



Opinion No 02/2024

in accordance with Article 76(1) of Regulation (EU) 2018/1139

Implementation of the latest CAEP amendments to ICAO Annex 16 Volumes I, II and III

RMT.0514 (SUBTASK 2)

EXECUTIVE SUMMARY

This Opinion proposes to update the applicable environmental protection requirements for the certification of products in Regulations (EU) 2018/1139 and (EU) No 748/2012.

Article 9(2) of Regulation (EU) 2018/1139, as amended by Regulation (EU) 2021/1087, sets out the essential requirements for environmental protection that refer to the requirements contained in Volumes I, II and III of Annex 16 'Environmental Protection' to the Convention on International Civil Aviation.

On 20 March 2023, the International Civil Aviation Organization (ICAO) Council adopted new amendments to these volumes for the continuous improvement of the environmental protection standards and recommended practices (SARPs).

The proposed regulatory material amends Article 9(2) of Regulation (EU) 2018/1139 to refer to these new amendments. The proposed updates to Annex I (Part 21) to Regulation (EU) No 748/2012 ensure the implementation of these amendments for the certification of products and clarify the applicable procedures for the environmental compatibility of the products.

The proposed regulatory material is expected to provide a level playing field for all stakeholders in the aviation market.

The objective is to maintain a high uniform level of environmental protection and to contribute to European policies on climate change, air quality and noise reduction.

REGULATIONS TO BE AMENDED

- Regulation (EU) 2018/1139 (the Basic Regulation)
- Regulation (EU) No 748/2012 (Initial Airworthiness Regulation)

ED DECISIONS TO BE AMENDED

n/a

AFFECTED STAKEHOLDERS

Design organisation approval (DOA) holders; production organisation approval (POA) holders.

WORKING METHODS

Development

By EASA

Impact assessment(s)

Light

Consultation

NPA — Public

RELATED DOCUMENTS / INFORMATION

- ToR RMT.0514 Issue 2, published on 10.12.2019
- NPA 2023-09
- CRD 2023-09

PLANNING MILESTONES: Refer to the latest edition of *EPAS Volume II*.

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1. About this Opinion

1.1. How this regulatory material was developed

The European Union Aviation Safety Agency (EASA) developed the regulatory material in question in line with Regulation (EU) 2018/1139¹ (the Basic Regulation) and the Rulemaking Procedure², as well as in accordance with the objectives and working methods described in the Terms of Reference (ToR) for this RMT³.

The draft regulatory material was publicly consulted through NPA 2023-09 in accordance with the ToR for this RMT.

EASA reviewed the comments received and duly considered them for the preparation of the regulatory material presented here.

EASA publishes the draft acceptable means of compliance (AMC) and guidance material (GM) to Annex I (Part 21) to Regulation (EU) No 748/2012⁴, which are intended to be issued to support the application of the Regulation proposed in this Opinion, for information only.

1.2. The next steps

The Opinion is submitted to the European Commission which, based on the Opinion's content, shall decide whether to adopt the amendments to the EU Regulations as proposed in the Opinion.

Following the adoption and issuance of the Regulation amending Regulation (EU) No 748/2012, EASA will issue a decision with the related AMC and GM to support the application of that Regulation. When issuing this Decision, EASA will also provide feedback to the commenters and information to the public on who engaged in the process and/or provided comments on the draft AMC and GM during the consultation of NPA 2023-09, which comments were received, how such engagement and/or consultation was used in rulemaking, and how the comments were considered.

¹ Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91 (OJ L 212, 22.8.2018, p. 1) (<http://data.europa.eu/eli/reg/2018/1139/oj>).

² EASA is bound to follow a structured rulemaking process as required by Article 115(1) of Regulation (EU) 2018/1139. Such a process has been adopted by the EASA Management Board (MB) and is referred to as the 'Rulemaking Procedure'. See MB Decision No 01-2022 of 2 May 2022 on the procedure to be applied by EASA for the issuing of opinions, certification specifications and other detailed specifications, acceptable means of compliance and guidance material ('Rulemaking Procedure'), and repealing Management Board Decision No 18-2015 ([EASA MB Decision No 01-2022 on the Rulemaking Procedure, repealing MB Decision 18-2015 \(by written procedure\) | EASA \(europa.eu\)](https://www.easa.europa.eu/en/management-board/decisions/mb-decision-no-01-2022-on-the-rulemaking-procedure-repealing-mb-decision-18-2015-by-written-procedure)).

³ [ToR RMT.0514 - Implementation of the latest CAEP amendments to ICAO Annex 16 Volumes I, II, and III | EASA \(europa.eu\)](https://www.easa.europa.eu/en/consultations/2023-09-to-r-rmt-0514-implementation-of-the-latest-caep-amendments-to-icao-annex-16-volumes-i-ii-and-iii)

⁴ Commission Regulation (EU) No 748/2012 of 3 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations (OJ L 224, 21.8.2012, p. 1) (<http://data.europa.eu/eli/reg/2012/748/oj>).

2. In summary — why and what

2.1. Why we need to act

The ICAO Council at the fifth meeting of its 228th Session on 20 March 2023 adopted Amendments 14, 11 and 2 to respectively Volumes I, II and III of Annex 16 to the Convention on International Civil Aviation (ICAO Annex 16), which became applicable on 1 January 2024. An overview of these amendments is provided in Appendix 1.

These amendments do not modify the noise limits or emissions maximum levels that a product shall comply with for certification. However, they improve and clarify the SARPs for a consistent and robust application of the certification procedures for aircraft noise, aircraft engine emissions and aeroplane CO₂ emissions.

Article 9(2) of the Basic Regulation, as amended by Regulation (EU) 2021/1087, sets out the essential requirements for environmental protection that refer to the requirements contained in the previous Amendments 13, 10 and 1 to respectively Volumes I, II and III of ICAO Annex 16.

Furthermore, EASA noticed some editorial errors in Regulation (EU) No 748/2012, for which the proposed corrections in Section 2.3 were not consulted under NPA 2023-09. They relate to inconsistent references and redundancy in Article 9 of Regulation (EU) No 748/2012 and to the missing title of Annex Ib (Part 21 Light).

2.2. What we want to achieve — objectives

The overall objectives of the EASA system are defined in Article 1 of the Basic Regulation. This Opinion is expected to contribute to achieving these overall objectives by addressing the issues described in Section 2.1.

The specific objective is to maintain a high uniform level of environmental protection, to contribute to European policies on climate change, air quality and noise reduction and to provide a level playing field for all stakeholders in the aviation market.

The transposition of the new amendments will avoid EASA Members States filing a difference with Volumes I, II and III of ICAO Annex 16 once the amending Regulations become applicable.

2.3. How we want to achieve it — overview of the amendments

a) Proposal

This Opinion proposes to:

- amend Article 9(2) of the Basic Regulation in order to refer to the new amendments;
- update Annex I (Part 21) to Regulation (EU) No 748/2012 to ensure the implementation of these amendments for the certification of products;
- provide other updates and corrections related to previous ICAO Annex 16 transpositions for consistent implementation of the applicable environmental protection requirements;
- correct editorial errors in Regulation (EU) No 748/2012.

b) Targeted applicability date

Due to the applicability date of 1 January 2024 of Amendments 14, 11 and 2 to respectively Volumes I, II and III of ICAO Annex 16, the targeted applicability of the Regulation amending Regulation (EU) 2018/1139 should be as soon as the amending Regulation is adopted (i.e. 20 days following their publication in the *Official Journal of the European Union*).

Since the proposed regulatory material for the Regulation amending Regulation (EU) No 748/2012 is based on the Commission Delegated Regulation (EU) 2024/1108 (see Chapter 4), the applicability date should not be before the date of applicability of that amending Regulation, i.e. 1 May 2025.

c) Legal basis

The legal basis for amending the references to the provisions of the Chicago Convention referred to in the first subparagraph of Article 9(2) of the Basic Regulation is Article 19(3) of that Regulation.

The legal basis for amending Regulation (EU) No 748/2012 is Article 19(1) of the Basic Regulation and specifically Article 19(1)(d) regarding the conditions for issuing type certificates and for changes to such certificates.

d) Rationale for the proposed regulatory material

Table 1 summarises the rationale behind the proposed amendments to the Basic Regulation, and Table 2 summarises the rationale behind the proposed amendments to Annex I to Regulation (EU) No 748/2012.

Table 1: Proposed amendments to Regulation (EU) 2018/1139

Article	Rationale behind the proposed regulatory text
Article 9(2) first subparagraph	<p>Amendment levels update</p> <p>Article 9(2) is amended to refer to Amendments 14, 11 and 2 to respectively Volumes I, II and III of the Annex 16 to the Chicago Convention.</p>

Table 2: Proposed amendments to Annex I to Regulation (EU) No 748/2012

Points/AMC/GM	Rationale behind the proposed regulatory text
21.B.85	<p>Applicable environmental protection requirements</p> <p>21.B.85 is amended to include the reference to the essential requirements in the first subparagraph of Article 9(2) of the Basic Regulation. This reference ensures that the applicable environmental protection requirements are those in the latest amendment levels of Volumes I, II and III of ICAO Annex 16 as adopted by the delegated act amending this subparagraph.</p> <p>The list of references to ICAO Annex 16 provided in 21.B.85(a)(1) to (a)(4) do not add any value to the applicable requirements in Article 9(2) of the Basic Regulation since these references can be easily found in ICAO Annex 16. Moreover, including these references may result in erroneous requirements due to typos. This is currently the case in 21.B.85(a)(1)(ii)(B) and (D) where ‘aeroplanes’ should read ‘aircraft’ and ‘helicopters’ respectively.</p>

	The reference to the first subparagraph of Article 9(2) of the Basic Regulation is necessary and sufficient. The list of references is therefore deleted.
21.A.15 21.A.91 21.A.93 21.A.147 21.A.243 21.A.245 21.A.247 21.A.251 21.A.432C 21.B.100	<p>Environmental compatibility</p> <p>‘Environmental compatibility’ is a new term introduced in the Basic Regulation that expresses the characteristic of a product that complies with the essential requirements for environmental protection.</p> <p>The term is introduced in Regulation (EU) No 748/2012 for the qualification of products that comply with the applicable environmental protection requirements in 21.B.85 (i.e. latest ICAO Annex 16 SARPs as implemented in Article 9 of the Basic Regulation).</p> <p>The use of this term permits the use of the adjectives ‘environmentally compatible’ or ‘environmentally incompatible’, and improves the drafting.</p> <p>Note: This new term was introduced in Annex Ib (Part 21 Light) with the adoption of Regulations (EU) 2022/1358⁵ and (EU) 2022/1361⁶.</p>
21.A.93 21.B.100 21.B.105 21.B.109 21.B.453	<p>‘Applicable’ environmental protection requirements</p> <p>‘Applicable’ is added in some points to clarify that it is about the environmental protection requirements in 21.B.85. Since 21.B.85 refers to Article 9 of the Basic Regulation, the applicable requirements are the applicable SARPs in ICAO Annex 16 as transposed in that article (i.e. the specific applicability criteria are determined in Volumes I, II and III of ICAO Annex 16).</p>
21.A.91	<p>Changes to a type certificate</p> <p>The amendments clarify the environmental protection criteria for the classification of changes, i.e. certified levels of noise and emissions (NO_x, CO, HC, smoke, nvPM for aircraft engines and CO₂ for aeroplanes) and other characteristics related to environmental compatibility (e.g. vented fuel standard in Volume II of ICAO Annex 16).</p> <p>‘Environmental characteristics’ is replaced with ‘environmental compatibility’ (see rationale on ‘environmental compatibility’) to improve the current sentence, which currently reads ‘... or other characteristics affecting ... its environmental characteristics’.</p> <p>Note: The proposed change in 21.A.91 is in line with 21L.A.63 in Annex Ib.</p>
21.A.432C(b) 21.A.433 21.B.450	<p>Repair design approval</p> <p>Subpart M of Sections A and B are amended for a consistent implementation of the environmental protection requirements for the repair design approval.</p> <p>The amendment in 21.A.432C(b) introduces the missing provision related to environmental protection for consistency with 21.B.453 and 21.B.100.</p>

⁵ Commission Delegated Regulation (EU) 2022/1358 of 2 June 2022 amending Regulation (EU) No 748/2012 as regards the implementation of more proportionate requirements for aircraft used for sport and recreational aviation (OJ L 205, 5.8.2022, p. 7) (http://data.europa.eu/eli/reg_del/2022/1358/oj).

⁶ Commission Implementing Regulation (EU) 2022/1361 of 28 July 2022 amending Regulation (EU) No 748/2012 as regards the certification, oversight and enforcement tasks of the competent authorities in the implementation of the rules concerning the organisations involved in the design and production of aircraft used for sport and recreational aviation (OJ L 205, 5.8.2022, p. 127) (http://data.europa.eu/eli/reg_impl/2022/1361/oj).

	<p>Note: These amendments are consistent with the requirements in 21L.A.205 in Annex Ib.</p> <p>The provision related to environmental protection is reintroduced in 21.A.433(a)(1) since it was incorrectly deleted with the adoption of Regulation (EU) 2019/897⁷ amending Regulation (EU) No 748/2012. The provision is also added in 21.A.433(a)(2) for consistency.</p> <p>The reference to ‘environmental protection requirements’ is deleted from the title of 21.B.450 for consistency with the provision. 21.B.450 relates to amendments to the type-certification basis necessary to maintain a level of safety equal to that previously established. This provision is linked to the last part of 21.A.433(a)(1) and relates to airworthiness only.</p>
21.B.70	<p>Certification specifications</p> <p>21.B.70 implements Article 76(3) of the Basic Regulation and provides the legal basis in Annex I (Part 21) to Regulation (EU) No 748/2012 for the issuance of certification specifications (CSs). CSs can only be used for those situations where the Basic Regulation provides for the establishment of a certification basis, i.e. for airworthiness and operational suitability data only (Article 11 and Article 19(1)(b)(i) and (ii)). The Basic Regulation does not provide for the establishment of an environmental protection certification basis. Instead, it provides for the applicable environmental protection requirements as per Article 9. As such, it is not possible to issue CSs for environmental protection, and 21.B.70 is amended to delete the reference to environmental protection.</p> <p>Additional information</p> <p>21.B.70 was inserted with Regulation (EU) 2019/897 to replace the former 21.A.16A related to CSs for airworthiness and operational suitability data. The former 21.A.18(c) provided for the issuance of CSs that provided for acceptable means to demonstrate compliance with the applicable environmental protection requirements laid down in 21.A.18(a) and (b). The intent of this provision was to use the CSs as acceptable means of compliance and not as certification specifications. When gathering the provisions related to CSs in 21.B.70 with Regulation (EU) 2019/897, the environmental protection CSs were automatically included in this point although they were acceptable means to demonstrate compliance.</p> <p>CS-34, CS-36 and CS-CO₂ were issued to clarify which Appendices to Annex 16 should be used as acceptable means to demonstrate compliance to the applicable environmental requirements, since these Appendices were excluded from the essential requirements in Article 6 of the former Basic Regulations. These CSs were not the applicable environmental protection requirements designated by EASA for the certification of products and as such were not relevant for the certification basis of the product. The relevant basis for the certification of the product was the level of amendment of Vol. I, II and III of Annex 16 (which are referred to in the TCDS and TCDSN).</p> <p>Article 9 of the current Basic Regulation provides for the applicable environmental protection requirements in Annex 16 including the Appendices.</p>

⁷ Commission Delegated Regulation (EU) 2019/897 of 12 March 2019 amending Regulation (EU) No 748/2012 as regards the inclusion of risk-based compliance verification in Annex I and the implementation of requirements for environmental protection (OJ L 144, 3.6.2019, p. 1) (http://data.europa.eu/eli/reg_del/2019/897/oj).

	The level of amendment of Vol. I, II and III of Annex 16 is the key element for the determination of the applicable environmental protection requirements for certification. Therefore, the amendment to 21.B.70 has no implication on the compliance demonstration for the applicant for a type certificate or a restricted type certificate.
Title of Regulation (EU) No 748/2012 (*) Article 1, para 1, introductory sentence (*) 21.A.165 21.A.701(a)	‘Environmental protection’ v ‘environmental’ ‘Protection’ is added after ‘environmental’ when the provision relates to environmental protection and not to environmental conditions, which are outside the aircraft and have an impact on airworthiness (e.g. lightning strikes). (*): Not proposed in NPA 2023-09
Appendix VII to Annex I (EASA Form 45)	Noise certificates The reference to the Basic Regulation in Appendix VII needs to be updated to refer to Article 14(1) of the Basic Regulation for the issuance of a noise certificate. For consistency with Block 5, the headers of Blocks 7 and 8 are amended to specify that the blocks should contain both the manufacturer and the manufacturer designation.
21.A.95(b)(3)	‘Environmental protection requirements’ is added for consistency with 21.A.95(b)(1). The compliance with these requirements shall also be declared and its justification recorded in the compliance documents.

e) Editorial corrections

Table 3 provides the rationale behind the proposed amendments to Regulation (EU) No 748/2012 to resolve the editorial errors identified in Section 2.1.

Table 3: Proposed amendments to Regulation (EU) No 748/2012 for editorial corrections

Topic	Rationale behind the proposed regulatory text
Article 9	‘control and monitoring unit’ (CMU) is in added paragraph 1, which misses the information on the installation in the CMU. Paragraphs 7 and 8 are merged (into paragraph 7) to contain the provisions for the production capabilities under Part 21 Light (i.e. for Subparts G and R organisations). It is drafted similarly to paragraph 1, which contains the provisions for the production organisation capabilities under Part 21 (i.e. for Subparts F and G organisations). The proposal ensures consistency of references and avoids redundancies.
Annex Ib	The title of Annex Ib is added before the table of contents since it was omitted in Annex II of Regulation (EU) 2022/1358, which created Annex Ib starting directly with the table of contents.

2.4. What are the stakeholders' views

The adopted Amendments 14, 11 and 2 to Volumes I, II and III respectively of ICAO Annex 16 arise from the recommendations of the 12th meeting of the Committee on Aviation Environmental Protection (CAEP/12).

These recommendations are the outcome of the work conducted during the 3 years preceding the meeting in accordance with the CAEP/12 Work Programme, and are the result of consensus discussions, which involved the stakeholders concerned with the subject matter together with representatives from civil aviation authorities.

During the consultation of the draft regulatory material EASA received 13 comments (including 6 comments on the quality of the NPA) from 5 national competent authorities (NCAs), and 21 comments from 7 representatives of the industry.

One third of the comments were accepted or partially accepted, a quarter of the comments were not accepted, and nearly half of the comments were noted.

The amendments proposed with this Opinion were positively received, except for the proposed amendments to EASA Form 45, for which EASA did not accept the comment since the reference to the Basic Regulation must be updated. The proposed amendment to 21.B.70 raised some questions to which EASA provides clarifications on the current environmental protection certification practice and the status of CS-34, CS-36 and CS-CO2.

The comments did not trigger any change to the regulatory text proposed in NPA 2023-09 for the amendments to Regulation (EU) 2018/1139 and Regulation (EU) No 748/2012.

The details of the comments and responses are provided in CRD 2023-09.

Note: Most of the comments that EASA did not accept are related to guidance material to Annex I (Part 21) to Regulation (EU) No 748/2012. About one third of the comments impacts the content of guidance material for clarifications and improvement of the regulatory text. Guidance material is outside the scope of this Opinion and will be covered under the Decision that will be issued to support the application of Regulation (EU) No 748/2012.

3. What are the expected benefits and drawbacks of the regulatory material

To address the issue described in Section 2.1, there are no alternative options to rulemaking for the implementation of Amendments 14, 11 and 2 to respectively Volumes I, II and III of ICAO Annex 16 into the EU regulatory framework.

EASA based its impact assessment on the assessment carried out by ICAO. A summary is provided in Table 4.

Table 4: Impacts

	Impact	Rationale
Safety	None	
Security	None	
Efficiency	None	
Environmental protection	Positive	The new amendments add clarity for a straightforward implementation of the new SARPs by the manufacturers. Although no new noise limits or emissions maximum levels were adopted, the implementation of the provisions within the EU regulatory framework will provide a level playing field for all actors in the aviation market and will maintain a high uniform level of environmental protection.
Cost for the Agency	Negligible	One-off cost for the implementation of the provisions within the EU regulatory framework.
Cost for industry	Negligible	One-off cost for the adaptation of the internal processes for the demonstration of compliance with the new amendments.
Cost for Member States	Negligible	One-off cost for the adaptation of Form 45.

The environmental protection benefit of the proposal outweighs the negligible cost impact.

EASA also assessed the impacts of the proposed regulatory material to ensure that the regulatory material delivers its full benefits with minimum drawbacks.

The proposed regulatory material has been developed in view of the 'Better regulation' principles, and in particular the 'Regulatory fitness' principles.

4. Proposed regulatory material

The regulatory material is proposed as annexes to this Opinion and considers the amendments contained in Commission Delegated Regulation (EU) 2024/1108⁸.

⁸ Commission Delegated Regulation (EU) 2024/1108 of 13 March 2024 amending Regulation (EU) No 748/2012 as regards the initial airworthiness of unmanned aircraft systems subject to certification and Delegated Regulation (EU) 2019/945 as regards unmanned aircraft systems and third-country operators of unmanned aircraft systems (OJ L, 2024/1108, 23.5.2024) (http://data.europa.eu/eli/reg_del/2024/1108/oj).



5. Monitoring and evaluation

EASA does not plan any specific monitoring or evaluation provisions for the transposition of Amendments 14, 11 and 2 to respectively Volumes I, II and III of ICAO Annex 16. However, the efficiency of actions contained in the EPAS in relation to environmental protection (i.e. including RMT.0514) is continuously monitored as part of the European Aviation Environmental Report⁹. This report is updated every 3 years and provides indicators on the environmental protection performance of the civil aviation sector in the EU.

⁹ [Downloads | EASA Eco \(europa.eu\)](#)



6. Proposed actions to support implementation

No specific action to support the implementation of the proposed amendments is foreseen.



7. References

- ICAO State Letter AN 1/17.14 – 23/35, 'Adoption of Amendment 14 to Annex 16, Volume I', 27 April 2023
- ICAO State Letter AN 1/17.14 – 23/36, 'Adoption of Amendment 11 to Annex 16, Volume II', 27 April 2023
- ICAO State Letter AN 1/17.14 – 23/37, 'Adoption of Amendment 2 to Annex 16, Volume III', 28 April 2023
- Annex 16 'Environmental Protection' to the Convention on International Civil Aviation:
 - Amendment 14 to Volume I 'Aircraft Noise',
 - Amendment 11 to Volume II 'Aircraft Engine Emissions',
 - Amendment 2 to Volume III 'Aeroplane CO₂ Emissions'.
 - ICAO Doc 9501 'Environmental Technical Manual', Volumes I, II and III



Appendix 1 — Overview of Amendments 14, 11 and 2 to respectively Volumes I, II and III of ICAO Annex 16

1. Amendment 14 to Volume I of ICAO Annex 16 on Environmental Protection — Aircraft Noise

The main amendments are:

- alignment with ICAO Doc 8143, Part II ‘Formulation of Proposals for International Standards, Recommended Practices and Procedures’ for the formulation of SARPs, especially the proper use of modal verbs;
- guidelines for acquiring helicopter hover noise data;
- addressing of the limitations of specifications with respect to the adjustment of test-day sound pressure levels (SPL) to reference conditions;
- editorial corrections.

2. Amendment 11 to Volume II of ICAO Annex 16 on Environmental Protection — Aircraft Engine Emissions

The main amendments are:

- restructuring in accordance with ICAO Doc 8143, Part II ‘Formulation of Proposals for International Standards, Recommended Practices and Procedures’;
- language consistency updates and consistent use of notes and recommendations;
- applicability language improvement (e.g. for smoke number and nvPM standards);
- ‘equivalent procedure’ definition;
- definitions, descriptions, references and language improvements;
- nvPM measurement procedure improvements in accordance with SAE ARP 6320A and AIR 6241A;
- editorial and technical corrections for clarity and consistency across the document.

3. Amendment 2 to Volume III of Annex 16 on Environmental Protection — Aeroplane CO₂ Emissions

The amendment concerns the improvement of definitions, descriptions, references and language (e.g. to avoid potential misinterpretation) and introduces additional clarifications related to the reference geometric factor (RGF).