. Also, it is recommended that there are no walls or doors covering the periphery of the EUT.

8.5 Control terminal and AEs installation

The AEs and a control terminal are not subject to the soft error test and their normality should be guaranteed. Therefore, these shall be installed in the accelerator control chamber of the test facility. If it is not possible to set up these devices in the accelerator control chamber, they shall be placed where the neutron flux is weak enough to avoid errors in the device, such as a position far from the neutron beam and be shielded by material such as concrete blocks.

8.6 Signal measurement equipment

To confirm operational normality during the irradiation test, the normality of client signals shall be checked using measurement equipment such as transmission signal test equipment. Client signals through all signal ports shall be measured since the occurrence probability depends on the signal port.

9 Operation of EUT and test procedure

9.1 Operation of EUT

From the perspective of client signal continuity and control/operational functionality in conjunction with telecommunication equipment functions, the following requirements must be met.

Client signal continuity perspective:

- Input traffic must be the maximum load possible with the test system configuration.
- Packet signals in the packet equipment must include packet lengths ranging from the minimum to the maximum length.
- Data patterns should be pseudo-random patterns.
- Monitoring of client signal error statuses for packet loss, packet errors and bit errors, etc., must be enabled.
- All notifications (alerts, warnings, and events, etc.) from the EUT must always be able to be monitored.

Control and operational functionality perspectives (required for the functions that are implemented in the equipment):

- Switching controls of redundant components should be performed.
- Test functions should be performed (path continuity test, loopback test, etc.).
- Start-up functions by both central processing unit (CPU) reset and circuit pack reset should be performed.
- A firmware update should be performed (test for this requirement may not be conducted if normality can be checked by the test of start-up function performance described above).

All the types of data necessary to evaluate three kinds of reliabilities, i.e., service reliability (SR), maintenance reliability (MR) and alert reliability (AR), must be obtained. Combinations of measurement methods to reduce the testing time can be applied if this does not affect the normal operation of the EUT and evaluation of reliability.

9.2 Test procedures

Neutron irradiation test procedures are described below and Figure 9-1 part a) and part b) shows the flowchart for this soft error testing.

1. Connect the control terminal to the EUT and enable the EUT status and notification from the EUT to be monitored.
2. Pass through client signals to the EUT and enable the client signal continuity to be monitored.
3. Start monitoring the EUT status, notifications from the EUT and client signals.
4. Generate the neutron beam and record the time at which the neutrons are generated.

The following procedures vary depending on whether the event that occurred can recover autonomously if an abnormality occurs (such as detecting an alert or error on the client signal).

a. When the event can recover autonomously:

   4a-1 Record the place where the soft error occurred, the period of continuous interruption of the client signals, the method used for recovery, notifications from the EUT and detected errors on the AE. (Notes 1, 2)

b. When the event cannot recover autonomously:

   4b-1 Turn off the neutron beam and record the time at which the neutron beam is stopped.

   4b-2 Record the place where the soft error occurred, the period of continuous interruption of the client signals, notifications from the EUT and detected errors on the AE. (Note 3)

   4b-3 Remotely reset or restart the equipment to return it to its normal operational state and record the method used for recovery.

   4b-4 Generate the neutron beam and record the time at which the neutrons are generated.

Repeat step 4 until the cumulative irradiation time of neutron beam becomes 25%, 50%, 75% and 100% of the irradiation time required to confirm conformance to the AR.

5. Turn off the neutron beam and record the time at which the neutron beam is stopped.
6. With the neutron beam stopped and client signals being passed through, perform the control and operational functions.
7. Record the place where the soft error occurred, the period of continuous interruption of the client signals, the method used for recovery, notifications from the EUT and detected errors

on the AE if an abnormality occurs (such as detecting an alert, errors on the client signal or control failure, etc.). (Note 3)

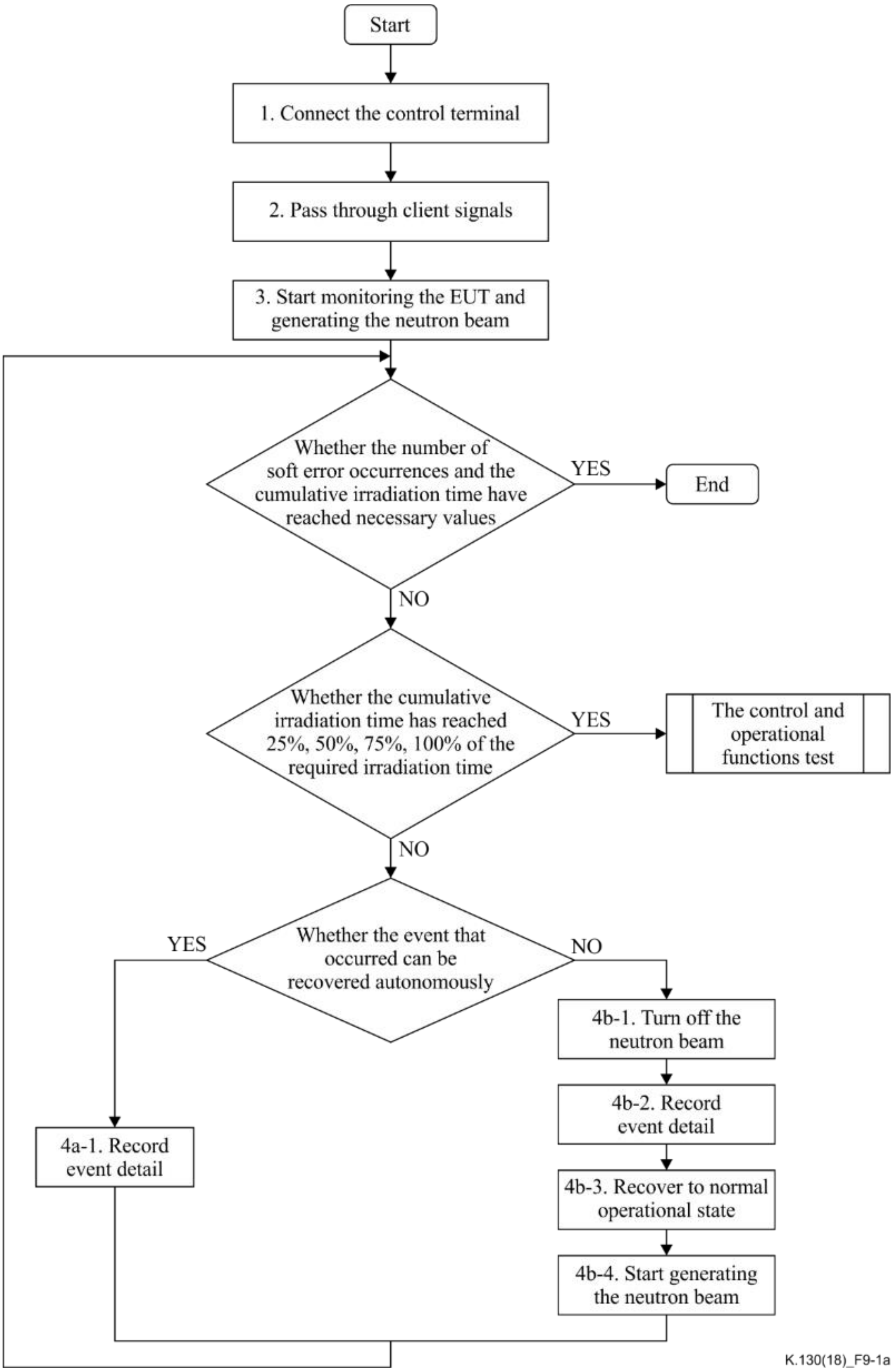
8. Repeat step 7 until confirmation that all functionalities defined in clause 9.1 is completed.

When confirmation of all functionalities is completed, return to step 3 and repeat steps 3-8 until the cumulative irradiation time reaches the total irradiation time required to confirm conformance to the AR.

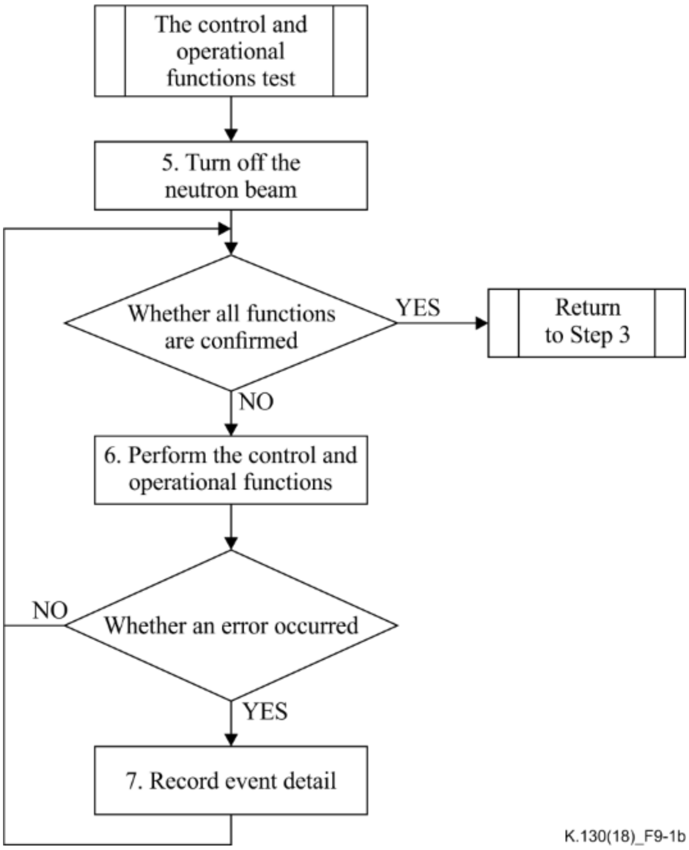
NOTE 1 – If the purpose of the testing is to confirm validity of soft error mitigation measures or to analyse soft error events in detail including autonomous recovery, the beam must be turned off and equipment logs retrieved.

NOTE 2 – If the neutron beam irradiation is continued, soft errors may reoccur during autonomous recovery. However, because a soft error that reoccurs during the autonomous recovery cannot exist stochastically in the natural environment, this shall be ignored in the test results. Also, if the autonomous recovery requires a long time to complete, the neutron beam may be turned off.

NOTE 3 – The purpose of testing the control and operational functions is to confirm whether a soft error is actualized when each function is executed, and an abnormality occurs. Thus, the neutron beam should be turned off when testing control and operational functions. Also, if a function that involves resetting the entire equipment is executed, soft errors that are present in the equipment will recover, so such a function must only be executed at the end of the test.


Start
1. Connect the control terminal
2. Pass through client signals
3. Start monitoring the EUT and generating the neutron beam
Whether the number of soft error occurrences and the cumulative irradiation time have reached necessary values
YES
End
NO
Whether the cumulative irradiation time has reached 25%, 50%, 75%, 100% of the required irradiation time
YES
The control and operational functions test
NO
Whether the event that occurred can be recovered autonomously
YES
NO
4a-1. Record event detail
4b-1. Turn off the neutron beam
4b-2. Record event detail
4b-3. Recover to normal operational state
4b-4. Start generating the neutron beam
K.130(18)_F9-1a

(a)



(b)

Figure 9-1 – Flowchart for neutron irradiation testing

9.3 Test report

In order to decide whether the reliability requirements (AR/SR/MR) are satisfied, the following items must be recorded in the test report.

1. Configuration of the EUT
2. Neutron energy spectrum
3. Irradiation area
4. Irradiation neutron fluence (calculated from the neutron energy spectrum, the total charge amount, the distance from the target, etc.) (see Appendix I)
5. Details of errors occurring during the irradiation test (information for evaluating the three types of reliability requirements)

Details of errors occurring during the irradiation test may include the period of continuous interruption of client signals, recovery time, whether the error recovered automatically, failure detection and issue of alert when a fault occurred, beam start time, beam stop time, etc.

Additionally, in order to reflect the test results in the design, it is recommended that the logs stored in the equipment be obtained and stored in an appropriate place and at an appropriate time so as not to be lost due to events such as equipment reset.

Appendix I

Method of calculation for neutron fluence

(This appendix does not form an integral part of this Recommendation.)

To evaluate the reliability specification for soft errors, the total number of neutrons (neutron fluence) irradiated to the EUT during testing and their energy distributions (neutron fluence energy spectrum) are required.

This clause describes the calculation method of the neutron fluence energy spectrum.

1. Obtain the total irradiation time $T_{irradiation}$ or total charge amount Q in the irradiation test.

   In the case of an accelerator in which the current value (the number of accelerated particles per unit time) can be changed, the total charge amount is obtained.

   In the case of an accelerator in which the current value cannot be changed, obtain the total irradiation time or the total charge amount.

2. Obtain the neutron flux energy spectrum $\Phi_A(E_n)$ of the accelerator at the irradiation position.

   The neutron flux energy spectrum represents the number of neutrons of each energy passing through a unit area per unit time, per unit current, or per acceleration particle.

   In the case of an accelerator in which the current value (the number of accelerated particles per unit time) can be changed, obtain a unit current or a neutron flux energy spectrum per accelerated particle.

   In the case of an accelerator in which the current value cannot be changed, a neutron flux energy spectrum of any of unit time, unit current, or accelerated particle is obtained.

3. Calculate the neutron fluence H from the information obtained in steps 1 and 2 by the following formula.

   a. When calculating from the total charge amount and the neutron flux energy spectrum per unit current.

   $$H(E_n) = \frac{Q}{\mathrm{A}} \times \Phi_A(E_n) \qquad A\text{: }unit\ current\ value$$

   b. When calculating from the total charge amount and the neutron flux energy spectrum per accelerated particle.

   $$H(E_n) = \frac{Q}{\mathrm{q}} \times \Phi_A(E_n) \qquad q\text{: }elementary\ charge, 1.6 \times 10^{-19}\ \mathrm{C}$$

   c. When calculating from total irradiation time and neutron flux energy spectrum per unit time.

   $$H(E_n) = \mathrm{T_{irradiation}} \times \Phi_A(E_n)$$

Bibliography

[b-ITU-T K-Sup.11]	ITU-T K-series Recommendations – Supplement 11 (2018), *ITU-T K.131 – Soft error measures of field programmable gate arrays*.
[b-Eid]	Eid, E.-S., *et al*. (2001), Design and characterization of ionizing radiation-tolerant CMOS APS image sensors up to 30 Mrd (Si) total dose. *IEEE Transactions on Nuclear Science,* 48.6: 1796-1806.
[b-Iwamoto]	Iwamoto, Yosuke, *et al*. (2011), Evaluation of the white neutron beam spectrum for single-event effects testing at the RCNP cyclotron facility. *Nuclear Technology*, 173.2: 210-217.
[b-Iwashita]	Iwashita, Hidenori, *et al*. (2017), Accelerated Tests of Soft Errors in Network Systems Using a Compact Accelerator-Driven Neutron *Source. IEEE Transactions on Nuclear Science*, 64.1: 689-696.
[b-Lisowski]	P. Lisowski *et al.* (1990), The Los Alamos National Laboratory Spallation Neutron *Sources Nucl. Sci. Eng.* v. 106, p. 208.
[b-Mondelaers]	Mondelaers, W., and P. Schillebeeckx (2006), GELINA, a neutron time-of-flight facility for high-resolution neutron data measurements. *Notiziario neutroni e luce di sincrotrone* 11.2: 19-25.
[b-Sato]	Sato, Tatsuhiko, *et al*. (2013), Particle and heavy ion transport code system, PHITS, version 2.52. *Journal of Nuclear Science and Technology*, 50.9: 913-923.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	**Protection against interference**
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2022