新規試験法提案書

皮膚感作性試験代替法
ARE-Nrf2 luciferase LuSens test method
(LuSens test method)

令和元年11月

国立医薬品食品衛生研究所

新規試験法提案書

令和元年 11 月 18 日

No. 2019-02

皮膚感作性試験代替法　ARE-Nrf2 luciferase LuSens test method (LuSens test method) に関する提案

令和元年 11 月 14 日に国立医薬品食品衛生研究所にて開催された新規試験法評価会議（通称：JaCVAM 評価会議）において以下の提案がなされた。

提案内容： 本試験法は、JaCVAM 皮膚感作性試験資料編纂委員会により、KeratinoSens™ 試験法とほぼ同等の予測性と評価されているため、本試験法で陽性の結果が得られた場合、その化学物質を強い感作性物質に分類することは行政上可能である。しかしながら、KeratinoSens™ 試験法同様、稀に偽陽性の結果が生じることに留意しなければならない。一方、本試験法で陰性の結果が得られても偽陰性の可能性もあり、本試験法単独でその皮膚感作性を評価することは難しい。本試験法は、その特性を十分に理解した上で、その他の情報源と組み合わせて適切に評価することが、行政的な受け入れに必要である。

この提案書は、皮膚感作性試験資料編纂委員会によりまとめられた文書を用いて、JaCVAM評価会議が評価および検討した結果、その有用性が確認されたことから作成された。

以上の理由により、行政当局の安全性評価方法として皮膚感作性試験代替法　LuSens test method の使用を提案するものである。

大野泰雄

JaCVAM 評価会議　議長

平林容子

JaCVAM 運営委員会　委員長

JaCVAM 評価会議

大 野 泰 雄　（公益財団法人　木原記念横浜生命科学振興財団）：座長
五十嵐良明　（国立医薬品食品衛生研究所）
石 井 雄 二　（国立医薬品食品衛生研究所　安全性生物試験研究センター）
稲 若 邦 文　（日本化学工業協会）
井 上 智 彰　（日本免疫毒性学会）
今 井 教 安　（日本動物実験代替法学会）
岩瀬裕美子　（日本製薬工業協会）
久 保 文 宏　（独立行政法人　医薬品医療機器総合機構）
杉山真理子　（日本化粧品工業連合会）*
中 村 るりこ　（独立行政法人　製品評価技術基盤機構）
西 川 秋 佳　（国立医薬品食品衛生研究所　病理部 / 済生会宇都宮病院）
西 村 次 平　（独立行政法人　医薬品医療機器総合機構）
沼 澤　聡　（日本毒性学会）
平 林 容 子　（国立医薬品食品衛生研究所　安全性生物試験研究センター）
廣 田 衞 彦　（日本化粧品工業連合会）**
増 村 健 一　（日本環境変異原学会）
横 関 博 雄　（日本皮膚免疫アレルギー学会）

任期：平成 30 年 4 月 1 日～令和 2 年 3 月 31 日
*：平成 30 年 4 月 1 日～平成 31 年 3 月 31 日
**：平成 31 年 4 月 1 日～令和 2 年 3 月 31 日

JaCVAM 運営委員会

平 林 容 子	（国立医薬品食品衛生研究所　安全性生物試験研究センター）：委員長
池 田 三 恵	（独立行政法人　医薬品医療機器総合機構）
石 井 孝 司	（国立感染症研究所）
小川久美子	（国立医薬品食品衛生研究所　安全性生物試験研究センター　病理部）
奥 田 晴 宏	（国立医薬品食品衛生研究所）
諫 田 泰 成	（国立医薬品食品衛生研究所　安全性生物試験研究センター　薬理部）
北 嶋　聡	（国立医薬品食品衛生研究所　安全性生物試験研究センター　毒性部）
高 木 篤 也	（国立医薬品食品衛生研究所　安全性生物試験研究センター　毒性部　動物管理室）
高 畑 正 浩	（厚生労働省　医薬・生活衛生局　医薬品審査管理課）
束 野 正 明	（厚生労働省　医薬・生活衛生局　医薬品審査管理課　化学物質安全対策室）
野 坂 佳 伸	（厚生労働省　医薬・生活衛生局　医薬品審査管理課　化学物質安全対策室）
広 瀬 明 彦	（国立医薬品食品衛生研究所　安全性生物試験研究センター　安全性予測評価部）
笛 木　修	（独立行政法人　医薬品医療機器総合機構）
渕 岡　学	（厚生労働省　医薬・生活衛生局　医薬品審査管理課　化学物質安全対策室）
本 間 正 充	（国立医薬品食品衛生研究所　安全性生物試験研究センター　変異遺伝部）
足利太可雄	（国立医薬品食品衛生研究所　安全性生物試験研究センター　安全性予測評価部第二室）：事務局
小 島　肇	（国立医薬品食品衛生研究所　安全性生物試験研究センター　安全性予測評価部第二室）：事務局

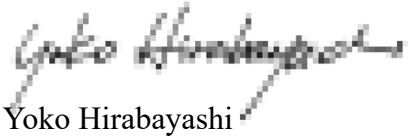
JaCVAM statement on the ARE-Nrf2 luciferase LuSens test method for skin sensitization (LuSens test method)

At a meeting held on 14 November 2019 at the National Institute of Health Sciences (NIHS) in Kanagawa, Japan, the Japanese Center for the Validation of Alternative Methods (JaCVAM) Regulatory Acceptance Board unanimously endorsed the following statement:

Proposal: A review of the LuSens test method by the JaCVAM Skin Sensitization Editorial Committee has determined that the LuSens test method exhibits a predictive capacity roughly equivalent to that of the KeratinoSens™ test method and that test chemicals yielding positive results in LuSens testing should in a regulatory context be considered strong sensitizers belonging to Category 1 of the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (UN GHS). At the same time, however, it should be remembered that, as with the KeratinoSens™ test method, LuSens testing does in rare cases yield false positive results. Conversely, LuSens testing also yields false negatives, which means that it would be unreasonable to use it as a standalone test for predicting skin sensitization potential. We therefore conclude that the use of the LuSens test method in a regulatory context requires a thorough understanding of the assay's strengths and weaknesses as a prerequisite to its application within an integrated approach to testing and assessment (IATA) that will also take into account information from other sources.

This statement was prepared to acknowledge that the results of a review and study by the JaCVAM Regulatory Acceptance Board have confirmed the usefulness of this assay.
Based on the above, we propose the LuSens test method as a useful means for estimating skin sensitization by regulatory agencies.

Yasuo Ohno
Chairperson
JaCVAM Regulatory Acceptance Board



Yoko Hirabayashi
Chairperson
JaCVAM Steering Committee

November 18, 2019

The JaCVAM Regulatory Acceptance Board was established by the JaCVAM Steering Committee and is composed of nominees from industry and academia.

This statement was endorsed by the following members of the JaCVAM Regulatory Acceptance Board:

Mr. Yasuo Ohno (Kihara Memorial Yokohama Foundation for the Advancement of Life Sciences): Chairperson
Ms. Yoko Hirabayashi (Center for Biological Safety and Research: CBSR, National Institute of Health Sciences: NIHS)
Mr. Morihiko Hirota (Japan Cosmetic Industry Association)**
Mr. Yoshiaki Ikarashi (NIHS)
Mr. Noriyasu Imai (Japanese Society for Alternatives to Animal Experiments)
Mr. Kunifumi Inawaka (Japan Chemical Industry Association)
Mr. Tomoaki Inoue (Japanese Society of Immunotoxicology)
Mr. Yuji Ishii (CBSR, NIHS)
Ms. Yumiko Iwase (Japan Pharmaceutical Manufacturers Association)
Mr. Fumihiro Kubo (Pharmaceuticals and Medical Devices Agency)
Mr. Kenichi Masumura (Japanese Environmental Mutagen Society)
Ms. Ruriko Nakamura (National Institute of Technology and Evaluation)
Mr. Akiyoshi Nishikawa (CBSR, NIHS/ Saiseikai Utsunomiya Hospital)
Mr. Jihei Nishimura (Pharmaceuticals and Medical Devices Agency)
Mr. Satoshi Numazawa (Japanese Society of Toxicology)
Ms. Mariko Sugiyama (Japan Cosmetic Industry Association)*
Mr. Hiroo Yokozeki (Japanese Society for Cutaneous Immunology and Allergy)

Term: From 1st April 2018 to 31st March 2020
*: From 1st April 2018 to 31st March 2019
**: From 1st April 2019 to 31st March 2020

This statement was endorsed by the following members of the JaCVAM steering Committee after receiving the report from the JaCVAM Regulatory Acceptance Board:

Ms. Yoko Hirabayashi (CBSR, NIHS): Chairperson
Mr. Manabu Fuchioka (Ministry of Health, Labour and Welfare)
Mr. Osamu Fueki (Pharmaceuticals and Medical Devices Agency)
Mr. Akihiko Hirose (Division of Risk Assessment, CBSR, NIHS)
Mr. Masamitsu Honma (Division of Genetics and Mutagenesis, CBSR, NIHS)
Ms. Mie Ikeda (Pharmaceuticals and Medical Devices Agency)
Mr. Koji Ishii (National Institute of Infectious Diseases)
Mr. Yasunari Kanda (Division of Pharmacology, CBSR, NIHS)
Mr. Satoshi Kitajima (Division of Toxicology, CBSR, NIHS)
Mr. Yoshinobu Nosaka (Ministry of Health, Labour and Welfare)
Ms. Kumiko Ogawa (Division of Pathology, CBSR, NIHS)
Mr. Haruhiro Okuda (NIHS)
Mr. Atsuya Takagi (Animal Management Section of the Division of Toxicology, CBSR, NIHS)
Mr. Masahiro Takahata (Ministry of Health, Labour and Welfare)
Mr. Masaaki Tsukano (Ministry of Health, Labour and Welfare)
Mr. Takao Ashikaga (Division of Risk Assessment, CBSR, NIHS): Secretary
Mr. Hajime Kojima (Division of Risk Assessment, CBSR, NIHS): Secretary

皮膚感作性試験代替法
ARE-Nrf2 luciferase LuSens test method (LuSens test method)

目　　次

評価会議報告書

皮膚感作性試験代替法

ARE-Nrf2 luciferase LuSens test method (LuSens test method)

JaCVAM 評価会議

令和元年（2019 年）10 月 2 日

JaCVAM 評価会議

大 野 泰 雄	（公益財団法人　木原記念横浜生命科学振興財団）：座長
五十嵐良明	（国立医薬品食品衛生研究所）
石 井 雄 二	（国立医薬品食品衛生研究所　安全性生物試験研究センター）
稲 若 邦 文	（日本化学工業協会）
井 上 智 彰	（日本免疫毒性学会）
今 井 教 安	（日本動物実験代替法学会）
岩瀬裕美子	（日本製薬工業協会）
久 保 文 宏	（独立行政法人　医薬品医療機器総合機構）
杉山真理子	（日本化粧品工業連合会）*
中 村 るりこ	（独立行政法人　製品評価技術基盤機構）
西 川 秋 佳	（国立医薬品食品衛生研究所　病理部 / 済生会宇都宮病院）
西 村 次 平	（独立行政法人　医薬品医療機器総合機構）
沼 澤　　聡	（日本毒性学会）
平 林 容 子	（国立医薬品食品衛生研究所　安全性生物試験研究センター）
廣 田 衞 彦	（日本化粧品工業連合会）**
増 村 健 一	（日本環境変異原学会）
横 関 博 雄	（日本皮膚免疫アレルギー学会）

任期：平成 30 年 4 月 1 日～令和 2 年 3 月 31 日

*：平成 30 年 4 月 1 日～平成 31 年 3 月 31 日

**：平成 31 年 4 月 1 日～令和 2 年 3 月 31 日

ARE[1]-Nrf2[2] luciferase LuSens test method（以下、本試験法）は、既に経済協力開発機構（OECD）試験法ガイドライン（TG）442D に登録されている ARE-Nrf2 luciferase KeratinoSens™ test method（KeratinoSens™ 試験法）と同様に、化学物質の皮膚感作性を予測する試験法である。本試験法は、ケラチノサイトにおける炎症性応答の一つである Keap1-Nrf2-ARE pathway を利用したレポーターアッセイである。本試験法は、開発者（BASF 社）によるインハウス試験および外部 4 機関の参加による TG 422D の Performance standards（性能標準）に基づく多施設バリデーション研究が行われ、その結果を EURL ECVAM Scientific Advisory Committee（ESAC）が第三者評価し、2018 年 6 月に OECD TG 442D Appendix 1B として追記された。JaCVAM 評価会議は、皮膚感作性試験資料編纂委員会により作成された皮膚感作性試験評価報告書 ARE-Nrf2 luciferase LuSens test method （LuSens test method）[1)] を基に本試験法の妥当性について検討した。

１．試験法の定義

名称：ARE-Nrf2 luciferase LuSens test method

代替する対象毒性試験：モルモットを用いる皮膚感作性試験（OECD TG 406）およびマウスを用いる局所リンパ節試験 [LLNA (OECD TG 429)、LLNA:DA (OECD TG 442A)、LLNA:BrdU-ELISAor -FCM (OECD TG 442B)]

試験法の概略：本試験法 [2)]は、既に OECD TG 442D に登録されている KeratinoSens™ 試験法と同様、Keap1-Nrf2- ARE pathway を利用したレポーターアッセイである。Keap1-Nrf2- ARE pathway は、転写因子 Nrf2 の抑制因子である Keap1 および ARE が関係する遺伝子発現経路である。Nrf2 と Keap1 の結合は、ARE に依存して発現する遺伝子群の発現量を制御している。Keap1 のシステイン残基に求電子性の化学物質が結合すると、Nrf2 は Keap1 から解離し、核内へ移行して DNA 上の ARE に結合する。その結果、下流の遺伝子群の発現が誘導され、化学物質による障害から細胞を保護するために機能する。多くの皮膚感作性物質が Keap1-Nrf2-ARE pathway を活性化することが知られており [3, 4)]、*in vitro* 感作性試験法の開発に利用されている。

KeratinoSens™ 試験法 [5)]では、Aldo-Keto Reductase Family 1 Member C2（AKR1C2）遺伝子の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入した HaCaT 細胞（ヒトケラチノサイト系培養細胞）を用いるのに対し、本試験法 [6)]ではラットの NADPH:quinone oxidoreductase 1（NQO1）遺伝子由来の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入したヒトケラチノサイト系培養細胞（株名は不詳）を試験に使用する。いずれの方法も化学物質による Keap1-Nrf2-ARE pathway の活性化に伴って誘導されるルシフェラーゼの活性を、基質を添加して発光強度を測定することにより、化学物質の皮膚感作性を評価する方法である。

---

[1] ARE: Antioxidant response element
[2] Nrf2: Nuclear factor (erythroid-derived 2)-like 2

２．評価に用いた資料および評価内容の科学的妥当性

本試験法は、EURL ECVAM によるバリデーション研究は行われず、BASF 社によるインハウス試験および外部 4 機関の参加による性能標準に基づくバリデーション研究が行われ[6-8]、その結果が ESAC によって評価されている[9]。それらの公表資料を基に、JaCVAM 皮膚感作性試験資料編纂委員会は、本試験法の皮膚感作性試験代替法としての科学的妥当性について、ESAC の評価結果と同様に、本試験法と KeratinoSens™ 試験法の予測性はほぼ同等と評価している[1]。また、同様の原理に基づく試験法である KeratinoSens™ 試験法が科学的に妥当であることは、平成 27 年に JaCVAM 評価会議において既に認められており[10]、本試験法も科学的に妥当であると考える。

３．本試験法の有用性と適用限界

本試験法はケラチノサイトにおける ARE 活性化による遺伝子発現を指標にした試験法であることから、同様に Keap1-Nrf2-ARE pathway を利用したレポーターアッセイである KeratinoSens™ 試験法と基本的な操作は同様である。本試験法における LuSens は開発者より無償提供される。

本試験法は、さまざまな構造や物理化学的性質を有する化学物質に適用可能であることが示されている[6]。また、本試験法に用いる溶媒に溶解する、もしくは安定に分散する化合物は適用可能であるが、適用可能最高濃度においても細胞毒性がみられない場合（細胞生存率 70%以上）の陰性結果は「評価不能」とされる。

本試験法は、KeratinoSens™ 試験法と同様、リジン残基特異的に結合する物質は偽陰性と判定されることが考えられ、注意が必要である。本試験法に使用する細胞株の代謝能は限定的であり、プロハプテンおよびプレハプテンは偽陰性となる可能性がある。一方、感作性のないケミカルストレッサー（例えば酸化ストレスを誘導する物質）は KeratinoSens™ 試験法と同様、偽陽性となる可能性がある。さらに、ルシフェラーゼに干渉する化学物質も評価に影響する可能性がある。陰性対照 8 物質および陽性対照 12 物質を用いて 5 施設で実施されたバリデーション研究では、感度 92%、特異度 75%、正確度 85%であり、特異度において性能標準の基準（80%以上）を満たさなかった。従って、本試験法において陽性の結果が得られた場合にも、偽陽性の可能性があることに留意しなければならない。開発者によるインハウス試験においては、ヒトデータ（69 物質）と比較した場合、感度は 83%、特異度は 78%、正確度は 81%、LLNA データ（72 物質）と比較した場合、感度は 75%、特異度は 71%、正確度は 74%であった[6]。偽陰性となった 13 物質中 2 物質（Phthalic anhydride 及び Propyl gallate）は UN GHS 1A に区分される物質であった。以上より、本試験法単独では皮膚感作性の予測性は不十分であり、証拠の重み付けや他の試験法と組み合わせでの評価を推奨する 。

本試験法は、Integrated Approaches to Testing and Assessment（IATA）において他の試験法と組み合わせることにより、感作性物質と非感作性物質との区別に使用することが可能である。しかし、本試験法単独での感作性強度分類や UN Globally Harmonized System of

Classification and Labeling of Chemicals（UN GHS）のサブカテゴリー分類への応用には適さない。

上記の様々な限界を勘案し、本試験法は単独での皮膚感作性の判定には不十分であるが、証拠の重み付けや他の試験法との組合せで用いることにより、化学物質の感作性を判断する上で重要な情報を与える。

４．目的とする物質又は製品の毒性を評価する試験法としての、社会的受け入れ性および行政上の利用の可能性

社会的受け入れ性：

本試験法は、KeratinoSens™ 試験法同様、細胞培養の技術と 96 ウェル対応のルミノメーターがあれば容易に実施可能である。実施に必要なランニングコストも KeratinoSens™ 試験法と同様、約 1.5 万円と見積もられ、LLNA（同約 10 万円）より低額であり、h-CLAT（同約 2 万円）や U-SENS™（同約 1.8 万円）とほぼ同程度であった。さらに本試験法は細胞の入手にあたりライセンス契約を結ぶ必要がなく、輸送費実費負担により細胞株の入手が可能である。本試験法の実施と結果の解釈に当たっては、化学物質の性質と本試験法の適用限界を見極める必要があるが、本試験法は皮膚感作性を有する多くの化学物質が ARE により制御されている遺伝子の発現を誘導するという皮膚感作性発現機序における重要なイベントを検出しており、化学物質の皮膚感作性を考える上で重要な情報を与える。さらに生きた動物を用いないという点で 3Rs の精神に合致していることから、本試験法の社会的受け入れ性は高い。

行政上の利用性：

本試験法は、JaCVAM 皮膚感作性試験資料編纂委員会により、KeratinoSens™ 試験法とほぼ同等の予測性と評価されているため、本試験法で陽性の結果が得られた場合、その化学物質を強い感作性物質である UN GHS 区分 1 に分類することは行政上可能である。しかしながら、KeratinoSens™ 試験法同様、稀に偽陽性の結果が生じることに留意しなければならない。一方、本試験法で陰性の結果が得られても偽陰性の可能性もあり、本試験法単独でその皮膚感作性を評価することは難しい。本試験法は、その特性を十分に理解した上で、IATA を構成するその他の情報源と組み合わせて適切に評価することが、行政的な受け入れに必要である。

引用文献

1) JaCVAM 皮膚感作性試験資料編纂委員会：皮膚感作性試験評価報告書 ARE-Nrf2 luciferase LuSens test method (LuSens test method)　（令和元年 9 月 30 日）
2) OECD (2018) Key event based test guideline. In vitro skin sensitization assay addressing the AOP key event on keratinocyte activation. OECD Guideline for the Testing of Chemicals. No.442D, OECD, Paris. Accessible at: https://www.oecd-ilibrary.org/docserver/9789264229822-en.pdf?expires=1540286232&id=id&accname=guest&checksum=F9DC614E0BBF02D46223C8FCABCFBA5E
3) Ade N, Leon F, Pallardy M, Peiffer JL, Kerdine-Romer S, Tissier MH, Bonnet PA, Fabre I, Ourlin JC; HMOX1 and NQO1 genes are upregulated in response to contact sensitizers in dendritic cells and THP-1 cell line: role of the Keap1/Nrf2 pathway. Toxicol Sci. 2009; 107(2):451-60.
4) Vandebriel RJ, Pennings JL, Baken KA, Pronk TE, Boorsma A, Gottschalk R, Van Loveren H; Keratinocyte gene expression profiles discriminate sensitizing and irritating compounds. Toxicol Sci. 2010; 117(1):81-9.
5) Emter R, Ellis G, Natsch A; Performance of a novel keratinocyte-based reporter cell line to screen skin sensitizers in vitro, Toxicol Applied Pharmacol, 2010; 245: 281-290.
6) Ramirez T, Mehling A, Kolle SN, Wruck CJ, Teubner W, Eltze T, Aumann A, Urbisch D, van Ravenzwaay B, Landsiedel R; LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification, Toxicol In Vitro, 2014; 28(8):1482-97.
7) Kolle SN; Corrigendum to “LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification.” by Ramirez, et al., Toxicol In Vitro. 2014; Dec; 28(8):1482–97. doi: 10.1016/j.tiv.2014.08.002
8) Ramirez T., Stein N., Aumann A., Remus T., Edwards A., Norman K.G., Ryan C., Bader J.E., Fehr M., Burleson F., Foertsch L., Wang X., Gerberick F., Beilstein P., Hoffmann S., Mehling A., van Ravenzwaay B., Landsiedel R.; Intra- and inter-laboratory reproducibility and accuracy of the LuSens assay: A reporter gene-cell line to detect keratinocyte activation by skin sensitizers, Toxicol. In Vitro, 2016; 32: 278-286.
9) ESAC (2016). ESAC Opinion on the BASF-coordinated Performance Standards-based validation of the LuSens test method for skin sensitization testing. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103706/esac_opinion_2016-04_lusens_final.pdf
10) JaCVAM 評価会議　評価会議報告書 ARE-Nrf2 Luciferase Test Method（角化細胞株レポーターアッセイ）（平成 27 年 4 月 30 日）

評価報告書

皮膚感作性試験代替法

ARE-Nrf2 luciferase LuSens test method (LuSens test method)

皮膚感作性試験資料編纂委員会

令和元年（2019 年）9 月 30 日

皮膚感作性試験資料編纂委員会

小 島 幸 一　（一般財団法人　食品薬品安全センター）
足利太可雄　（国立医薬品食品衛生研究所）
安 達 玲 子　（国立医薬品食品衛生研究所）
佐 藤 一 博　（国立大学法人　福井大学）
瀬 崎 拓 人　（三井化学株式会社）
武 吉 正 博　（一般財団法人　化学物質評価研究機構）
福 山 朋 季　（麻布大学）

要旨

皮膚感作性は化学物質の安全性評価において重要な評価項目であり、モルモットやマウスを用いた動物実験によって評価されてきた。近年 EU における欧州化学品規制では、コンピューターを用いた定量的構造活性相関（Quantitative Structure-Activity Relationship、以下、QSAR と記す）モデルや *in vitro* 試験法による安全性評価が推奨されており、動物実験によって安全性が評価された成分を含む化粧品の販売が禁止（2013 年 3 月全面施行）されたことから、*in vitro* 試験法の開発が強く望まれている。

ARE-Nrf2 luciferase LuSens test method（以下、LuSens test method と記す）は、既に経済協力開発機構（以下、OECD と記す）試験法ガイドライン（以下、TG と記す）TG 442D に登録されている ARE-Nrf2 luciferase KeratinoSens™ test method（以下、KeratinoSens™ と記す）と同様に、感作性発現機序における第 2 の Key event（「2. 試験法の原理」参照）に対応する試験法であり、基本原理は Keap1-Nrf2-ARE pathway を利用したレポーターアッセイである。

LuSens test method は、開発者（BASF 社）によるインハウス試験および外部 4 機関の参加による TG 442D の Performance standards（以下、性能標準と記す）に基づくバリデーション研究が行われ、その結果を EURL ECVAM Scientific Advisory Committee（以下、ESAC と記す）が第三者評価し、2018 年 6 月に OECD の TG に追記された（OECD TG 442D Appendix 1B）。

本報告書は、OECD TG 442D Appendix 1B および関連資料などをもとに、試験手順をまとめ、有用性や限界などについて評価したものである。

性能標準に記載されている 20 物質のうちの 12 物質を用いた 3 機関による施設内再現性は 100%であった。性能標準に記載されている 20 物質を用いて開発者を含む 5 施設において、少なくとも 1 物質につき 3 施設以上で実施した施設間再現性は 100%であった。いずれも性能標準で要求している 80%以上であることという基準を満たしていた。

開発者によるインハウス試験においては、ヒトデータ（69 物質）と比較した場合、感度は 83%、特異度は 78%、正確度は 81%、LLNA データ（72 物質）と比較した場合、感度は 75%、特異度は 71%、正確度は 74%であった。

性能標準に記載されている 20 物質を用いて行った LuSens test method のバリデーション研究と KeratinoSens™ のバリデーションデータを比較したところ、両試験法とも 20 物質中 17 物質を正しく判定しており、正確度は 85%であった。両試験法の試験結果の詳細は、ESAC で評価され、両試験法についてどちらか一方を推奨する科学的な根拠はないとされており、両試験法の予測性はほぼ同等と本委員会では評価した。

LuSens test method は、KeratinoSens™ と同様、リジン残基特異的に結合する物質は偽陰性と判定されることが考えられ、注意が必要である。本試験法に使用する細胞株の代謝能は限定的であり、プロハプテンおよびプレハプテンは陰性となる可能性がある。一方、感作性のないケミカルストレッサー（例えば酸化ストレスを誘導する物質）も KeratinoSens™ と同様、偽陽性となる可能性がある。さらに、ルシフェラーゼに干渉する化学物質も評価に影響する可能性がある。

以上の結果から、LuSens test method は、KeratinoSens™ と同様、試験の実施と評価のための戦略的統合方式（Integrated Approaches to Testing and Assessment, 以下、IATA と記す）において他の試験法と組み合わせることにより、感作性物質と非感作性物質との区別に使用

することが可能である。しかし、本試験法単独での感作性強度分類や UN GHS（UN Globally Harmonized System of Classification and Labeling of Chemicals）のサブカテゴリー分類への応用には適さない。

本委員会は、上記の本試験法の様々な限界を勘案すると、本試験法単独では皮膚感作性の判定は不十分であり、証拠の重み付けや他の試験法との組合せで用いることを推奨する。

1．緒言

皮膚感作性を評価することは化学物質の安全性評価において重要である。化学物質の皮膚での接触感作性のリスクを動物で予測する試験法としてモルモットを用いる皮膚感作性試験（OECD TG 406）やマウスを用いる局所リンパ節試験（以下、LLNA と記す。OECD TG 429）がある。この[^{3}H-Methyl]-thymidine 取込量を測定する LLNA 以外に、ATP 量を測定する LLNA:DA（OECD TG 442A）や Bromodeoxyuridine 量を測定する LLNA: BrdU-ELISA および BrdU-FCM（OECD TG 442B）がある。

EU における欧州化学品規則（REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals）では、安全性評価においてはコンピューターを用いた QSAR モデルや *in vitro* 試験等による代替法の活用が推奨されており、動物実験により安全性が評価された成分を含んだ化粧品の販売が禁止された（2013 年 3 月全面施行）。そのため、化学物質の皮膚感作性を評価する代替法の開発が強く求められた。

現在、ペプチドとの結合反応を利用した Direct Peptide Reactivity Assay（DPRA, OECD TG 442C）、多くの皮膚感作性物質が Antioxidant response element (ARE）に制御される遺伝子の発現を誘導することを利用した ARE-Nrf2 Luciferase Test Method（KeratinoSens™, OECD TG 442D）、単球系細胞の活性化を利用した human Cell Line Activation Test（h-CLAT, OECD TG 442E）、U-SENS™（OECD TG 442E）および IL-8 Luc assay（OECD TG 442E）などの皮膚感作性試験の *in vitro* 法が EURL ECVAM 等においてバリデーション研究が行われガイドライン化されている。

LuSens test method [1] は、ヒトケラチノサイト由来細胞株にルシフェラーゼレポーター遺伝子を安定的に導入した細胞系を使用する試験法である。EURL ECVAM によるバリデーション研究は行われず、BASF 社を中心に TG 442D の性能標準に基づくバリデーション研究が行われた [2, 3]。その結果について、ESAC による第三者評価が行われ、2018 年 6 月に OECD の TG 442D に追記された（Appendix 1B）[1]。一方、KeratinoSens™ は、OECD TG 442D Appendix 1A となった。

JaCVAM 皮膚感作性試験資料編纂委員会（以下、委員会）は、LuSens test method の皮膚感作性試験代替法としての科学的妥当性について、BASF 社主導で行われたバリデーション研究の結果および現在までに公開されている情報等をもとに評価したので、その結果を報告する。

2．試験法の原理

皮膚感作性は、ヒトでは接触皮膚炎、動物（齧歯類）では接触過敏症として知られる化学物質の毒性の一つである。OECD がまとめた Adverse Outcome Pathway（有害性発現経

路、AOP）では、化学物質による皮膚感作は次の 4 つの Key event（KE）からなるとされている。

KE1: 化学物質とタンパク質のシステイン残基あるいはリジン残基との共有結合
KE2: ケラチノサイト応答（細胞防御関連遺伝子の活性化等）
KE3: 樹状細胞応答（特異的細胞表面マーカー、炎症性サイトカインの発現等）
KE4: リンパ節応答（T 細胞の活性化、増殖等）

LuSens test method は既に OECD TG 442D に登録されている KeratinoSens™ と同様に、上記の KE2 に対応する試験法であり、基本原理は Keap1-Nrf2- ARE pathway（図 1）を利用したレポーターアッセイである。

Keap1-Nrf2- ARE pathway は、転写因子 Nrf2（Nuclear factor-erythroid 2-related factor 2）の抑制因子である Keap1（Kelch-like ECH-associated protein 1）および ARE が関係する遺伝子発現経路である。Nrf2 は Keap1 と結合し、ARE に依存して発現する遺伝子群の発現量を制御している。Keap1 のシステイン残基に求電子性の化学物質が結合すると、Nrf2 は Keap1 から解離し、核内へ移行して DNA 上の ARE に結合する。その結果、下流の遺伝子群の発現が誘導され、化学物質による障害から細胞を保護するために機能する。多くの皮膚感作性物質が Keap1-Nrf2-ARE pathway を活性化することが知られており [4, 5]、*in vitro* 感作性試験法の開発に利用されている。

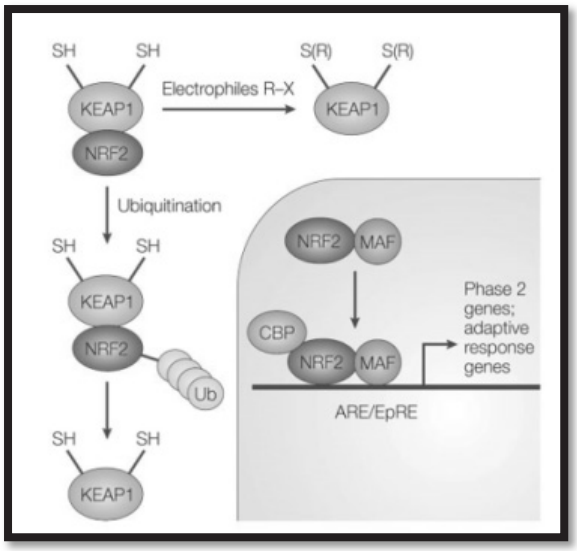


図 1. Keap1-Nrf2-ARE pathway の模式図

KeratinoSens™ [6] では、Aldo-Keto Reductase Family 1 Member C2（AKR1C2）遺伝子の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入した HaCaT 細胞（ヒトケラチノサイト系培養細胞）を用いるのに対し、LuSens test method [7] ではラットの NADPH:quinone oxidoreductase 1（NQO1）遺伝子由来の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入したヒトケラチノサイト系培養細胞（株名は不詳）を試験に使用する。

いずれの方法も化学物質による Keap1-Nrf2-ARE pathway の活性化に伴って誘導されるルシフェラーゼの活性を、基質を添加して発光強度を測定することにより、化学物質の皮膚感作性を評価する方法である。

3．試験手順／判定

LuSens test method を実施するうえでのプロトコルは EURL ECVAM のデータベース（DB-ALM）より、遺伝子組み換え培養細胞株（LuSens）は BASF 社よりそれぞれ提供されている。ルシフェラーゼレポーター遺伝子検査は、既に同 TG に収載されている KeratinoSens™ と同様に、①発光検出試薬は Promega 社から購入し、②レポーター遺伝子として利用されている改変ルシフェラーゼ遺伝子（Luc2）の使用に際しては、特許権者である Promega 社とライセンス契約を必要とする。

3−1．遺伝子改変細胞の準備および調製

ARE 制御下のルシフェラーゼレポーター遺伝子を安定的に取り込んだトランスジェニック細胞系を用いる。細胞の受領後、標準プロトコルで指定された継代数の細胞（1 から 3 代）を増殖し、主ストック細胞として凍結保存する。主ストック細胞から増殖させた細胞は、指定された継代数（20 代）以内で試験に使用する。細胞培養培地は標準プロトコルに記載されているように基礎培地（例：Dulbecco’s Modified Eagle’s medium（DMEM））に成長因子と抗生物質として Penicillin/Streptomycin および Puromycin を加えたものを使用する。しかし、検査実施中の細胞には抗生物質は使用しない。実験には、継代の時も含め 1 度も 100%コンフルエントになった事がない細胞を、80〜90%コンフルエントの状態で用いる。実験前日に、培養フラスコから調製した均一な細胞懸濁液を 96 ウェルプレートに播種（10,000 cells / well）する。96 ウェルプレートへの播種時には、ウェル間の細胞数に偏りが出ないように、調製した細胞懸濁液が常に均一となるように留意する。ルシフェラーゼ活性測定および細胞生存性検査では、濃度毎に 3 ウェルを実施する。

3−2．被験物質の調製および濃度設定手順

被験物質および対照物質ともに原則として実験当日の調製とする（安定的に凍結保存されている液体は実験当日に溶解する）。被験物質はジメチルスルホキシド（DMSO, CAS No. 67-68-5）等の適切な媒体に溶解して、最高濃度（例：200 mM）の溶液を調製する（DMSO はそれ自体が滅菌状態にあると考える）。DMSO に不溶の場合は、滅菌精製水あるいは培養液にて同様に調製し、その溶液は、滅菌（例えば濾過）する。分子量が不明の被験物質の場合、200 mg/mL あるいは 20%（w/v）の溶液とする。DMSO、滅菌水あるいは培養液以外の媒体を使用した場合は、その科学的な妥当性を明記する。

これらの溶液を DMSO（不溶の場合は滅菌水または滅菌培養液）で倍々希釈して 12 段階の濃度（0.098〜200 mM）溶液を調製する。これを血清含有培養液で 25 倍希釈する。これらの調製溶液を各ウェルに加え、最終濃度を 0.98〜2000 μM とする。分子量が不明の被験物質の場合、段階希釈は DMSO もしくは適切な媒体で実施し、最終濃度を

0.98～2000 μg/mL とする。

濃度設定のための細胞毒性検査は上記に記載された濃度を基に実施し、細胞生存率が 75%となる濃度（CV_{75}）を決定するために実施する。CV_{75} はルシフェラーゼ活性測定および並行して実施される細胞毒性検査における濃度設定の際に使用される（例：公比 1.2 で設定した濃度群において、CV_{75} より 1 濃度高い濃度（CV_{75}×1.2）、CV_{75}、CV_{75} の下 4 濃度（CV_{75}/1.2, CV_{75}/1.44, CV_{75}/1.73, CV_{75}/2.07））。細胞毒性が強すぎる、弱すぎる、もしくは溶解性が著しく低い被験物質の場合は、正当な理由に基づき代替の濃度が使用される。

媒体対照（例：DMSO）は、検査毎に 1 プレートあたり十分なウェル数を同様に調製する（例：標準プロトコルに準じ、細胞毒性検査では 12 ウェル、ルシフェラーゼ活性測定では 24 ウェル）。媒体は被験物質や陽性対照物質と同様に希釈を行い（例：1%）、細胞生存率に影響を及ぼさないようにする。

陰性対照も検査毎に 1 プレートあたり十分なウェル数を同様に調製する（例：標準プロトコルに準じ、細胞毒性検査では 3 ウェル、ルシフェラーゼ活性測定では 6 ウェル）。LuSens test method では、陰性反応が得られる事が既知の非感作性物質の DL-Lactic acid（CAS No. 50-21-5, ≥ 99%）を 5000 μM（もしくは 450 μg/mL）にて用いる。上記以外の陰性対照物質についても十分な背景データがある場合には使用可能とする。また、十分なウェル数の培養液のみを細胞に添加した無処理区画を同様に調製する（例：標準プロトコルに準じ、細胞毒性検査では 6 ウェル、ルシフェラーゼ活性測定では 12 ウェル）。

LuSens test methodが適切に実施されているかを確認する目的で、陽性対照を検査毎に1プレートあたり十分なウェル数を同様に調製する（例：標準プロトコルに準じ、細胞毒性検査では 2 ウェル、ルシフェラーゼ活性測定では 5 ウェル）。LuSens test methodでは、120 μM Ethylene Glycol Dimethacrylate（EGDMA, CAS No. 97-90-5, ≥ 99%）を被験物質と同様の希釈方法にて適用する。120 μM にて細胞毒性がみられる、もしくは陽性反応がみられない場合は、細胞毒性がみられない（細胞生存率が70%以上）もしくは陽性反応がみられる濃度を使用する。上記以外の陽性対照物質についても十分な背景データがある場合には使用可能とする。

3−3．被験物質および対照物質の適用

各被験物質および陽性対照物質について、1 プレート毎に 3 ウェルずつ、独立した少なくとも 2 回の繰り返し検査（各被験物質および陽性対照物質について n = 6）を実施する。独立した 2 回の検査結果が不一致の場合、3 回目の検査を実施し、それぞれ合計で n = 9 とする。各検査は別日に同じ継代細胞を用いるが、各実験は新たな被験物質調製液および細胞を用いて別日に行う。

細胞を播種した 24 時間培養後のプレートの培養液を捨て、1 ウェルあたり 150 μL の血清含有培地（抗生物質不含）で置き換える。調製した被験物質溶液等を 50 μL ずつ各ウェルに加え、48 時間、37± 1℃、5%CO_2 インキュベータ内で培養する。ただし、1 ウェルは無処置（無細胞、空ウェル）とする。ウェルからの蒸発や交差汚染を避けるためにプレートごとに遮蔽する。

3−4．ルシフェラーゼ活性の測定

適切なルシフェラーゼ活性の測定には、1）感度の良いルミノメーター、2）光の交差による測定の妨害を防ぐに十分なウェルの高さを持ったプレート、3）十分な感度とばらつきの低い測定値を得るためのルシフェラーゼ基質の選択、および 4）適切かつ安定した背景値が重要である。これらを確認するために TG 442D Appendix 1B-Annex 3 に示されたセットアップ方法を試験前に確認することを勧める。

培養終了後、上清を捨て、リン酸緩衝化生理食塩水で一度洗う。細胞溶解用緩衝液を各ウェルに加え、暗所で十分な時間処理する（例えば5〜10分）。細胞溶解物を含むプレートを標準プロトコルに従って処理し、ルミノメーターで測定する。

3−5．細胞生存率の測定

LuSens test method における細胞生存率の測定は、培養終了後に培地を 0.5 mg/ml の MTT（3-（4,5-Dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide, Thiazolyl blue tetrazolium bromide; CAS No. 298-93-1）含有新鮮培地に交換する。細胞は 2 時間、37± 1℃、5%CO_2 インキュベータ内で培養する。 培養後、MTT 含有培地を捨て、10% SDS （Sodium Dodecyl Sulphate）溶液などで一晩細胞溶解後、570 nm の吸光度を測定する。

3−6．データの解析

LuSens test method では、以下の指標を算出する。

・被験物質および陽性対照で観察されたルシフェラーゼ活性の最大誘導倍率
・被験物質の 75%生存率（CV_{75}）

ルシフェラーゼ活性が 1.5 倍以上の被験物質各濃度について、ルシフェラーゼ活性の誘導が統計学的に陰性対照に対して有意（p＜0.05、two-tailed Student's t-test）であるかを検証する。さらに、上記の濃度において細胞毒性がみられないことを確認する。グラフを作成して視覚的に確認することも推奨される。明らかな濃度依存性が認められない場合や濃度反応曲線が二相性を示す場合には、測定を繰り返し、被験物質特異的か、測定エラーなのか、などを確認する。二相性であることが確認できた場合は、低い方の $EC_{1.5}$ 値を選択する。

3−7．試験成立の条件

LuSens test method においては、以下の 3 条件をすべて満たす場合に成立する。

・陽性対照物質の 120 μM EGDMA（もしくはそれと同等の濃度）において、平均のルシフェラーゼ活性が 2.5 以上かつ細胞生存率が媒体対照群と比較して 70%以上でなくてはならない。
・陰性対照物質（例：5000 μM DL-Lactic acid）および無処置区画において平均のルシフェラーゼ活性が媒体対照と比較して 1.5 より低くなければならない。
・プレート間の媒体対照の平均変動係数が 20%以下でなければならない。
・少なくとも被験物質 3 濃度の細胞生存率が媒体対象群と比較して 70%以上でなけ

ればならない。さらに、結果が陰性の場合、少なくとも 1 濃度の細胞生存率は 70%より低くなければならない。

3−8．陽性の判定

2 回の繰り返し実験の 2 回あるいは 3 回の繰り返し実験の 2 回で、以下の条件に合致した場合に被験物質は感作性物質と判断する。そうでない場合は、陰性と判断する。

・連続した細胞毒性のない（細胞生存率が 70%以上）被験物質 2 濃度においてルシフェラーゼ活性が媒体対照と比較して 1.5 倍以上で、媒体対照と比較して統計学的に有意であること。上記を満たすためには少なくとも被験物質 3 濃度において細胞毒性がない必要がある。

上記に加え、2000 μM（分子量未知の場合は 2000 mg/mL）でも検査間のばらつきなく陰性で、細胞毒性もみられない場合、その結果は評価不能とする。

4．精度

本試験法の技術移転性、施設内再現性、施設間再現性については、BASF 社によるインハウス試験、および外部 4 施設が参加したバリデーション研究において検討され、EURL ECVAM によって評価されている [2, 3, 7, 8]。

4−1．技術移転性 [2, 8]

8 物質を用いて、主導施設の BASF 社から Burleson Research Technologies 社、DSM Nutritional Products 社、Institute for In Vitro Sciences（IIVS）および The Procter & Gamble 社の 4 施設への技術移転性について評価が行われた（Phase I）。4 施設のうち 2 施設は KeratinoSens™ のバリデーション研究にも参加していた。技術移転性の基準は、

（1）8 物質中 6 物質以上で正しい判定結果が得られること

（2）Validity criteria を満たす試験結果の割合が全体の 70%以上であること

とされた。1 施設は開発者である BASF 社で試験法を習得し、3 施設は SOP の提供だけで試験を実施した。

結果を表 1-1 に示す。全ての施設で上記（1）、（2）の基準を満たしており、技術移転性に問題は無いと考えられた。但し、陽性対照物質である EGDMA に関しては、その細胞毒性により細胞生存率が 60%未満となる場合があったため、以降のバリデーション研究（Phase II）では、Validity criteria として陽性対照物質を添加した際の細胞生存率が 70%以上であることが追加された。

表 1-1.　技術移転性に関する試験結果

Lead lab						
	Human/LLNA data		Results			
			Positive	Negative	invalid	Final
α-Hexyl-cinnamic aldehyde	+		5	0	0	+
1-Chloro-2,4-dinitrobenzene	+		4	1	0	+
Chlorobenzene	−		0	4	0	−
Citral	+		2	0	1	+
DL-Lactic acid	−		0	2	1	−
Ethylene glycol dimethacrylate	+		3	0	0	+
Methyl salicylate	−		2	0	1	+
Sulfanilamide	−		2	2	0	?
		Total repetitions	30			**6/8**
		Valid repetitions (%)	**90**			
Lab 1						
	Human/LLNA data		Results			
			Positive	Negative	invalid	Final
α-Hexyl-cinnamic aldehyde	+		2	2	0	?
1-Chloro-2,4-dinitrobenzene	+		3	0	0	+
Chlorobenzene	−		0	2	0	−
Citral	+		4	0	0	+
DL-Lactic acid	−		0	4	0	−
Ethylene glycol dimethacrylate	+		3	0	0	+
Methyl salicylate	−		2	0	0	+
Sulfanilamide	−		0	2	0	−
		Total repetitions	24			**6/8**
		Valid repetitions (%)	**100**			
Lab 2						
	Human/LLNA data		Results			
			Positive	Negative	invalid	Final
α-Hexyl-cinnamic aldehyde	+		2	0	1	+
1-Chloro-2,4-dinitrobenzene	+		3	0	0	+
Chlorobenzene	−		2	2	0	?
Citral	+		2	0	0	+
DL-Lactic acid	−		0	2	0	−
Ethylene glycol dimethacrylate	+		2	0	0	+
Methyl salicylate	−		2	1	0	+
Sulfanilamide	−		0	2	0	−
		Total repetitions	21			**6/8**
		Valid repetitions (%)	**95**			
Lab 3						
	Human/LLNA data		Results			
			Positive	Negative	invalid	Final
α-Hexyl-cinnamic aldehyde	+		2	1	2	+
1-Chloro-2,4-dinitrobenzene	+		3	1	1	+
Chlorobenzene	−		0	3	1	−
Citral	+		4	0	0	+
DL-Lactic acid	−		1	3	0	−
Ethylene glycol dimethacrylate	+		3	0	1	+
Methyl salicylate	−		3	0	1	+
Sulfanilamide	−		0	3	1	−
		Total repetitions	34			**7/8**
		Valid repetitions (%)	**79**			
Lab 4						
	Human/LLNA data		Results			
			Positive	Negative	invalid	Final
α-Hexyl-cinnamic aldehyde	+		2	1	2	+
1-Chloro-2,4-dinitrobenzene	+		4	0	1	+
Chlorobenzene	−		0	4	1	−
Citral	+		4	0	1	+
DL-Lactic acid	−		0	5	0	−
Ethylene glycol dimethacrylate	+		3	0	2	+
Methyl salicylate	−		0	3	2	−
Sulfanilamide	−		0	3	2	−
		Total repetitions	40			**8/8**
		Valid repetitions (%)	**73**			

4–2．施設内再現性 [2, 7, 8)]

BASF 社によるインハウス試験では、74 物質中 69 物質（93%）で再現性がみられた [2, 7)]。

3 機関によるバリデーション研究では、性能標準 [9)] に記載されている 20 物質の内から 12 物質が選択され、施設内再現性が評価された。3 機関とも施設内再現性は 100%であり、性能標準に記載されている 80%以上という基準を満たしていた（表 1-2）[2, 8)]。ただし、ヒト/ LLNA データと比較すると、4-Methoxy-acetophenone は偽陽性、Phenyl benzoate は偽陰性である。なお本委員会では、用いられた 20 物質および 12 物質の Chemical class、Mechanism、感作性カテゴリー、Pro/ prehapten に関する情報から、これらの物質は適切に選択されたものと判断した。

表 1-2．施設内再現性に関する試験結果 [2)]

	Lead Lab			Laboratory 1			Laboratory 2		
test substances	Exp1	Exp2	Exp3	Exp1	Exp2	Exp3	Exp1	Exp2	Exp3
2,4-Dinitrochlorobenzene	+	+	+	+	+	+	+#	+	+
4-methoxy-acetophenone	+	+	+	+	+	+	+	+	+
4-Nitrobenzylbromide	+	+	+	+	+	+	+	+	+
Citral	+	+	+	+#	+	+	+#	+	+
Ethylene glycol dimethacrylate	+	+	+	+#	+	+	+#	+	+
Glycerol	-	-	-	-	-	-	-	-	-
Isoeugenol	+	+	+	+	+	+	+	+	+
Isopropanol	-	-*	-	-	-	-	-	-	-
Methyldibromo glutaronitrile	+	+	+	+	+	+	+	+	+
para-phenylenediamine	+	+	+	+	+	+	+	+	+
Phenyl benzoate	-	-	-	-	-*	-	-*	-	-
Salicylic acid	-	-	-	-	-	-	-	-	-

+: positive/skin sensitiser prediction; -: negative/non-sensitiser prediction; #experiments conducted in the transferability phase; *experiments with three repetitions.

4–3．施設間再現性 [2, 8)]

性能標準 [9)] に記載されている 20 物質を用いて施設間再現性が評価された。12 物質に関しては、前述の 3 施設（Lead lab、Lab 1 および Lab 2）の施設内再現性評価の際の結果が用いられた。残りの 8 物質に関しては Lead lab、Lab 3 および Lab 4 の 3 施設で試験を実施した。また Lab 3、Lab 4 の 2 施設はさらに 5 物質の試験を実施した。

結果を表 1-3 に示す。全ての物質で施設間再現性は 100%であり、性能標準に記載されている 80%以上という基準を満たしていた。ただし、ヒト / LLNA データと比較すると、4-Methoxy-acetophenone および Methyl salicylate は偽陽性、Phenyl benzoate は偽陰性である。

表 1-3．5 施設によるバリデーション研究結果 [2)]

test substance	LLNA reference		Lead lab	Lab1	Lab2	Lab3	Lab4
	NS vs S	LLNA potency					
4-methoxy-acetophenone	NS	na	+	+	+	nt	nt
Chlorobenzene	NS	na	-	nt	nt	-	-
Glycerol	NS	na	-	-	-	-	-
Isopropanol	NS	na	-	-	-	-	-
Lactic acid	NS	na	-	nt	nt	-	-
Methylsalicylate	NS	na	+	nt	nt	+	+
Salicylic acid	NS	na	-	-	-	-	-
Sulfanilamide	NS	na	-	nt	nt	-	-
2-Mercaptobenzothiazole	S	moderate	+	nt	nt	+	+
2,4-Dinitrochlorobenzene	S	extreme	+	+	+	+	+
4-Methylaminophenolsulfate	S	strong	+	nt	nt	+	+
4-Nitrobenzylbromide	S	extreme	+	+	+	nt	nt
Citral	S	moderate	+	+#	+	nt	nt
Ethylene glycol dimethacrylate	S	weak	+	+#	+	nt	nt
Eugenol	S	weak	+	nt	nt	+	+
Isoeugenol	S	moderate	+	+	+	nt	nt
Methyldibromo glutaronitrile	S	strong	+	+	+	+	+
Oxazolone	S	extreme	+	nt	nt	+	+
para-phenylenediamine	S	strong/extreme	+	+	+	nt	nt
Phenyl benzoate	S	weak	-	-	-	nt	nt
Predictivity							
n			20	12	12	13	13
sensitivity (%)			91.7	87.5	87.5	100.0	100.0
specificity (%)			75.0	75.0	75.0	85.7	85.7
PPV (%)			84.6	87.5	87.5	85.7	85.7
NPV (%)			85.7	75.0	75.0	100.0	100.0
accuracy (%)			85.0	83.3	83.3	92.3	92.3

NS: non-sensitiser; S: sensitiser; na: not applicable; +: positive/skin sensitiser prediction; -: negative/non-sensitiser prediction; nt: not tested; #experiment conducted in the transferability phase.

5．正確度（感度および特異度）[2, 3, 7, 8, 9)]

BASF 社による 74 物質を用いたインハウス試験の結果 [2, 7, 8)]、および 5 施設によるバリデーション研究の結果（表 1-3）[2, 9)]から、感度、特異度および正確度が評価された。

BASF 社によるインハウス試験においては、ヒトデータ（69 物質）と比較した場合、感度は 83%、特異度は 78%、正確度は 81%、LLNA データ（72 物質）と比較した場合、感度は 75%、特異度は 71%、正確度は 74%であった（なおインハウス試験結果 [7)] およびその改訂結果 [8)]とも本文中の数値が表の内容と一致しなかったため、これらの正確度の数値は表の記載から本委員会により計算された）。本試験法の感度は 83%（ヒト）、75%（LLNA）であり、陰性の結果が得られた場合は偽陰性の可能性を考慮し、本試験法のみで皮膚感作性を陰性と判定することはできない。さらに偽陰性となった 13 物質中 2 物質（Phthalic anhydride 及び Propyl gallate）は UN GHS 1A に区分される物質であったことに特に注意する必要がある。

また、特異度も 78%（ヒト）と 71%（LLNA）であることから、本試験法で陽性の結果が得られた場合にも、偽陽性の可能性があることに留意しなければならない。

Phthalic anhydride はアシル基転移剤であり [7]、リジン残基特異的に結合することが知られているため、Keap1-Nrf2-ARE pathway の活性化を指標とする本試験法では偽陰性になったと考えられる。Propyl gallate については Prohapten の一種である Pro Michael acceptor であり [7]、代謝されないとタンパクと結合しないため偽陰性になったと考えられる。その他の偽陰性物質については、アシル基転移剤（Benzoyl peroxide および Phenyl benzoate）、Pro/ prehapten（4-Allylanisole, Ethylene diamine および Resorcinol）、システイン残基と共有結合しない金属イオン（Nickel chloride）などの理由が考えられた。一方、偽陽性物質については、光感作性物質として知られている 6-Methlycoumarin が Michael acceptor としてタンパク質と結合する可能性がある以外、不明であった。

5 施設によるバリデーション研究（表 1-3）においては、感度は 88-100%、特異度は 75-86%、正確度は 83-92%であった。ただし、試験に用いた検体のサブセットは施設によって異なっている。Lab 3 および Lab 4 の感度および特異度が他施設より高いのは、他施設の試験において偽陰性となった Phenyl benzoate および偽陽性となった 4-Methoxy-acetophenone の試験を実施していないためと考えられる。20 物質全ての試験結果をまとめると、感度は 92%、特異度は 75%、正確度は 85%であった。性能標準 [10] では、これら 20 物質を用いた評価において、感度、特異度および正確度が 80%以上という基準が示されている。本試験法の感度および正確度は 80%以上であったが、特異度はこの基準を満たさなかった。特異度が 80%未満だったのは非感作性物質 8 品のうち 2 品が偽陽性になったためであり、本試験法の特異度を判断するためにはこの被験物質数では不十分と考えられたものの、本試験法において陽性の結果が得られた場合には、偽陽性の可能性があることに留意しなければならない。

上記 20 物質の本試験法と KeratinoSens™ の VRM（Validated Reference Method）による比較試験結果を表 2-1 に示す。両試験法とも 20 物質中 17 物質を正しく判定しており、正確度は 85%であった。本試験法で偽陽性となった Methyl salicylate は、KeratinoSens™ では陰性と判定され、本試験法で陽性と判定された Eugenol は KeratinoSens™ では偽陰性となった。ESAC opinion [3] では、両試験法のバリデーション研究結果の詳細が確認されており、この 2 物質については両試験法ともに陽性と判定された個別の実験（run）と陰性と判定された個別の実験があったこと、すなわちこの 2 物質は判定の難しい物質であると記載されている（表 2-2）。両試験法で偽陰性となった Phenyl benzoate は Weak sensitizer である。また 4-Methoxy-acetophenone は両試験法で偽陽性となった。これらの結果から、ESAC opinion では両試験法についてどちらか一方を推奨する科学的な根拠はないと評価されており、両試験法の予測性はほぼ同等と考えられる。

以上より、本試験法単独では皮膚感作性の予測性は不十分であり、証拠の重み付けや他の試験法と組み合わせでの評価を推奨する。

表 2-1．LuSens test method と KeratinoSens™ との比較-1[2)]

test substance	LLNA reference result		LuSens	KeratinoSens
	NS vs S	LLNA potency		
4-methoxy-acetophenone	NS	na	+	+
Chlorobenzene	NS	na	-	-
Glycerol	NS	na	-	-
Isopropanol	NS	na	-	-
Lactic acid	NS	na	-	-
Methylsalicylate	NS	na	+	-
Salicylic acid	NS	na	-	-
Sulfanilamide	NS	na	-	-
2-Mercaptobenzothiazole	S	moderate	+	+
2,4-Dinitrochlorobenzene	S	extreme	+	+
4-Methylaminophenolsulfate	S	strong	+	+
4-Nitrobenzylbromide	S	extreme	+	+
Citral	S	moderate	+	+
Ethylene glycol dimethacrylate	S	weak	+	+
Eugenol	S	weak	+	-
Isoeugenol	S	moderate	+	+
Methyldibromo glutaronitrile	S	strong	+	+
Oxazolone	S	extreme	+	+
para-phenylenediamine	S	strong/extreme	+	+
Phenyl benzoate	S	weak	-	-
Total n			20	20
Sensitivity			91.7	83.3
Specificity			75.0	87.5
PPV			84.6	90.9
NPV			85.7	77.8
Accuracy			85.0	85.0

NS: non-sensitiser; S: sensitiser; +: positive/skin sensitiser; -: negative/non-sensitiser.

表 2-2．LuSens test method と KeratinoSens™ との比較-2 [3)]

Performance Standards Reference Substances		KeratinoSens™					LuSens				
		Lead Lab	Lab 1	Lab 2	Lab 3	Lab 4	Lead Lab	Lab 1	Lab 2	Lab 3	Lab 4
4-Methoxy-acetophenone	**Non-sensitiser**	(P-P-P-P)					(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
Glycerol	**Non-sensitiser**	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N) (N-N) (N-N)	(N-N) (N-N) (N-N)	(N-N) (N-N) (N-N)	(N-N)	(N-N)
Isopropanol	**Non-sensitiser**	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N) (***N-P-N***) (N-N)	(N-N) (N-N) (N-N)	(N-N) (N-N) (N-N)	(N-N)	(N-N)
Salicylic acid	**Non-sensitiser**	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N) (N-N) (N-N)	(N-N) (N-N) (N-N)	(N-N) (N-N) (N-N)	(N-N)	(N-N)
Chlorobenzene	Non-sensitiser	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(***P-N-N***)	(***P-N-N***)			(N-N)	(N-N)
Lactic acid	Non-sensitiser	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(***P-N-N***)			(N-N)	(N-N)
Methyl salicylate	Non-sensitiser	(N-N-N)	(***P-N-N***)	(N-N-N)	(***P-N-N***)	(***P-N-N***)	(***N-P-P***)			(P-P)	(P-P)
Sulphanilamide	Non-sensitiser	(N-N-N)	(N-N-N)	(N-N-N)	(***P-N-N***)	(N-N-N)	(N-N)			(N-N)	(N) (N)
Ethylene glycol dimethacrylate	**Skin sensitiser (weak)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
Phenyl benzoate	**Skin sensitiser (weak)**	(N-N-N)	(N-N-N)	(N-N-N)	(N-N-N)	(***N-N-P***)	(N-N) (N-N) (N-N)	(N-N-N) (***P-N-N***) (N-N)	(***P-N-N***) (N-N) (N-N)		
Citral	**Skin sensitiser (moderate)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
Isoeugenol	**Skin sensitiser (moderate)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
Methyldibromo glutaronitrile	**Skin sensitiser (strong)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P)	(P-P)
para-Phenylenediamine	**Skin sensitiser (strong/extreme)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
2,4-Dinitrochlorobenzene	**Skin sensitiser (extreme)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P)	(P-P)
4-Nitrobenzylbromide	**Skin sensitiser (extreme)**	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)	(P-P) (P-P) (P-P)		
Eugenol	Skin sensitiser (weak)	(***P-N-N***)	(***P-N-N***)	(P-P-P)	(P-P-P)	(***P-N-N***)	(***N-P-P***)			(P-P)	(P-P)
2-Mercaptobenzothiazole	Skin sensitiser (moderate)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P)			(P-P)	(P) (P)
4-Methylaminophenol sulphate	Skin sensitiser (strong)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P)			(***P-N-P***)	(P-P)
Oxazolone	Skin sensitiser (extreme)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P-P)	(P-P)			(P-P)	(P-P)

P = Positive run

N = Negative run

( ) = Tested in addition to what is requested in the performance standards (PS)

( ) brackets correspond to an experiment, e.g., for experiment (N-P-P) the final conclusion is P.

In bold face are the 12 reference substances for which, according to the PS, WLR information needs to be generated. BLR information in turn, is required for all 20 reference substances.

6．評価可能な物質の範囲および有用性と限界

本試験法は、さまざまな構造や物理化学的性質を有する化学物質に適用可能であることが示されている [7)]。また、本試験法に用いる溶媒に溶解する、もしくは安定に分散する化合物は適用可能であるが、適用可能最高濃度においても細胞毒性がみられない場合（細胞生存率 70%以上）の陰性結果は「評価不能」とされる。

本試験法は KE2 を評価する *in vitro* 試験法である KeratinoSens™ と同様、システイン残基との反応が必要な Keap1-Nrf2-ARE pathway の活性化を指標としており、リジン残基特異的に結合し、感作性を示す物質は偽陰性と判定されることが考えられるため、そのような物質（例えば、UN GHS 1A の Phthalic anhydride）の陰性結果は注意が必要である [7)]。本試験法

に使用する細胞株の代謝能は限定的であり [11]、本試験条件からも、プロハプテンおよびプレハプテン（例えば、UN GHS 1A の Propyl gallate）は陰性となる可能性がある。一方、感作性のないケミカルストレッサー（例えば酸化ストレスを誘導する物質）は KeratinoSens™ と同様、偽陽性となる可能性がある [12]。さらに、ルシフェラーゼ活性に干渉する化学物質も評価に影響する可能性がある [13]。

本試験法は、細胞培養の技術と 96 ウェル対応のルミノメーターの使用技術があれば容易に実施可能である。LuSens test method はケラチノサイトにおける ARE-dependent pathway による遺伝子発現を指標にした検査法であることから、同様に Keap1- Nrf2-ARE pathway を利用したレポーターアッセイである KeratinoSens™ と基本的な操作は同様である。本試験法の実施に必要なランニングコストは KeratinoSens™ と同様約 1.5 万円と見積もられ、LLNA（同約 10 万円）より低額であり、h-CLAT（同約 2 万円）や U-SENS™（同約 1.8 万円）とほぼ同程度であった。本試験法の場合、開発元の BASF 社より細胞株の入手が無償で可能である（輸送費など実費別）。一方、KeratinoSens™ では現在は細胞株の入手に関して販売を委託された acCELLerate 社より 500 ユーロで購入可能である（実費別）。両試験法とも細胞の入手に関して開発元とのライセンス契約は不要である。

本試験法は、IATA において他の試験法と組み合わせることにより、感作性物質と非感作性物質との識別に使用することが可能である。しかし、本試験法単独での感作性強度分類や GHS のサブカテゴリー分類への応用には適さない。

7. 結論

LuSens test method は、既に OECD TG 442D に登録されている KeratinoSens™ と同様に、感作性発現機序における KE2 に対応する試験法である。

KeratinoSens™ では、AKR1C2 遺伝子の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入した HaCaT 細胞（ヒトケラチノサイト系培養細胞）を用いるのに対し、LuSens test method ではラットの NQO1 遺伝子由来の ARE をエンハンサーとするルシフェラーゼレポーター遺伝子を安定的に導入したヒトケラチノサイト系培養細胞（株名不詳）を使用する。いずれも化学物質による Keap1-Nrf2-ARE pathway の活性化に伴って誘導されるルシフェラーゼの活性を、基質を添加して発光強度を測定することにより、化学物質の皮膚感作性を評価する方法である。

LuSens test method は、EURL ECVAM によるバリデーション研究は行われず、BASF 社によるインハウス試験および外部 4 機関が参加した性能標準に基づくバリデーション研究が行われ、その結果を EURL ECVAM が評価して、2018 年 6 月に OECD TG 442D に追記された（Appendix 1B）。

本試験法は、細胞培養の技術と 96 ウェル対応のルミノメーターの使用技術があれば容易に実施可能である。また、本試験法に用いる細胞株は BASF 社から入手可能である。

BASF 社による 74 物質を用いた施設内再現性は 93%であり、3 機関による施設内再現性（12 物質について）は 100%であった。20 物質を用いて BASF 社を含む 5 施設において少なくとも 1 物質につき 3 施設以上が実施した施設間再現性試験の結果は 100%であった。いずれも性能標準で要求している 80%以上の基準を満たしていた。

BASF 社によるインハウス試験においては、ヒトデータ（69 物質）と比較した場合、感度は 83%、特異度は 78%、正確度は 81%、LLNA データ（72 物質）と比較した場合、感度は 75%、特異度は 71%、正確度は 74%であった。用いた検体のサブセットは施設によって異なっているが、5 施設によるバリデーション研究においては、感度は 88-100%、特異度は 75-86%、正確度は 83-92%であった。

性能標準に記載されている 20 物質を用いて行われた LuSens test method と KeratinoSens™ の比較試験の結果では、両試験法とも 20 物質中 17 物質を正しく判定しており、正確度は 85%であった。両試験法の試験結果の詳細から、ESAC による評価では両試験法についてどちらか一方を推奨する科学的な根拠はないとしている。本委員会は両試験法の予測性はほぼ同等と評価した。

LuSens test method は、KeratinoSens™ と同様にシステイン残基との反応が必要な Keap1-Nrf2-ARE pathway の活性化を指標としており、リジン残基特異的に結合し、感作性を示す物質は偽陰性と判定されることが考えられるので注意が必要である。本試験法に使用する細胞株の代謝能は限定的であり、プロハプテンおよびプレハプテンは陰性となる可能性がある。一方、感作性のないケミカルストレッサー（例えば酸化ストレスを誘導する物質）は KeratinoSens™ と同様、偽陽性となる可能性がある。さらに、ルシフェラーゼに干渉する化学物質も評価に影響する可能性がある。

以上の結果から、LuSens test method は、IATA において他の試験法と組み合わせることにより、感作性物質と非感作性物質との区別に使用することが可能である。しかし、本試験法単独での感作性強度分類や UN GHS のサブカテゴリー分類への応用には適さない。

本委員会は、上記の本試験法の様々な限界を勘案すると、本試験法単独では皮膚感作性の判定は不十分であり、証拠の重み付けや他の試験法との組合せで用いることを推奨する。

引用文献

1) OECD (2018). Key event based test guideline. In vitro skin sensitization assay addressing the AOP key event on keratinocyte activation. OECD Guideline for the Testing of Chemicals. No. 442D, OECD, Paris. Accessible at: https://www.oecd-ilibrary.org/docserver/9789264229822-en.pdf?expires=1540286232&id=id&accname=guest&checksum=F9DC614E0BBF02D46223C8FCABCFBA5E
2) EURL ECVAM (2018). The LuSens Test Method Validation Study Report. Accessible at; https://tsar.jrc.ec.europa.eu/test-method/tm2011-10
3) ESAC (2016). ESAC Opinion on the BASF-coordinated Performance Standards-based validation of the LuSens test method for skin sensitization testing. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103706/esac_opinion_2016-04_lusens_final.pdf
4) Ade N, Leon F, Pallardy M, Peiffer JL, Kerdine-Romer S, Tissier MH, Bonnet PA, Fabre I, Ourlin JC; HMOX1 and NQO1 genes are upregulated in response to contact sensitizers in dendritic cells and THP-1 cell line: role of the Keap1/Nrf2 pathway. Toxicol Sci. 2009; 107(2):451-60.
5) Vandebriel RJ, Pennings JL, Baken KA, Pronk TE, Boorsma A, Gottschalk R, Van Loveren H; Keratinocyte gene expression profiles discriminate sensitizing and irritating compounds. Toxicol

Sci. 2010; 117(1):81-9.

6) Emter R, Ellis G, Natsch A; Performance of a novel keratinocyte-based reporter cell line to screen skin sensitizers in vitro. Toxicol Applied Pharmacol, 2010; 245: 281-290.
7) Ramirez T, Mehling A, Kolle SN, Wruck CJ, Teubner W, Eltze T, Aumann A, Urbisch D, van Ravenzwaay B, Landsiedel R; LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification. Toxicol In Vitro. 2014; 28(8):1482-97.
8) Kolle SN; Corrigendum to "LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification." by Ramirez et al., Toxicol In Vitro. 2014; Dec; 28(8):1482–97. doi: 10.1016/j.tiv.2014.08. 002
9) Ramirez T., Stein N., Aumann A., Remus T., Edwards A., Norman K.G., Ryan C., Bader J.E., Fehr M., Burleson F., Foertsch L., Wang X., Gerberick F., Beilstein P., Hoffmann S., Mehling A., van Ravenzwaay B., Landsiedel R; Intra- and inter-laboratory reproducibility and accuracy of the LuSens assay: A reporter gene-cell line to detect keratinocyte activation by skin sensitizers. Toxicol. In Vitro. 2016; 32: 278-286.
10) OECD (2015). Guidance Document No. 213. Performance Standards for assessment of proposed similar or modified in vitro skin sensitisation ARE-NrF2 luciferase test methods. Series on Testing and Assessment. Available at: http://www.oecd.org/env/ehs/testing/series-testing-assessment-publications-number.htm
11) Fabian E., Vogel D., Blatz V., Ramirez T., Kolle S., Eltze T., van Ravenzwaay B., Oesch F., Landsiedel R. ; Xenobiotic metabolizn enzyme activities in cells used for testing skin sensitization in vitro. Arch Toxicol. 2013; 87: 1683-1969.
12) EURL-ECVAM (2014). Recommendation on the KeratinoSensTM assay for skin sensitisation testing, 42 pp. Available at: http://ihcp.jrc.ec.europa.eu/our_labs/eurl-ecvam/eurl-ecvamrecommendations/recommendation-keratinosens-skin-sensitisation.
13) Thorne N., Inglese J., Auld D.S. ; Illuminating Insights into Firefly Luciferase and Other Bioluminescent Reporters Used in Chemical Biology. Chemistry and Biology. 2010; 17: 646-657.

KEY EVENT BASED TEST GUIDELINE 442D

IN VITRO SKIN SENSITISATION ASSAYS ADDRESSING THE AOP KEY EVENT ON KERATINOCYTE ACTIVATION

GENERAL INTRODUCTION

Keratinocyte activation Key Event based Test Guideline

1. A skin sensitiser refers to a substance that will lead to an allergic response following repeated skin contact as defined by the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (UN GHS) (1). There is general agreement on the key biological events underlying skin sensitisation. The current knowledge of the chemical and biological mechanisms associated with skin sensitisation has been summarised as an Adverse Outcome Pathway (AOP) (2), starting with the molecular initiating event through intermediate events to the adverse effect, namely allergic contact dermatitis. This AOP focuses on chemicals that react with thiol (i.e. cysteine) and primary amines (i.e. lysine) such as organic chemicals. In this instance, the molecular initiating event (i.e. the first key event) is the covalent binding of electrophilic substances to nucleophilic centres in skin proteins. The second key event in this AOP takes place in the keratinocytes and includes inflammatory responses as well as changes in gene expression associated with specific cell signalling pathways such as the antioxidant/electrophile response element (ARE)-dependent pathways. The third key event is the activation of dendritic cells, typically assessed by expression of specific cell surface markers, chemokines and cytokines. The fourth key event is T-cell proliferation (3).

2. This Test Guideline describes in vitro assays that address mechanisms described under the second Key Event of the AOP for skin sensitisation, namely keratinocyte activation (2). The Test Guideline comprises test methods to be used for supporting the discrimination between skin sensitisers and non-sensitisers in accordance with the UN GHS (1). The test methods currently described in this Test Guideline are:

- The ARE-Nrf2 luciferase KeratinoSens™ test method (Appendix IA), and
- The ARE-Nrf2 luciferase LuSens test method (Appendix IB).

3. These two in vitro ARE-Nrf2 luciferase test methods have been considered scientifically valid. The KeratinoSens™ test method first underwent a validation study followed by an independent peer-review by EURL ECVAM Scientific Advisory Committee (ESAC) and positive recommendations by EURL ECVAM, and is considered the validated reference method (VRM) (3) (4) (5) (6). The LuSens test method later

© OECD, (2018)

You are free to use this material subject to the terms and conditions available at http://www.oecd.org/termsandconditions/.

In accordance with the decision of the Council on a delegation of authority to amend Annex I of the decision of the council on the Mutual Acceptance of Data in the assessment of chemicals [C(2018)49], this Guideline was amended by the OECD's Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology by written procedure on 25 June 2018.

underwent a Performance Standard-based validation study based on which it was also reviewed and received positive opinion by ESAC (7) (8) (9) (10).

4. The test methods included in this Test Guideline may differ in relation to the procedure used to generate the data and the readouts measured but can be used indiscriminately to address countries' requirements for test results on the keratinocytes activation Key Event of the AOP for skin sensitisation while benefiting from the Mutual Acceptance of Data.

Background and principles of the test methods included in the Key Event based Test Guidelines

5. The assessment of skin sensitisation has typically involved the use of laboratory animals. The classical methods that use guinea-pigs, the Guinea Pig Maximisation Test (GPMT) of Magnusson and Kligman and the Buehler Test (OECD TG 406) (11), assess both the induction and elicitation phases of skin sensitisation. The murine tests, the LLNA (OECD TG 429) (12) and its three non-radioactive modifications, LLNA: DA (OECD TG 442A) (13) as well as LLNA: BrdU-ELISA and BrdU-FCM (OECD TG 442B) (14), all assess the induction response exclusively, and have gained acceptance since they provide an advantage over the guinea pig tests in terms of animal welfare together with an objective measurement of the induction phase of skin sensitisation.

6. Mechanistically-based in chemico and in vitro test methods addressing the first three key events of the skin sensitisation AOP have been adopted for contributing to the evaluation of the skin sensitisation hazard potential of chemicals: the OECD TG 442C describes the Direct Peptide Reactivity Assay (15) addressing the first key event; the present Test Guideline assesses keratinocyte activation addressing the second key event and the OECD TG 442E addresses the activation of dendritic cells, the third key event of the skin sensitisation AOP (16). Finally, the fourth key event representing T-cell proliferation is indirectly assessed in the murine Local Lymph Node Assay (LLNA) (12).

7. As keratinocyte activation represents only one key event of the skin sensitisation AOP (2) (17), information generated with test methods developed to address this specific key event may not be sufficient to conclude on the presence or absence of skin sensitisation potential of chemicals. Therefore data generated with the test methods described in this Test Guideline are proposed to support the discrimination between skin sensitisers (i.e. UN GHS Category 1) and non-sensitisers when used within Integrated Approaches to Testing and Assessment (IATA), together with other relevant complementary information, e.g. derived from in vitro assays addressing other key events of the skin sensitisation AOP as well as non-testing methods, including read-across from chemical analogues (17). Examples on the use of data generated with these methods within Defined Approaches, i.e. approaches standardised both in relation to the set of information sources used and in the procedure applied to derive predictions have been published (17) and can be employed as useful elements within IATA.

8. The test methods described in this Test Guideline cannot be used on their own, neither to sub-categorise skin sensitisers into subcategories 1A and 1B as defined by UN GHS (1), for authorities implementing these two optional subcategories, nor to predict potency for safety assessment decisions. However, depending on the regulatory framework, positive results generated with these methods may be used on their own to classify a chemical into UN GHS category 1.

© OECD 2018

9. The term "test chemical" is used in this Test Guideline to refer to what is being tested[1] and is not related to the applicability of the test methods to the testing of mono-constituent substances, multi-constituent substances and/or mixtures. When testing in submerged cultures, it should be determined that the test chemical is dissolved in the exposure medium or at least forms a stable dispersion (e.g. by visual inspection of the test chemical dissolved/prepared at the maximal final test concentration in the exposure medium, showing that no undissolved residues remain and that no precipitate or phase separation forms if the solution is left to settle for several hours).

10. Limited information is currently available on the applicability of the test methods to multi-constituent substances/mixtures (18) (19) (20). Although not evaluated in the validation studies, the test methods may nevertheless be technically applicable to the testing of multi-constituent substances and mixtures. When considering testing of mixtures, difficult-to-test chemicals (e.g. unstable), or test chemicals not clearly within the applicability domain described in this Guideline, upfront consideration should be given to whether the results of such testing will yield results that are meaningful scientifically. Moreover, when testing multi-constituent substances or mixtures, consideration should be given to possible interference of cytotoxic constituents with the observed responses (e.g. the presence of a high content of non-sensitising cytotoxic constituents may mask the response of weakly sensitising components or sensitising components present at low concentration). It might, depending on the particular case, be scientifically justified to test either single main constituents forming the major fraction or several fractions of the mixture to conclude on the sensitisation potential of the complex mixture.

Literature

1) United Nations (UN) (2017). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Seventh revised edition, New York and Geneva, United Nations Publications. Available at: [https://www.unece.org/trans/danger/publi/ghs/ghs_rev07/07files_e0.html]

2) OECD (2012). Series on Testing and Assessment No. 168. The Adverse Outcome Pathway for Skin Sensitisation Initiated by Covalent Binding to Proteins. Part 1: Scientific Evidence. Organisation for Economic Cooperation and Development, Paris. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2012)10/PART1&docLanguage=En

3) Emter R., Ellis G., Natsch A.(2010). Performance of a novel keratinocyte-based reporter cell line to screen skin sensitizers in vitro. Toxicology and Applied Pharmacology 245, 281-290.

4) Natsch A., Bauch C., Foertsch L., Gerberick F., Normann K., Hilberer A., Inglis H., Landsiedel R., Onken S., Reuter H., Schepky A., Emter R. (2011). The intra- and inter-laboratory reproducibility and predictivity of the KeratinoSens assay to predict skin sensitizers in vitro: results of a ring-study in five laboratories. Toxicol. In Vitro 25, 733-744.

[1] In June 2013, the Joint Meeting agreed that where possible, a more consistent use of the term "test chemical" describing what is being tested should be applied in new and updated Test Guidelines.

© OECD 2018

5) Natsch A., Ryan C.A., Foertsch L., Emter R., Jaworska J., Gerberick G.F., Kern P. (2013). A dataset on 145 chemicals tested in alternative assays for skin sensitization undergoing prevalidation. Journal of Applied Toxicology 33, 1337-1352.

6) EURL-ECVAM (2014). Recommendation on the KeratinoSensTM assay for skin sensitisation testing, 42 pp. Available at: [http://ihcp.jrc.ec.europa.eu/our_labs/eurl-ecvam/eurl-ecvam-recommendations/recommendation-keratinosens-skin-sensitisation].

7) Ramirez T., Mehling A., Kolle S.N., Wruck C.J., Teubner W., Eltze T., Aumann A., Urbisch D., van Ravenzwaay B., Landsiedel R. (2014). LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification. Toxicol In Vitro 28, 1482-1497.

8) Ramirez T., Stein N., Aumann A., Remus T., Edwards A., Norman K.G., Ryan C., Bader J.E., Fehr M., Burleson F., Foertsch L., Wang X., Gerberick F., Beilstein P., Hoffmann S., Mehling A., van Ravenzwaay B., Landsiedel R. (2016). Intra- and inter-laboratory reproducibility and accuracy of the LuSens assay: A reporter gene-cell line to detect keratinocyte activation by skin sensitizers. Toxicol In Vitro 32, 278-286.

9) ESAC (2016). ESAC opinion on the BASF-coordinated Performance Standards-based validation of the LuSens test method for skin sensitisation testing. Available at: [http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103706/esac_opinion_2016-04_lusens_final.pdf].

10) OECD (2015). Guidance Document No 213. Performance Standards for assessment of proposed similar or modified in vitro skin sensitisation ARE-NrF2 luciferase test methods. Series on Testing and Assessment. Available at: http://www.oecd.org/env/ehs/testing/series-testing-assessment-publications-number.htm

11) OECD (1992). OECD Guidelines for the Testing of Chemicals No. 406. Skin Sensitisation. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

12) OECD (2010). OECD Guidelines for Chemical Testing No. 429. Skin sensitization: Local Lymph Node assay. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

13) OECD (2010). OECD Guidelines for Chemical Testing No. 442A.Skin sensitization: Local Lymph Node assay: DA. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

14) OECD (2010). OECD Guidelines for Chemical Testing No. 442B. Skin sensitization: Local Lymph Node assay: BrdU-ELISA. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

15) OECD (2015). OECD Guideline for the Testing of Chemicals No. 442C: In Chemico Skin Sensitisation: Direct Peptide Reactivity Assay (DPRA). Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

16) OECD (2017). OECD Guideline for the Testing of Chemicals No. 442E: In Vitro Skin Sensitisation assays addressing the AOP Key Event on Activation of Dendritic Cells. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

17) OECD (2016). Series on Testing & Assessment No. 256: Guidance Document On The Reporting Of Defined Approaches And Individual Information Sources To Be Used Within Integrated

© OECD 2018

Approaches To Testing And Assessment (IATA) For Skin Sensitisation, Annex 1 and Annex 2. ENV/JM/HA(2016)29. Organisation for Economic Cooperation and Development, Paris. Available at: [https://community.oecd.org/community/iatass].

18) Andres E., Sa-Rocha V.M., Barrichello C., Haupt T., Ellis G., Natsch A. (2013). The sensitivity of the KeratinoSensTM assay to evaluate plant extracts: A pilot study. Toxicology In Vitro 27, 1220-1225.

19) Kolle, S.N., Mehling A., Teubner W., van Ravenzwaay B., Landsiedel R. (2013). Alternative method in practice: Post-validation experience of the skin sensitization in vitro test strategy. Toxicology Letters 221, S204.

20) Settivari RS, Gehen SC, Amado RA, Visconti NR, Boverhof DR, Carney EW (2015). Application of the KeratinoSens™ assay for assessing the skin sensitization potential of agrochemical active ingredients and formulations. Regul Toxicol Pharmacol; 72(2):350-60.

© OECD 2018

Annex I - DEFINITIONS

Accuracy: The closeness of agreement between test method results and accepted reference values. It is a measure of test method performance and one aspect of "relevance." The term is often used interchangeably with "concordance", to mean the proportion of correct outcomes of a test method (3).

AOP (Adverse Outcome Pathway): sequence of events from the chemical structure of a target chemical or group of similar chemicals through the molecular initiating event to an in vivo outcome of interest (2).

ARE: Antioxidant response element (also called EpRE, electrophile response element), is a response element found in the upstream promoter region of many cytoprotective and phase II genes. When activated by Nfr2, it mediates the transcriptional induction of these genes.

CV: Cell viability

Coefficient of variation: a measure of variability that is calculated for a group of replicate data by dividing the standard deviation by the mean. It can be multiplied by 100 for expression as a percentage.

CV75: The estimated concentration resulting in 75% cell viability.

EC1.5: Interpolated concentration resulting in a 1.5 fold luciferase induction.

Fold luciferase activity induction: Represents the ratio of luminescence of treated cells (minus blank) over the luminescence of the cells exposed to the concurrent solvent/vehicle control (minus blank).

IC30: Concentration effecting a reduction of cellular viability by 30%.

IC50: Concentration effecting a reduction of cellular viability by 50%.

Hazard: Inherent property of an agent or situation having the potential to cause adverse effects when an organism, system or (sub) population is exposed to that agent.

IATA (Integrated Approach to Testing and Assessment): A structured approach used for hazard identification (potential), hazard characterisation (potency) and/or safety assessment (potential/potency and exposure) of a chemical or group of chemicals, which strategically integrates and weights all relevant data to inform regulatory decision regarding potential hazard and/or risk and/or the need for further targeted and therefore minimal testing.

Imax: Maximal induction factor of luciferase activity compared to the solvent (negative) control measured at any test chemical concentration.

Keap1: Kelch-like ECH-associated protein 1, is a sensor protein that can regulate the Nrf2 activity. Under un-induced conditions the Keap1 sensor protein targets the Nrf2 transcription factor for ubiquitinylation and proteolytic degradation in the proteasome.

© OECD 2018

Covalent modification of the reactive cysteine residues of Keap 1 by small molecules can lead to dissociation of Nrf2 from Keap1 (4) (5) (6).

Mixture: A mixture or a solution composed of two or more substances in which they do not react (1).

Mono-constituent substance: A substance, defined by its quantitative composition, in which one main constituent is present to at least 80% (w/w).

Multi-constituent substance: A substance, defined by its quantitative composition, in which more than one main constituent is present in a concentration ≥ 10% (w/w) and < 80% (w/w). A multi-constituent substance is the result of a manufacturing process. The difference between mixture and multi-constituent substance is that a mixture is obtained by blending of two or more substances without chemical reaction. A multi-constituent substance is the result of a chemical reaction.

Negative control: A sample containing all components of a test system and treated with a substance known not to induce a positive response in the test system. This sample is processed with test chemical-treated samples and other control samples.

Nrf2: nuclear factor (erythroid-derived 2)-like 2, is a transcription factor involved in the antioxidant response pathway. When Nrf2 is not ubiquitinylated, it builds up in the cytoplasm and translocates into the nucleus, where it combines to the ARE in the upstream promoter region of many cytoprotective genes, initiating their transcription (4) (5) (6).

Performance standards: Standards, based on a validated test method, that provide a basis for evaluating the comparability of a proposed test method that is mechanistically and functionally similar. Included are (i) essential test method components; (ii) a minimum list of reference chemicals selected from among the chemicals used to demonstrate the acceptable performance of the validated test method; and (iii) the comparable levels of accuracy and reliability, based on what was obtained for the validated test method, that the proposed test method should demonstrate when evaluated using the minimum list of reference chemicals (3).

Positive control: A replicate containing all components of a test system and treated with a substance known to induce a positive response. To ensure that variability in the positive control response across time can be assessed, the magnitude of the positive response should not be excessive.

Proficiency chemicals (substances): A subset of the Reference Chemicals included in the Performance Standards that can be used by laboratories to demonstrate technical competence with a standardised test method. Selection criteria for these substances typically include that they represent the range of responses, are commercially available, and have high quality reference data available.

Reference chemicals (substances): A set of chemicals to be used to demonstrate the ability of a new test method to meet the acceptability criteria demonstrated by the validated reference test method(s). These chemicals should be representative of the classes of chemicals for which the test method is expected to be used, and should

© OECD 2018

represent the full range of responses that may be expected from the chemicals for which it may be used, from strong, to weak, to negative.

Relevance: Description of relationship of the test to the effect of interest and whether it is meaningful and useful for a particular purpose. It is the extent to which the test correctly measures or predicts the biological effect of interest. Relevance incorporates consideration of the accuracy (concordance) of a test method (3).

Reliability: Measures of the extent that a test method can be performed reproducibly within and between laboratories over time, when performed using the same protocol. It is assessed by calculating intra- and inter-laboratory reproducibility and intra-laboratory repeatability (3).

Reproducibility: The agreement among results obtained from testing the same substance using the same test protocol (see reliability) (3).

Sensitivity: The proportion of all positive / active chemicals that are correctly classified by the test method. It is a measure of accuracy for a test method that produces categorical results, and is an important consideration in assessing the relevance of a test method (3).

Solvent/vehicle control: A replicate containing all components of a test system except of the test chemical, but including the solvent that is used. It is used to establish the baseline response for the samples treated with the test chemical dissolved in the same solvent.

Specificity: The proportion of all negative / inactive chemicals that are correctly classified by the test method. It is a measure of accuracy for a test method that produces categorical results and is an important consideration in assessing the relevance of a test method (3).

Substance: Chemical elements and their compounds in the natural state or obtained by any production process, including any additive necessary to preserve the stability of the product and any impurities deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition (1).

Test chemical: The term "test chemical" is used to refer to what is being tested.

United Nations Globally Harmonized System of Classification and Labelling of Chemicals (UN GHS): A system proposing the classification of chemicals (substances and mixtures) according to standardised types and levels of physical, health and environmental hazards, and addressing corresponding communication elements, such as pictograms, signal words, hazard statements, precautionary statements and safety data sheets, so that to convey information on their adverse effects with a view to protect people (including employers, workers, transporters, consumers and emergency responders) and the environment (1).

UVCB: substances of unknown or variable composition, complex reaction products or biological materials.

© OECD 2018

Validated Reference Method (VRM): the first method(s) endorsed as scientific valid and used as a reference for performance-based validation studies.

Valid test method: A test method considered to have sufficient relevance and reliability for a specific purpose and which is based on scientifically sound principles. A test method is never valid in an absolute sense, but only in relation to a defined purpose (3).

Xeno-free: which does not contain any element that is not from the same species as the cells used, in this case, human.

Literature

1) United Nations (UN) (2017). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Seventh revised edition, New York and Geneva, United Nations Publications. Available at: [https://www.unece.org/trans/danger/publi/ghs/ghs_rev07/07files_e0.html]
2) OECD (2012). Series on Testing and Assessment No. 168. The Adverse Outcome Pathway for Skin Sensitisation Initiated by Covalent Binding to Proteins. Part 1: Scientific Evidence. Organisation for Economic Cooperation and Development, Paris. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2012)10/PART1&docLanguage=En
3) OECD (2005). Guidance Document the Validation and International Acceptance of New or Updated Test Methods for Hazard Assessment. OECD Environment, Health and Safety publications, OECD Series on Testing and Assessment No.34. Organisation for Economic Cooperation and Development, Paris.
4) Natsch A. (2010). The Nrf2-Keap1-ARE Toxicity Pathway as a Cellular Sensor for Skin Sensitizers-Functional Relevance and Hypothesis on Innate Reactions to Skin Sensitizers. Toxicological Sciences 113, 284-292.
5) Dinkova-Kostova A.T., Holtzclaw W.D., Kensler T.W. (2005). The role of Keap1 in cellular protective responses. Chem. Res. Toxicol. 18, 1779-1791.
6) Kansanen E., Kuosmanen S.M., Leinonen H., Levonen A.L. (2013). The Keap1-Nrf2 pathway: Mechanisms of activation and dysregulation in cancer. Redox Biol. 1, 45-49.

© OECD 2018

Appendix IA: In Vitro Skin Sensitisation: The ARE-Nrf2 Luciferase KeratinoSens™ Test Method

INITIAL CONSIDERATIONS, APPLICABILITY AND LIMITATIONS

1. The test method described in this Appendix to Test Guideline 442D addresses the second key event of the skin sensitisation AOP (1), namely keratinocytes activation, by assessing with the help of luciferase, the Nrf2-mediated activation of antioxidant response element (ARE)-dependent genes. Skin sensitisers have been reported to induce genes that are regulated by the ARE (2) (3). Small electrophilic substances such as skin sensitisers can act on the sensor protein Keap1 (Kelch-like ECH-associated protein 1), by e.g. covalent modification of its cysteine residue, resulting in its dissociation from the transcription factor Nrf2 (nuclear factor-erythroid 2-related factor 2). The dissociated Nrf2 can then activate ARE-dependent genes such as those coding for phase II detoxifying enzymes (2) (4) (5).

2. The in vitro ARE-Nrf2 luciferase KeratinoSens™ test method (hereafter called the KeratinoSens™ test method) underwent validation studies (3) (6) (7) followed by an independent peer review conducted by the European Union Reference Laboratory for Alternatives to Animal Testing (EURL ECVAM) (8). The KeratinoSens™ test method was considered scientifically valid to be used as part of an IATA, to support the discrimination between skin sensitisers and non-sensitisers for the purpose of hazard identification (8).

3. Based on the dataset from the validation study and in-house testing used for the independent peer-review of the test method, the KeratinoSens™ test method proved to be transferable to laboratories experienced in cell culture techniques (8). The level of reproducibility in predictions that can be expected from the KeratinoSens™ test method is in the order of 85% within and between laboratories (8). The accuracy (77% - 155/201), sensitivity (78% - 71/91) and specificity (76% - 84/110) of the KeratinoSens™ test method for discriminating skin sensitisers (i.e. UN GHS Cat. 1) from non-sensitisers when compared to LLNA results were calculated by considering all of the data submitted to EURL ECVAM for evaluation and peer-review of the test method (8). These figures are similar to those published based on in-house testing of about 145 test substances (77% accuracy, 79% sensitivity, 72% specificity) (7). This information indicates the usefulness of the KeratinoSens™ test method to contribute to the identification of skin sensitisation hazard. However, the accuracy values given here for KeratinoSens™ test method as a stand-alone test method, are only indicative since the test method should be considered in combination with other sources of information in the context of a Defined Approach or an IATA and in accordance with the provisions of paragraphs 7 and 8 in the General Introduction of this Test Guideline. Furthermore when evaluating non-animal methods for skin sensitisation, it should be kept in mind that the LLNA test as well as other animal tests may not fully reflect the situation in humans.

4. On the basis of the current data available, the KeratinoSens™ test method was shown to be applicable to test chemicals covering a variety of organic functional groups, reaction mechanisms, skin sensitisation potency (as determined with in vivo studies) and physico-chemical properties (3) (6) (7) (8). The test method is applicable to test chemicals soluble or that form a stable dispersion in the exposure medium (i.e. a colloid or suspension in which the test chemical does not settle or separate from the solvent into different phases). Test chemicals that do not fulfil these conditions at the highest final

© OECD 2018

required concentration of 2 000 µM may still be tested at lower concentrations. In such a case, results fulfilling the criteria for positivity could still be used to support the identification of the test chemical as a skin sensitiser. In cases where a negative result is obtained in a test with a maximal concentrations < 1000 µM and no cytotoxicity is reached, the result should be considered as inconclusive (see prediction model in paragraph 32). If cytotoxicity (< 70% viability) is reached at a maximal soluble test concentration < 1000 µM, criteria for negativity can still be applied. In general mono constituent substances with a LogP above 7 may be insoluble in the exposure medium, however, if solubility or stable dispersion can be obtained and documented, testing may still be conducted.

5. Negative results should be interpreted with caution as substances with an exclusive reactivity towards lysine-residues can be detected as negative by the test method as the key mechanism leading to the activation of the Keap1-Nrf2-ARE pathway appears to be the electrophilic reaction of stressors with nucleophilic thiols (cysteine sulfhydryl groups) of Keap-1. Complementary information from peptide reactivity assays may help addressing this uncertainty, in particular assays able to distinguish between cysteine and lysine reactivity. Furthermore, because of the limited metabolic capability of the cell line used (10) and because of the experimental conditions, pro-haptens (i.e. chemicals requiring enzymatic activation for example via P450 enzymes) and pre-haptens (i.e. chemicals activated by auto-oxidation) in particular with a slow oxidation rate may also provide negative results. However, it has been shown that the majority of pre-haptens (i.e. chemicals activated by auto-oxidation) and pro-haptens (i.e. chemicals requiring enzymatic activation for example via P450 enzymes) are sufficiently well identified by a combination of test methods covering key events 1, 2 and 3 on the AOP so that negative results can in general be used to support classification (12) (20) (34). On the other hand, test chemicals that do not act as a sensitiser but are nevertheless chemical stressors may lead to false positive results (8). Finally, test chemicals that interfere with the luciferase enzyme can confound the activity of luciferase in cell-based assays causing either apparent inhibition or increased luminescence (13). For example, phytoestrogen concentrations higher than 1 µM were reported to interfere with the luminescence signals in other luciferase-based reporter gene assays due to over-activation of the luciferase reporter gene (14) As a consequence, luciferase expression obtained at high concentrations of phytoestrogens or similar compounds suspected of producing phytoestrogen-like over-activation of the luciferase reporter gene needs to be examined carefully (14). In cases where evidence can be demonstrated on the non-applicability of the KeratinoSens™ test method to other specific categories of test chemicals, the test method should not be used for those specific categories.

6. In addition to supporting discrimination between skin sensitisers (i.e. UN GHS Category 1) and non-sensitisers, the KeratinoSens™ test method also provides concentration-response information that may potentially contribute to the assessment of sensitising potency when used in integrated approaches such as IATA (11) (15). Examples on how to use the KeratinoSens™ test method results in combination with other information sources are reported in the literature (7) (11) (16) (17) (18) (19) (20). Specifically, the use of KeratinoSens™ test method dose-response data along with quantitative peptide reactivity data to assess potency in the LLNA and in human tests has been described (21) and has been used in Bayesian integrated testing strategies on LLNA potency (11) (22). Furthermore, evaluation has been conducted on how to specifically

© OECD 2018

address potency in humans (23). Finally, the use of KeratinoSens™ test method to assess potency of specific chemical classes has also been described (21) (24).

7. Definitions are provided in the Annex 1 of the General Introduction.

PRINCIPLE OF THE TEST

8. The KeratinoSens™ test method makes use of an immortalised adherent cell line derived from human keratinocytes stably harbouring a luciferase reporter gene under the control of the antioxidant response element of the human AKR1C2 gene (25). This gene is known to be up-regulated by skin sensitisers (26) (27). The cell line contains the luciferase gene under the transcriptional control of a constitutive promoter fused with the ARE element. The luciferase signal reflects the activation by sensitisers of endogenous Nrf2 dependent genes, and the dependence of the luciferase signal in the recombinant cell line on Nrf2 has been demonstrated (28). This allows quantitative measurement (by luminescence detection) of luciferase gene induction, using well established light producing luciferase substrates, as an indicator of the activity of the Nrf2 transcription factor in cells following exposure to electrophilic test substances.

9. Test chemicals are considered positive in the KeratinoSens™ test method if they induce a statistically significant induction of the luciferase activity above a given threshold (i.e. ≥ 1.5 fold, or 50% increase), below a defined concentration which does not significantly affect cell viability (i.e. below 1000 μM and at a concentration at which the cellular viability is above 70% (3) (6). For this purpose, the maximal fold induction of the luciferase activity over solvent (negative) control (I_{max}) is determined. Furthermore, since cells are exposed to series of concentrations of the test chemicals, the concentration needed for a statistically significant induction of luciferase activity above the threshold (i.e. $EC_{1.5}$ value) should be interpolated from the dose-response curve obtained from the series of tested concentrations of the test chemical (see paragraph 26 for calculations). Finally, parallel cytotoxicity measurements should be conducted to assess whether luciferase induction occurs at sub-cytotoxic concentrations.

10. Prior to routine use of the KeratinoSens™ test method that adheres to this Test Guideline, laboratories should demonstrate technical proficiency, using the ten Proficiency Substances listed in Annex 1 of this Appendix.

11. Performance standards (PS) (29) are available to facilitate the validation of new or modified in vitro ARE-Nrf2 luciferase test methods similar to the KeratinoSens™ VRM and allow for timely amendment of this Test Guideline for their inclusion. Mutual Acceptance of Data (MAD) will only be guaranteed for test methods validated according to the PS, if these test methods have been reviewed and included in this Test Guideline by the OECD.

PROCEDURE

12. A DB-ALM protocol for the KeratinoSens™ test method is available and should be employed when implementing and using the test method in the laboratory (9). Laboratories implementing the test method can obtain the recombinant cell line used in the KeratinoSens™ test method by signing a standard agreement with the test method developer[2] which includes the licence for the commercial use of the luciferase gene. The

[2] Givaudan Schweiz AG, CH-8310 Kemptthal

© OECD 2018

luciferase reporter gene assay is also subject to a Promega limited use licence that requires the use of luminescent assay reagents purchased from Promega. The following paragraphs provide with a description of the main components and procedures of the KeratinoSens™ test method. Furthermore, an adaptation of the KeratinoSens™ test method to xeno-free culture conditions using human reagents is described in Annex 2 of this Appendix (33). However, it is recommended that the relevant regulatory authorities be consulted before deciding on the type of serum to be used in the KeratinoSens™ test method.

Preparation of the keratinocyte cultures

13. The KeratinoSens™ transgenic cell line having a stable insertion of the luciferase reporter gene under the control of the ARE-element should be used. Upon receipt, KeratinoSens™ cells are propagated as defined by the test method protocol (e.g. 2 to 4 passages) and stored frozen as a homogeneous stock. Cells from this original stock can be propagated up to maximum 25 passages and are employed for routine testing using the maintenance/growth medium (Dulbecco's Modified Eagle's medium (DMEM) containing serum and Geneticin to allow maintaining the gene) as described within the test method's DB-ALM protocol (9).

14. For testing, cells should be 80-90% confluent, and care should be taken to ensure that cells are never grown to full confluence. One day prior to testing cells are harvested, and distributed into 96-well plates at a cell density of 10,000 cells/well. Attention should be paid to avoid sedimentation of the cells during seeding to ensure homogeneous cell number distribution across wells. If this is not the case, this step may give rise to high well-to-well variability. For each repetition, three replicates are used for the luciferase activity measurements, and at least one parallel replicate is used for the cell viability assay.

Preparation of the test chemical and control substances

15. The test chemical and control substances are prepared on the day of testing. Test chemicals are dissolved in dimethyl sulfoxide (DMSO, CAS No. 67-68-5, ≥ 99% purity) to the final desired concentration (e.g. 200 mM). The DMSO solutions can be considered self-sterilising, so that no sterile filtration is needed. Test chemicals not soluble in DMSO are dissolved in sterile water or culture medium, and the solutions sterilised by e.g. filtration. For a test chemical which has no defined molecular weight (MW), a stock solution is prepared to the default concentration of 40 mg/mL or 4% (w/v). In case solvents other than DMSO, water or the culture medium are used, appropriate scientific rationale should be provided.

16. Based on the stock solutions of the test chemical, serial dilutions are made using DMSO or a suitable solvent (i.e. sterile water or culture medium) to obtain 12 master concentrations of the chemical to be tested (from 0.098 to 200 mM). Independent of the solvent used, the master concentrations, are then further diluted 25 fold into culture medium containing serum, and finally used for treatment with a further 4 fold dilution factor so that the final concentrations of the tested chemical range from 0.98 to 2000 µM (based on a dilution factor of 2). Alternative concentrations may be used upon justification (e.g. in case of cytotoxicity or poor solubility). For a test chemical which has no defined MW, serial dilutions are made using DMSO or a suitable solvent to obtain the

© OECD 2018

desired final concentrations of the test chemical (e.g. 12 concentrations ranging from 0.196 to 400 µg/ml).

17. A concurrent solvent/vehicle control should be tested within each repetition (i.e. DMSO), for which a sufficient number of wells should be prepared per plate (i.e. six). The solvent/vehicle control undergoes the same dilutions as described for the master concentrations in paragraph 16, so that the final solvent/vehicle control concentration is 1%, known not to affect cell viability and corresponding to the same concentration of DMSO found in the tested chemical and in the positive control. For a test chemical not soluble in DMSO, for which the dilutions were made in water, the DMSO level in all wells of the final test solution must be adjusted to 1% as for the other test chemicals and control substances. This solvent/vehicle control (i.e. DMSO) also represents the negative control for the KeratinoSens™ test method.

18. A concurrent positive control should also be tested in a sufficient number of wells within each repetition as described within the DB-ALM protocol (9) to demonstrate appropriate response of the test system. For example, five concentrations of cinnamic aldehyde (CAS No. 14371-10-9, ≥ 98% purity) are used within each replicate in the KeratinoSens™ test method, for which a series of 5 master concentrations ranging from 0.4 to 6.4 mM are prepared in DMSO (from a 6.4 mM stock solution) and diluted as described for the master concentrations in paragraph 16, so that the final concentration of the positive control range from 4 to 64 µM. Other suitable positive controls, preferentially providing $EC_{1.5}$ values in the mid-range, may be used if historical data are available to derive comparable run acceptance criteria.

Application of the test chemical and control substances

19. For each test chemical and positive control substance, one experiment is needed to derive a prediction (positive or negative), consisting of at least two independent repetitions containing each three replicates (i.e. n=6). In case of discordant results between the two independent repetitions, a third repetition containing three replicates should be performed (i.e. n=9). Each independent repetition is performed on a different day with fresh stock solution of test chemicals and independently harvested cells. Cells may come from the same passage however.

20. After seeding as described in paragraph 14, cells are grown for 24 hours in the 96-wells microtiter plates. The medium is then removed and replaced with fresh culture medium (150 µl culture medium containing serum but without Geneticin as described within the DB-ALM protocol (9)) to which 50 µl of the 25 fold diluted test chemical and control substances are added. At least one well per plate should be left empty (no cells and no treatment) to assess background values.

21. The treated plates are then incubated for about 48 hours at 37±1°C in the presence of 5% CO_2. Care should be taken to avoid evaporation of volatile test chemicals and cross-contamination between wells by test chemicals by e.g. covering the plates with a foil during incubation with the test chemicals.

Luciferase activity measurements

22. The following factors are critical to ensure appropriate luminescence readings:

- the choice of a sensitive luminometer,

© OECD 2018

- the use of a plate format with sufficient height to avoid light-cross-contamination,
- the use of a luciferase substrate with sufficient light output to ensure sufficient sensitivity and low variability; and
- an appropriate and stable background level.

Prior to testing, a control experiment setup as described in Annex 3 of this Appendix should be carried out to ensure that these points are met.

23. After the 48 hour exposure time with the test chemical and control substances, cells are washed with a phosphate buffered saline, and the relevant lysis buffer for luminescence readings added to each well for a sufficient time (e.g. 20 min at room temperature).

24. Plates with the cell lysate are then placed in the luminometer for reading which is programmed to: (i) add the luciferase substrate to each well (i.e. 50 µl), (ii) wait for 1 second, and (iii) integrate the luciferase activity for 2 seconds. In case alternative settings are used, e.g. depending on the model of luminometer used, these should be justified. Furthermore, a glow substrate may also be used provided that the quality control experiment of Annex 3 of this Appendix is successfully fulfilled.

Cytotoxicity Assessment

25. For the KeratinoSensTM cell viability assay, medium is replaced after the 48 hour exposure time with fresh medium containing 5 mg/ml MTT (3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, Thiazolyl blue tetrazolium bromide; CAS No. 298-93-1) and cells are incubated for 4 hours at 37±1°C in the presence of 5% CO_2. The MTT medium is then removed and cells are lysed by using an appropriate lysing agent for a sufficient amount of time (e.g. 10% SDS overnight). After shaking, the absorption is then measured at i.e. 600 nm with a photometer as described in the test method protocols (9).

DATA AND REPORTING

Data evaluation

26. The following parameters are calculated in the KeratinoSens™ test method:

- the maximal average fold induction of luciferase activity (Imax) value observed at any concentration of the tested chemical and positive control;
- the $EC_{1.5}$ value representing the concentration for which induction of luciferase activity is above the 1.5 fold threshold (i.e. 50% enhanced luciferase activity) was obtained; and
- the IC_{50} and IC_{30} concentration values for which 50% and 30% reduction of cellular viability occur respectively.

Fold luciferase activity induction is calculated by Equation 1, and the overall maximal fold induction (I_{max}) is calculated as the average of the individual repetitions.

Equation 1: $$Fold\ induction = \frac{(L_{sample} - L_{blank})}{(L_{solvent} - L_{blank})}$$

where

© OECD 2018

L_{sample} is the luminescence reading in the test chemical well
L_{blank} is the luminescence reading in the blank well containing no cells and no treatment
$L_{solvent}$ is the average luminescence reading in the wells containing cells and solvent (negative) control

$EC_{1.5}$ is calculated by linear interpolation according to Equation 2, and the overall $EC_{1.5}$ is calculated as the geometric mean of the individual repetitions.

Equation 2: $$EC1.5 = (C_b - C_a) \times \left(\frac{1.5 - I_a}{I_b - I_a}\right) + C_a$$

where

C_a is the lowest concentration in µM with > 1.5 fold induction
C_b is the highest concentration in µM with < 1.5 fold induction
I_a is the fold induction measured at the lowest concentration with > 1.5 fold induction (mean of three replicate wells)
I_b is the fold induction at the highest concentration with < 1.5 fold induction (mean of three replicate wells)

Viability is calculated by Equation 3:

Equation 3: $$Viability = \frac{(V_{sample} - V_{blank})}{(V_{solvent} - V_{blank})} \times 100$$

where

V_{sample} is the MTT-absorbance reading in the test chemical well
V_{blank} is the MTT-absorbance reading in the blank well containing no cells and no treatment
$V_{solvent}$ is the average MTT-absorbance reading in the wells containing cells and solvent (negative) control

IC_{50} and IC_{30} are calculated by linear interpolation according to Equation 4, and the overall IC_{50} and IC_{30} are calculated as the geometric mean of the individual repetitions.

Equation 4: $$IC_x = (C_b - C_a) \times \left(\frac{(100 - x) - V_a}{V_b - V_a}\right) + C_a$$

where

X is the % reduction at the concentration to be calculated (50 and 30 for IC_{50} and IC_{30})
C_a is the lowest concentration in µM with > x% reduction in viability
C_b is the highest concentration in µM with < x% reduction in viability
V_a is the % viability at the lowest concentration with > x% reduction in viability
V_b is the % viability at the highest concentration with < x% reduction in viability

27. For each concentration showing a luciferase activity induction equal or higher (≥) than 1.5 fold, statistical significance is determined (e.g. using a two-tailed Student's t-test) by comparing the luminescence values of the three replicate samples with the luminescence values in the solvent/vehicle control wells to assess whether the luciferase activity induction is statistically significant ($p < 0.05$). Furthermore, it should be checked that no significant cytotoxic effects occur at the lowest concentration leading to ≥1.5 fold luciferase induction and that this concentrations is below the IC_{30} value, indicating that there is less than or equal to 30% reduction in cellular viability. In addition, at least two

© OECD 2018

consecutive concentrations should have > 70% viability, otherwise the concentration range should be adjusted.

28. It is recommended that data are visually checked with the help of graphs. If no clear dose-response curve is observed, or if the dose-response curve obtained is biphasic (i.e. crossing the threshold of 1.5 twice), the experiment should be repeated to verify whether this is specific to the test chemical or due to an experimental artefact. In case the biphasic response is reproducible in an independent experiment, the lower concentration, i.e. when the threshold of 1.5 is crossed the first time should be reported.

29. In the KeratinoSens™ test method, in the rare cases where a statistically non-significant luciferase induction equal or above 1.5 fold is observed followed by a higher concentration with a statistically significant induction, results from this repetition are only considered as valid and positive if the statistically significant induction equal or above the threshold of 1.5 was obtained for a non-cytotoxic concentration.

30. Finally, for test chemicals generating in the KeratinoSens™ test method a 1.5 fold or higher induction already at the lowest tested concentration (i.e. 0.98 µM), the EC1.5 value of <0.98 is set based on visual inspection of the dose-response curve.

Acceptance criteria

31. The following acceptance criteria should be met when using the KeratinoSens™ test method.

- The luciferase activity induction obtained with the positive control, cinnamic aldehyde, should be statistically significant above the threshold of 1.5 (e.g. using a t-test) in at least one of the tested concentrations (4 to 64 µM).
- The EC1.5 value of the positive control should be within two standard deviations of the historical mean of the testing facility (e.g. between 7 µM and 30 µM based on the validation dataset) which should be regularly updated. In addition, the average induction in the three replicates for cinnamic aldehyde at 64 µM should be between 2 and 8. If the latter criterion is not fulfilled, the dose-response of cinnamic aldehyde should be carefully checked, and tests may be accepted only if there is a clear dose-response with increasing luciferase activity induction at increasing concentrations for the positive control.
- The average coefficient of variation of the luminescence reading for the solvent/vehicle control (i.e. DMSO) should be below 20% in each repetition. If the variability is higher, results should be discarded.

Interpretation of results and prediction model

32. A KeratinoSens™ prediction is considered positive if the following 4 conditions are all met in 2 of 2 or in the same 2 of 3 repetitions, otherwise the KeratinoSens™ prediction is considered negative (Figure 1):

- the I_{max} is equal or higher than (≥) 1.5 fold and statistically significantly different as compared to the solvent/vehicle control (as determined by a two-tailed, unpaired Student's T-test);

© OECD 2018

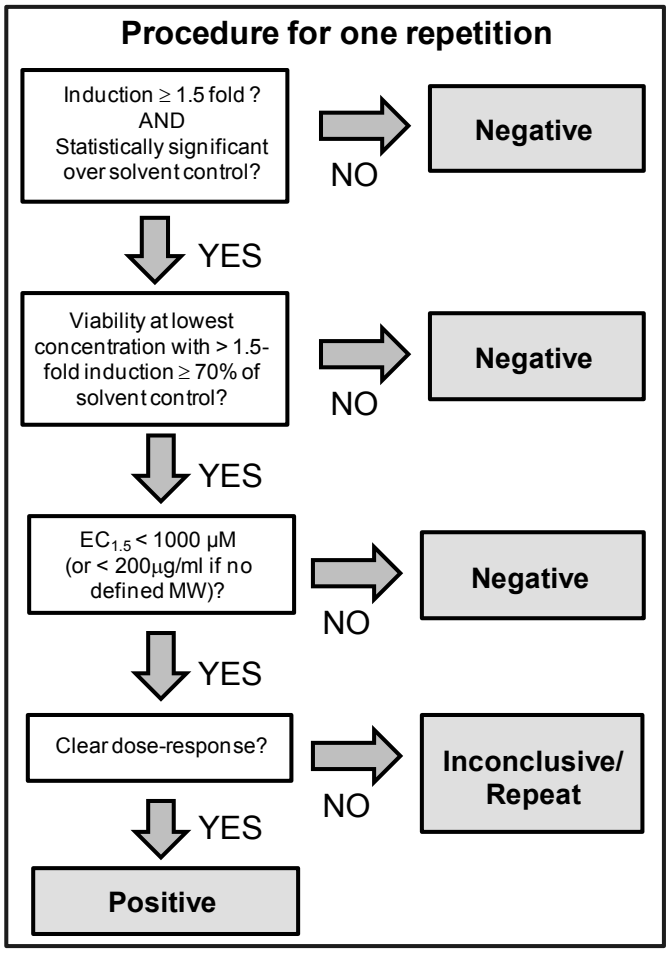
- the cellular viability is higher than (>) 70% at the lowest concentration with induction of luciferase activity ≥1.5 fold (i.e. at the $EC_{1.5}$ determining concentration);
- the $EC_{1.5}$ value is less than (<) 1000 µM (or < 200 µg/mL for test chemicals with no defined MW);
- there is a dose-dependent increase in luciferase induction (or a biphasic response as mentioned under paragraph 28).

If in a given repetition, all of the three first conditions are met but a clear dose-dependent increase in luciferase induction cannot be observed, then the result of that repetition should be considered inconclusive and further testing may be required (Figure 1). In addition, a negative result obtained with test chemicals tested at a maximal test concentration < 1000 µM (or 200 µg/mL for test chemicals with no defined MW) and which do not reach cytotoxicity (< 70% viability) at the maximal tested concentration should also be considered as inconclusive (see paragraph 4).

© OECD 2018

Figure 1. Prediction model used in the KeratinoSens™ test method.

A KeratinoSens™ prediction should be considered in the framework of a Defined Approach or of an IATA and in accordance with the provisions of paragraphs 7 and 8 of the general introduction



Perform at least two independent repetitions

- **If the two repetitions are positive, final outcome is: POSITIVE**
- **If the two repetitions are negative, final outcome is: NEGATIVE**

In case the first two repetitions are not concordant, perform a third repetition and conclude on the basis of the mode of the outcomes (i.e., 2 out of 3).

© OECD 2018

33. In cases when test chemicals induce the luciferase activity very close to the cytotoxic levels, they can be positive in some repetitions at non-cytotoxic levels (i.e. $EC_{1.5}$ determining concentration below (<) the IC_{30}), and in other repetitions only at cytotoxic levels (i.e. $EC_{1.5}$ determining concentration above (>) the IC_{30}). Such test chemicals shall be retested with more narrow dose-response analysis using a lower dilution factor (e.g. 1.33 or √2 (=1.41) fold dilution between wells), to determine if induction has occurred at cytotoxic levels or not (3).

Test report

34. The test report should include the following information:

Test chemical

- Mono-constituent substance
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), SMILES or InChI code, structural formula, and/or other identifiers, like batch/ lot number and expiry date;
  - Physical appearance, water solubility, DMSO solubility, molecular weight, and additional relevant physicochemical properties, to the extent available;
  - Statement on (in)solubility or stable dispersion in exposure media;
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;
  - Treatment prior to testing, if applicable (e.g. warming, grinding);
  - Concentration(s) tested;
  - Storage conditions and stability to the extent available.
- Multi-constituent substance, UVCB and mixture:
  - Characterisation as far as possible by e.g. chemical identity (see above), purity, quantitative occurrence and relevant physicochemical properties (see above) of the constituents, to the extent available;
  - Physical appearance, water solubility, DMSO solubility and additional relevant physicochemical properties, to the extent available;
  - Molecular weight or apparent molecular weight in case of mixtures/polymers of known compositions or other information relevant for the conduct of the study;
  - Statement on (in)solubility or stable dispersion in exposure media;
  - Treatment prior to testing, if applicable (e.g. warming, grinding);
  - Concentration(s) tested;
  - Storage conditions and stability to the extent available.

Controls

- Positive control

© OECD 2018

- Chemical identification, such as IUPAC or CAS name(s), CAS number(s), SMILES or InChI code, structural formula, and/or other identifiers;
- Physical appearance, water solubility, DMSO solubility, molecular weight, and additional relevant physicochemical properties, to the extent available and where applicable;
- Purity, chemical identity of impurities as appropriate and practically feasible, etc;
- Treatment prior to testing, if applicable (e.g. warming, grinding);
- Concentration(s) tested;
- Storage conditions and stability to the extent available;
- Reference to historical positive control results demonstrating suitable run acceptance criteria, if applicable.

- Solvent/vehicle/negative control
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), and/or other identifiers;
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;
  - Physical appearance, molecular weight, and additional relevant physicochemical properties in the case other solvents/vehicles /negative controls than those mentioned in this Appendix are used and to the extent available;
  - Storage conditions and stability to the extent available;
  - Justification for choice of solvent/vehicle for each test chemical.

Test method conditions

- Name and address of the sponsor, test facility and study director;
- Description of test method used;
- Cell line used, its storage conditions and source (e.g. the facility from which they were obtained);
- Passage number and level of confluence of cells used for testing;
- Cell counting method used for seeding prior to testing and measures taken to ensure homogeneous cell number distribution (cf. paragraph 14);
- Luminometer used (e.g. model), including instrument settings, luciferase substrate used, and demonstration of appropriate luminescence measurements based on the control test described in Annex 3 of this Appendix;
- The procedure used to demonstrate proficiency of the laboratory in performing the test method (e.g. by testing of proficiency substances) or to demonstrate reproducible performance of the test method over time.

© OECD 2018

Test procedure

- Number of repetitions and replicates used;
- Test chemical concentrations, application procedure and exposure time used (if different than the one recommended)
- Description of evaluation and decision criteria used;
- Description of study acceptance criteria used;
- Description of any modifications of the test procedure.

Results

- Tabulation of Imax, $EC_{1.5}$ and viability values (i.e. IC_{50}, IC_{30}) obtained for the test chemical and for the positive control for each repetition as well as the mean values (Imax: average; $EC_{1.5}$ and viability values: geometric mean) and SD calculated using data from all individual repetitions and an indication of the rating of the test chemical according to the prediction model;
- Coefficient of variation obtained with the luminescence readings for the solvent/vehicle/negative control for each experiment;
- A graph depicting dose-response curves for induction of luciferase activity and viability;
- Description of any other relevant observations, if applicable.

Discussion of the results

- Discussion of the results obtained with the KeratinoSens™ test method;
- Consideration of the test method results within the context of an IATA, if other relevant information is available.

Conclusion

Literature

1) OECD (2012). Series on Testing and Assessment No. 168. The Adverse Outcome Pathway for Skin Sensitisation Initiated by Covalent Binding to Proteins. Part 1: Scientific Evidence. Organisation for Economic Cooperation and Development, Paris. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2012)10/PART1&docLanguage=En

2) Natsch A. (2010). The Nrf2-Keap1-ARE Toxicity Pathway as a Cellular Sensor for Skin Sensitizers-Functional Relevance and Hypothesis on Innate Reactions to Skin Sensitizers. Toxicological Sciences 113, 284-292.

3) Emter R., Ellis G., Natsch A.(2010). Performance of a novel keratinocyte-based reporter cell line to screen skin sensitizers in vitro. Toxicology and Applied Pharmacology 245, 281-290.

4) Dinkova-Kostova A.T., Holtzclaw W.D., Kensler T.W. (2005). The role of Keap1 in cellular protective responses. Chem. Res. Toxicol. 18, 1779-1791.

© OECD 2018

5) Kansanen E., Kuosmanen S.M., Leinonen H., Levonen A.L. (2013). The Keap1-Nrf2 pathway: Mechanisms of activation and dysregulation in cancer. Redox Biol. 1, 45-49.

6) Natsch A., Bauch C., Foertsch L., Gerberick F., Normann K., Hilberer A., Inglis H., Landsiedel R., Onken S., Reuter H., Schepky A., Emter R. (2011). The intra- and inter-laboratory reproducibility and predictivity of the KeratinoSens assay to predict skin sensitizers in vitro: results of a ring-study in five laboratories. Toxicol. In Vitro 25, 733-744.

7) Natsch A., Ryan C.A., Foertsch L., Emter R., Jaworska J., Gerberick G.F., Kern P. (2013). A dataset on 145 chemicals tested in alternative assays for skin sensitization undergoing prevalidation. Journal of Applied Toxicology 33, 1337-1352.

8) EURL-ECVAM (2014). Recommendation on the KeratinoSensTM assay for skin sensitisation testing, 42 pp. Available at: http://ihcp.jrc.ec.europa.eu/our_labs/eurl-ecvam/eurl-ecvam-recommendations/recommendation-keratinosens-skin-sensitisation.

9) DB-ALM (INVITTOX) (2013) Protocol 155: KeratinoSensTM., 17 pp. Available: [http://ecvam-dbalm.jrc.ec.europa.eu/].

10) Fabian E., Vogel D., Blatz V., Ramirez T., Kolle S., Eltze T., van Ravenzwaay B., Oesch F., Landsiedel R. (2013). Xenobiotic metabolizin enzyme activities in cells used for testing skin sensitization in vitro. Arch Toxicol 87, 1683-1969.

11) Jaworska J., Dancik Y., Kern P., Gerberick F., Natsch A. (2013). Bayesian integrated testing strategy to assess skin sensitization potency: from theory to practice. J. Appl. Toxicol. 33, 1353-1364.

12) Casati S., Aschberger K., Asturiol D., Basketter D., Dimitrov S., Dumont C., Karlberg A.T., Lepoittevin J.P., Patlewicz G., Roberts D.W., Worth A. (2016). Ability of non-animal methods for skin sensitisation to detect pre- and pro-haptens: Report and recommendations of an EURL ECVAM expert meeting. EUR 27752 EN. Available at : https://eurl-ecvam.jrc.ec.europa.eu/eurl-ecvam-status-reports/pre-prohapten-workshop-report.

13) Thorne N., Inglese J., Auld D.S. (2010). Illuminating Insights into Firefly Luciferase and Other Bioluminescent Reporters Used in Chemical Biology. Chemistry and Biology 17, 646-657.

14) OECD (2012). BG1Luc Estrogen Receptor Transactivation Test Method for Identifying Estrogen Receptor Agonists and Antagonists. OECD Guidelines for Chemical Testing No. 457. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

15) ECETOC (2003). Contact sensitization: Classification according to potency. European Centre for Ecotoxicology & Toxicology of Chemicals (Technical Report No. 87).

16) Bauch C., Kolle S.N., Ramirez T., Eltze T., Fabian E., Mehling A., Teubner W., van Ravenzwaay B., Landsiedel R. (2012). Putting the parts together: combining in vitro methods to test for skin sensitizing potentials. Regul. Toxicol. Pharmacol. 63, 489-504.

17) Natsch A., Emter R., Ellis G. (2009). Filling the concept with data: integrating data from different in vitro and in silico assays on skin sensitizers to explore the battery approach for animal-free skin sensitization testing. Toxicol. Sci. 107, 106-121.

18) Ball N., Cagen S., Carrillo J.C., Certa H., Eigler D., Emter R., Faulhammer F., Garcia C., Graham C., Haux C., Kolle S.N., Kreiling R., Natsch A., Mehling A. (2011). Evaluating the sensitization potential of surfactants: integrating data from the local lymph node assay, guinea

© OECD 2018

pig maximization test, and in vitro methods in a weight-of-evidence approach. Regul Toxicol. Pharmacol. 60, 389-400.

19) Urbisch D., Mehling A., Guth K., Ramirez T., Honarvar N., Kolle S., Landsiedel R., Jaworska J., Kern P.S., Gerberick F., Natsch A., Emter R., Ashikaga T., Miyazawa M., Sakaguchi H. (2015). Assessing skin sensitization hazard in mice and men using non-animal test methods. Regul. Toxicol. Pharmacol. 71, 337–351.

20) Urbisch D., Becker M., Honarvar N., Kolle S.N., Mehling A., Teubner W., Wareing B., Landsiedel R. (2016). Assessment of Pre- and Pro-haptens Using Non-animal Test Methods for Skin Sensitization. Chem. Res. Toxicol. 29, 901-13.

21) Natsch A, Emter R, Gfeller H, Haupt T, Ellis G (2015). Predicting Skin Sensitizer Potency Based on In Vitro Data from KeratinoSens and Kinetic Peptide Binding: Global Versus Domain-Based Assessment. Toxicol Sci 143, 319-332.

22) Jaworska JS, Natsch A, Ryan C, Strickland J, Ashikaga T, Miyazawa M (2015). Bayesian integrated testing strategy (ITS) for skin sensitization potency assessment: a decision support system for quantitative weight of evidence and adaptive testing strategy. Arch Toxicol 89, 2355-2383.

23) Strickland J, Zang Q, Paris M, Lehmann DM, Allen D, Choksi N, Matheson J, Jacobs A, Casey W, Kleinstreuer N (2017). Multivariate models for prediction of human skin sensitization hazard. J Appl Toxicol 37, 347-360.

24) Delaine T, Ponting DJ, Niklasson IB, Emter R, Hagvall L, Norrby PO, Natsch A, Luthman K, Karlberg AT (2014). Epoxyalcohols: bioactivation and conjugation required for skin sensitization. Chem Res Toxicol 27, 1860-1870.

25) Wasserman W.W., Fahl W.E. (1997). Comprehensive analysis of proteins which interact with the antioxidant responsive element: correlation of ARE-BP-1 with the chemoprotective induction response. Arch. Biochem. Biophys. 344, 387-396.

26) Gildea L.A., Ryan C.A., Foertsch L.M., Kennedy J.M., Dearman R.J., Kimber I., Gerberick G.F. (2006). Identification of gene expression changes induced by chemical allergens in dendritic cells: opportunities for skin sensitization testing. J. Invest. Dermatol. 126, 1813-1822.

27) Ryan C.A., Gildea L.A., Hulette B.C., Dearman R.J., Kimber I. And Gerberick G.F. (2004). Gene expressing changes in peripheral blood-derived dendritic cells following exposure to a contact allergen. Toxicol. Lett. 150, 301-316.

28) Emter R., van der Veen J.W., Adamson G., Ezendam J., van Loveren H., Natsch A. (2013). Gene expression changes induced by skin sensitizers in the KeratinoSens™ cell line: Discriminating Nrf2-dependent and Nrf2-independent events. Toxicol. In Vitro 27, 2225-2232.

29) OECD (2015). Guidance Document No 213. Performance Standards for assessment of proposed similar or modified in vitro skin sensitisation ARE-NrF2 luciferase test methods. Series on Testing and Assessment. Available at: http://www.oecd.org/env/ehs/testing/series-testing-assessment-publications-number.htm

30) OECD (2005). Guidance Document the Validation and International Acceptance of New or Updated Test Methods for Hazard Assessment. OECD Environment, Health and Safety publications, OECD Series on Testing and Assessment No.34. Organisation for Economic Cooperation and Development, Paris.

© OECD 2018

United nations (UN) (2017). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Seventh revised edition, New York and Geneva, United Nations Publications. Available at: [https://www.unece.org/trans/danger/publi/ghs/ghs_rev07/07files_e0.html]

31) Basketter D.A., Alépée N., Ashikaga T., Barroso J., Gilmour N., Goebel C., Hibatallah J., Hoffmann S., Kern P., Martinozzi-Teissier S., Maxwell G., Reisinger K., Sakaguchi H., Schepky A., Tailhardat M., Templier M. (2014). Categorization of chemicals according to their relative human skin sensitizing potency. Dermatitis 25, 11-21.

32) Belot N, Sim B, Longmore CL, Roscoe L, Treasure C. (2017) Adaptation of the KeratinoSens™ skin sensitisation test to animal-product-free cell culture.ALTEX. 2017 Mar 16. doi: 10.14573/altex.1701311

33) Patlewicz G, Casati S, Basketter DA, Asturiol D, Roberts DW, Lepoittevin J-P, Worth A and Aschberger K (2016) Can currently available non-animal methods detect pre and pro haptens relevant for skin sensitisation? Regul Toxicol Pharmacol, 82, 147-155.

© OECD 2018

APPENDIX IA - ANNEX 1: PROFICIENCY SUBSTANCES

In Vitro Skin Sensitisation: The ARE-Nrf2 Luciferase KeratinoSensTM Test Method

Prior to routine use of a test method that adheres to this Appendix of Test Guideline 442D, laboratories should demonstrate technical proficiency by correctly obtaining the expected KeratinoSens™ prediction for the 10 Proficiency Substances recommended in Table 1 and by obtaining the $EC_{1.5}$ and IC_{50} values that fall within the respective reference range for at least 8 out of the 10 proficiency substances. These Proficiency Substances were selected to represent the range of responses for skin sensitisation hazards. Other selection criteria were commercial availability, availability of high quality in vivo reference, and availability of high quality in vitro data from the KeratinoSens™ test method.

Table 1. Recommended substances for demonstrating technical proficiency with the KeratinoSens™ test method

Proficiency Substances	CASRN	Physical Form	LLNA Prediction (1)	Human category (2)	KeratinoSens™ Prediction (3)	$EC_{1.5}$ (µM) Reference Range (4)	IC_{50} (µM) Reference Range (5)
Salicylic acid	69-72-7	Solid	Non-sensitiser	Cat. 6	Negative	> 1000	> 1000
Lactic acid	50-21-5	Liquid	Non-sensitiser	Cat. 6	Negative	> 1000	> 1000
Glycerol	56-81-5	Liquid	Non-sensitiser	Cat. 6	Negative	> 1000	> 1000
Isopropanol	67-63-0	Liquid	Non-sensitiser	Cat. 5	Negative	> 1000	> 1000
Ethylene glycol dimethacrylate	97-90-5	Liquid	Sensitiser (weak)	Cat. 4	Positive	5 - 125	> 500
Cinnamyl alcohol	104-54-1	Solid	Sensitiser (weak)	Cat. 3	Positive	25 - 175	> 1000
2-Mercaptobenzothiazole	149-30-4	Solid	Sensitiser (moderate)	Cat. 3	Positive	25 - 250	> 500
4-Methylaminophenol sulfate	55-55-0	Solid	Sensitiser (strong)	Cat. 3	Positive	< 12.5	20 - 200
Methyldibromo	35691-65-7	Solid	Sensitiser	Cat. 2	Positive	< 20	20 - 100

© OECD 2018

glutaronitrile			(strong)				
2,4-Dinitrochlorobenzene	97-00-7	Solid	Sensitiser (extreme)	Cat. 1	Positive	< 12.5	5 - 20

Notes: (1) The in vivo hazard (and potency) predictions are based on LLNA data (7). The in vivo potency is derived using the criteria proposed by ECETOC (15); (2) According to Basketter and co-workers (32). Cat. 1 represents clear evidence of contact allergy, Cat. 2 a frequent cause of contact allergy, Cat. 3 a common cause of contact allergy, Cat. 4 an infrequent cause of contact allergy, Cat. 5 a rare cause of contact allergy, and Cat. 6 essentially absent evidence of contact allergy (32). (3) A KeratinoSensTM prediction should be considered in the framework of a Defined Approach or of an IATA and in accordance with the provisions of paragraphs 7 and 8 of the general introduction. (4) Based on the historical observed values (6).

© OECD 2018

APPENDIX IA - ANNEX 2: ADAPTATION OF THE KERATINOSENS™ TEST METHOD USING HUMAN REAGENTS TO ACHIEVE XENO-FREE CELL CULTURE

The following adaptation to the KeratinoSens™ test method may be performed using human reagents (human serum and recombinant human trypsin) to achieve xeno-free cell culture, subject to demonstration of technical proficiency (as described in Annex 1) using the adapted method (33).

Table 2. Summary of adaptations

Aspect of the Method	Validated Reference Method (KeratinoSens™) (Appendix 1A)	Xeno-Free Adaptation (this Annex)
Serum[1]	States "serum" (DB-ALM protocol 155 states Foetal Calf Serum) (paragraph 13)	Specifies 10% human serum
Cytotoxicity measurement[2]	MTT: 4hrs incubation; solubilise in 10% SDS overnight; read at 600nm (paragraph 25)	MTT (1mg/ml): 3hrs incubation; solubilise in isopropanol; read at 570nm
Positive control[2]	Cinnamic aldehyde 4-64µM (paragraph 18)	Cinnamic aldehyde 8-128µM.
Trypsin[1]	Not specified (DB-ALM protocol 155 states Trypsin EDTA)	Non-animal recombinant trypsin (TrypZean, Sigma-Aldrich T3499)

Note: [1]adaptations to achieve xeno-free conditions; [2]other adaptations to the method (33).

Prior to use for testing purposes, the KeratinoSens™ cell line should be adapted to routine culture using 10% human serum. Human serum (from pooled donors) should be obtained from a reliable commercial source, with appropriate donor consent and QC testing for cell culture applications. As with any type of serum, when a new batch is used, an internal validation of the batch including cell morphology, growth rates and Imax / $EC_{1.5}$ values with at least the positive control, and preferably representative reference chemicals (at least one sensitiser and one non sensitiser) should be conducted, with subsequent reservation of successfully performing batches for long term use. If the cells have previously been cultured in foetal calf serum, they should be weaned into human serum over at least 3 passages. Provided that the cells are showing healthy morphology and comparable growth rates with those in foetal calf serum, a cell bank should then be created for future use. It should be noted that the KeratinoSens™ cell line, when cultured in human serum, should be cultured up to a maximum passage number of 22 for optimal performance, including the number taken to adapt them to human serum. To achieve fully xeno-free cell culture, a non-animal source of recombinant trypsin (for example, Trypzean™) should be used to harvest the cells during sub-culture (33). In all other respects, the cells should be cultured in the same way as described in this Appendix to Test Guideline 442D and the DB-ALM protocol (9) for the reference KeratinoSens™ cell line

With reference to paragraph 18, the xeno-free adaptation of the KeratinoSens™ test method using human reagents has been optimised using cinnamic aldehyde (CAS No. 14371-10-9, >98% purity) as a positive control, at a final concentration range from 8 to

© OECD 2018

128µM. Other positive controls, preferentially providing EC1.5 values in the mid-range, may be used if historical data are available to derive comparable run acceptance criteria (33).

With reference to paragraph 25, the xeno-free adaptation of the KeratinoSens™ test method using human reagents has been optimised using the following method for cytotoxicity assessment. Medium is replaced after the 48 hour exposure time with fresh medium containing MTT (3-(4,5-dimethyl2-thiazolyl)-2,5-diphenyl-2H-tetrazolium bromide; CAS No. 298-93-1) at a concentration of 1mg/ml, and cells incubated for 3 hours at 37 ± 1°C in the presence of 5% CO_2. The MTT medium is then removed and cells are solubilised by the addition of isopropanol. After shaking for 30 minutes, the absorption is measured at 570 nm with a spectrophotometer.

All other aspects the xeno-free adaptation of the KeratinoSens™ test method using human reagents should be conducted in the same way as described for the standard method described in this Appendix to Test Guideline 442D and the DB-ALM protocol (9) for the reference KeratinoSens™ cell line.

© OECD 2018

APPENDIX IA - ANNEX 3: QUALITY CONTROL OF LUMINESCENCE MEASUREMENTS

Basic experiment for ensuring optimal luminescence measurements in the KeratinoSensTM test method

The following three parameters are critical to ensure obtaining reliable results with the luminometer:

- having a sufficient sensitivity giving a stable background in control wells;
- having no gradient over the plate due to long reading times; and
- having no light contamination in adjacent wells from strongly active wells.

Prior to testing it is recommended to ensure having appropriate luminescence measurements, by testing a control plate set-up as described below (triplicate analysis).

Table 1. Plate setup of first training experiment

	1	2	3	4	5	6	7	8	9	10	11	12
A	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
B	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
C	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
D	**EGDMA 0.98**	**EGDMA 1.95**	**EGDMA 3.9**	**EGDMA 7.8**	**EGDMA 15.6**	**EGDMA 31.25**	**EGDMA 62.5**	**EGDMA 125**	**EGDMA 250**	**EGDMA 500**	**EGDMA 1000**	**EGDMA 2000**
E	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
F	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
G	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
H	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	**CA 4**	**CA 8**	**CA 16**	**CA 32**	**CA 64**	**Blank**

Notes: EGDMA = Ethylene glycol dimethacrylate (CAS No.: 97-90-5) a strongly inducing compound.
C = Cinnamic aldehyde, positive reference (CAS No.: 104-55-2). Concentrations are given in µM

The quality control analysis should demonstrate:

- a dose-dependent increase in luciferase induction in row D, with the I_{max} > 20 fold above background (in most cases Imax values between 100 and 300 are reached);
- a dose-dependent increase in luciferase induction in wells H7 to H11, with a fold induction of 2 to 8 in well H11;
- no dose-dependent increase in luciferase induction in row C and E (no induction value equal or above 1.5 (ideally not above 1.3) due to possible light contamination especially next to strongly active wells in the EGDMA row;

© OECD 2018

- no statistically significant difference between the rows A, B, C, E, F and G. (i.e. no gradient over plate); and
- variability in any of the rows A, B, C, E, F and G and in the DMSO wells in row H should be below 20% (i.e. stable background).

© OECD 2018

Appendix IB: In Vitro Skin Sensitisation: The ARE-Nrf2 Luciferase LuSens Test Method

INITIAL CONSIDERATIONS, APPLICABILITY AND LIMITATIONS

1. The test method described in this Appendix to Test Guideline 442D addresses the second key event of the skin sensitisation AOP (1), namely keratinocytes activation, by assessing with the help of luciferase, the Nrf2-mediated activation of antioxidant response element (ARE)-dependent genes. Skin sensitisers have been reported to induce genes that are regulated by the ARE (2) (3). Small electrophilic substances such as skin sensitisers can act on the sensor protein Keap1 (Kelch-like ECH-associated protein 1), by e.g. covalent modification of its cysteine residue, resulting in its dissociation from the transcription factor Nrf2 (nuclear factor-erythroid 2-related factor 2). The dissociated Nrf2 can then activate ARE-dependent genes such as those coding for phase II detoxifying enzymes (2) (4) (5).

2. The in vitro ARE-Nrf2 luciferase LuSens test method (hereafter called the LuSens test method) underwent a Performance Standard-based validation study based on the KeratinoSens™ Validated Reference Method (VRM) (6) (7) (8) (9), followed by an independent peer review conducted by the European Union Reference Laboratory for Alternatives to Animal Testing (EURL ECVAM) (10). The LuSens test method was considered scientifically valid to be used as part of an IATA, to support the discrimination between skin sensitisers and non-sensitisers for the purpose of hazard identification (10).

3. The LuSens test method proved to be transferable to laboratories experienced in cell culture techniques and met the reproducibility performance standards required both within and between laboratories (10). Additional information from earlier in-house study on 72 test chemicals showed similar predictive capacity as the VRM (74% accuracy, 74% sensitivity, and 74% specificity) for discriminating skin sensitisers (i.e. UN GHS Cat. 1) from non-sensitisers when compared to LLNA results (7) (10), indicating the usefulness of the LuSens test method to contribute to the identification of skin sensitisation hazard. However, the accuracy values given here for LuSens test method as a stand-alone test method, are only indicative since the test method should be considered in combination with other sources of information in the context of a Defined Approach or an IATA and in accordance with the provisions of paragraphs 7 and 8 in the General Introduction of this Test Guideline. Furthermore when evaluating non-animal methods for skin sensitisation, it should be kept in mind that the LLNA test as well as other animal tests may not fully reflect the situation in humans.

4. On the basis of the current data available, the LuSens test method was shown to be applicable to test chemicals covering a variety of organic functional groups, reaction mechanisms, skin sensitisation potency (as determined with in vivo studies) and physico-chemical properties (7) (8). The test method is applicable to test chemicals soluble or that form a stable dispersion in the exposure medium (i.e. a colloid or suspension in which the test chemical does not settle or separate from the solvent into different phases). Test chemicals that do not fulfil these conditions at the highest final required testing concentration (i.e. 2000 µM or 2000 µg/mL if no molecular weight is available) may still be tested at lower concentrations. In such a case, results fulfilling the criteria for positivity could still be used to support the identification of the test chemical as a skin sensitiser. In cases where a negative result is obtained in a test with a maximal

© OECD 2018

concentrations < 2000 µM (or < 2000 µg/mL if no molecular weight is available) and no cytotoxicity is observed, the result should be considered as inconclusive (see prediction model in paragraph 32). If cytotoxicity (<70% viability) is reached at a test concentration < 2000 µM (or < 2000 µg/mL if no molecular weight is available), criteria for negativity can still be applied. In general mono constituent substances with a LogP above 7 may be insoluble in the exposure medium, however, if solubility or stable dispersion can be obtained and documented, testing may still be conducted.

5. Negative results should be interpreted with caution as substances with an exclusive reactivity towards lysine-residues can be detected as negative by the test method as the key mechanism leading to the activation of the Keap1-Nrf2-ARE pathway appears to be the electrophilic reaction of stressors with nucleophilic thiols (cysteine sulfhydryl groups) of Keap-1. Complementary information from peptide reactivity assays may help addressing this uncertainty, in particular assays able to distinguish between cysteine and lysine reactivity. Furthermore, because of the limited metabolic capability of the cell line used (12) and because of the experimental conditions, pro-haptens (i.e. chemicals requiring enzymatic activation for example via P450 enzymes) and pre-haptens (i.e. chemicals activated by auto-oxidation) in particular with a slow oxidation rate may also provide negative results. However, it has been shown that the majority of pre-haptens (i.e. chemicals activated by auto-oxidation) and pro-haptens (i.e. chemicals requiring enzymatic activation for example via P450 enzymes) are sufficiently well identified by a combination of test methods covering key events 1, 2 and 3 on the AOP so that negative results can in general be used to support classification (13) (14) (15). On the other hand, test chemicals that do not act as a sensitiser but are nevertheless chemical stressors may lead to false positive results as shown with the VRM (11). Finally, test chemicals that interfere with the luciferase enzyme can confound the activity of luciferase in cell-based assays causing either apparent inhibition or increased luminescence (16). For example, phytoestrogen concentrations higher than 1 µM were reported to interfere with the luminescence signals in other luciferase-based reporter gene assays due to over-activation of the luciferase reporter gene (17). As a consequence, luciferase expression obtained at high concentrations of phytoestrogens or similar compounds suspected of producing phytoestrogen-like over-activation of the luciferase reporter gene needs to be examined carefully (17). In cases where evidence can be demonstrated on the non-applicability of the LuSens test method to other specific categories of test chemicals, the test method should not be used for those specific categories.

6. In addition to supporting discrimination between skin sensitisers (i.e. UN GHS Category 1) and non-sensitisers, the LuSens test method also provides information (e.g. dose- response) that may potentially contribute to the assessment of sensitising potency when used in integrated approaches such as IATA such as described for the VRM (13). However, further work, preferably based on human data, is required to determine how the LuSens test method results can contribute to potency assessment, especially in the context of an IATA (18). Examples on how to use the ARE-Nrf2 luciferase test methods in combination with other information are reported in literature (15) (18).

7. Definitions are provided in Annex 1 of the General Introduction.

PRINCIPLE OF THE TEST

8. The LuSens test method makes use of an immortalised adherent cell line derived from human keratinocytes stably harbouring a luciferase reporter gene under the control

© OECD 2018

of the antioxidant response element of the rat NQO1 gene (20). Genes dependent on the ARE such as NQO1 are known to be up-regulated by contact sensitisers (21) (22). The cell line contains the luciferase gene under the transcriptional control of a promoter fused with the ARE element (7). The luciferase signal reflects the activation by sensitisers of endogenous Nrf2 dependent genes, and the dependence of the luciferase signal in the recombinant cell line on Nrf2 has been directly demonstrated for the VMR (23), and indirectly demonstrated for the LuSens (7). This allows quantitative measurement (by luminescence detection) of luciferase gene induction, using well established light producing luciferase substrates, as an indicator of the activity of the Nrf2 transcription factor in cells following exposure to electrophilic test substances.

9. Test chemicals are considered positive in the LuSens test method if they induce a statistically significant induction of the luciferase activity above a given threshold (i.e. ≥ 1.5 fold, or 50% increase) in at least two consecutive concentrations which do not significantly affect cell viability (i.e. at which the cellular viability is above 70%) (7) (8). For this purpose, induction of the luciferase activity over solvent/vehicle control is determined. Furthermore, parallel cytotoxicity measurements should be conducted to assess whether luciferase activity induction levels occur at sub-cytotoxic concentrations.

10. Prior to routine use of the LuSens test method that adheres to this Test Guideline, laboratories should demonstrate technical proficiency, using the ten Proficiency Substances listed in Annex 1 of this Appendix.

PROCEDURE

11. A DB-ALM protocol for the LuSens test method is available and should be employed when implementing and using the test method in the laboratory (24). A summary of the main protocol steps of the LuSens test method as compared to the VRM is given in Annex 2 of this Appendix. Laboratories implementing this Test Guideline can obtain the recombinant cell line used in the test method by requests to the test developers[3]. The luciferase reporter gene assay is subject to a Promega limited use licence requiring i) the use of luminescent assay reagents purchased from Promega; or ii) to contact Promega to obtain a free license for commercial use. The following paragraphs provide with a description of the main components and procedures of the LuSens test method.

Preparation of the keratinocyte cultures

12. The LuSens transgenic cell line having a stable insertion of the luciferase reporter gene under the control of the ARE-element should be used. Upon receipt, cells are propagated as defined by the test method protocol (e.g. 1 to 3 passages) and stored frozen as a homogeneous stock. Cells from this original stock can be propagated up to a maximum of 20 passage number and are employed for routine testing using the appropriate maintenance/growth medium (e.g. Dulbecco's Modified Eagle's medium (DMEM) containing serum and antibiotics such as puromycin in the maintenance medium (for selection) and penicillin/streptomycin (to prevent contamination)) as described within the test method's protocol (24). No antibiotics are added however to the medium during testing.

[3] BASF SE, 67056 Ludwigshafen, Germany.

© OECD 2018

13. For testing, cells should be 80-90% confluent, and care should be taken to ensure that cells are never grown to full confluence. One day prior to testing cells are harvested, and distributed into 96-well plates at the appropriate cell density (i.e. 10 000 cells/well). Attention should be paid to avoid sedimentation of the cells during seeding to ensure homogeneous cell number distribution across wells. If this is not the case, this step may result in high well-to-well variability. For each repetition of the main luciferase test for each test chemical concentration, three replicates are used for the luciferase activity measurements, and three replicates used for the cell viability assay.

Preparation of the test chemical and control substances

14. The test chemical and control substances are prepared (or thawed in case of stable frozen solutions) on the day of testing. Test chemicals are dissolved in a suitable solvent, e.g. dimethyl sulfoxide (DMSO, CAS No. 67-68-5, ≥ 99% purity) to the final concentration that allows reaching the maximum concentration tested (e.g. 200 mM). The DMSO solutions can be considered self-sterilising, so that no sterile filtration is needed. Test chemicals not soluble in DMSO are dissolved in sterile water or culture medium, in which the appropriate measures should be taken to ensure that the final solutions are sterile. For a test chemical which has no defined molecular weight (MW), a stock solution is prepared to a default concentration of 200 mg/mL or 20% (w/v). In case solvents other than DMSO, water or the culture medium are used, appropriate scientific rationale should be provided.

15. Based on the stock solutions of the test chemical, serial dilutions are made using DMSO or for test chemicals not soluble in DMSO, using sterile water or culture medium, to obtain master concentrations of the chemical to be tested (e.g. 12 concentrations ranging from 0.098 to 200 mM). Independent of the solvent used, the master concentrations, are then further diluted 25 fold into culture medium containing serum, and finally used for treatment with a further 4 fold dilution factor so that the final concentrations of the tested chemical are reached (e.g. ranging from 0.98 to 2000 µM based on a dilution factor of 2). For a test chemical which has no defined MW, serial dilutions are made using DMSO or a suitable solvent to obtain the desired final concentrations of the test chemical (e.g. from 0.98 to 2000 µg/ml).

16. A cytotoxicity pre-range dose finding test is first performed, based e.g. on the above concentrations, to determine the concentration at which cell viability is reduced to 75% (CV_{75}). The CV_{75} is then used as a basis for determining the concentrations to be tested in the main luciferase test and the parallel cytotoxicity test (e.g., one concentration above CV_{75}, the CV_{75} and four concentrations below CV_{75} using a serial dilution factor of 1.2 resulting in the concentrations CV_{75}/2.07, CV_{75}/1.73, CV_{75}/1.44, CV_{75}/1.2, CV_{75} and CV_{75}x1.2 µM). Alternative concentrations may be used upon justification (e.g. in case of too low or too high cytotoxicity or poor solubility) (24).

17. A concurrent solvent/vehicle control should be tested within each repetition (e.g. DMSO), for which a sufficient number of wells should be prepared per plate (e.g. 12 for the cytotoxicity pre-range dose finding test and 24 for the main luciferase test as described in the protocol (24)). The solvent/vehicle control undergoes the same dilutions as described for the master concentrations in paragraph 15, so that the final solvent/vehicle control concentration should correspond to the same concentration as in the tested chemicals and in the positive control (i.e. 1%), and should not significantly affect cell viability. For a test chemical not soluble in the used solvent (e.g. DMSO), for

© OECD 2018

which the dilutions were made in water, the solvent level in all wells of the final test solution of this test chemical must be adjusted to be equal to the solvent concentration used for the other test chemicals and control substances (i.e. 1%).

18. A concurrent negative control should also be tested within each repetition, for which a sufficient number of wells should be prepared per plate (e.g. 3 for the cytotoxicity pre-range dose finding test and 6 for the main luciferase test as described in the protocol (24)). In the LuSens test method, the concurrent negative control tested is 5 000 µM (or 450 µg/mL) DL-Lactic acid (CAS No. 50-21-5, ≥ 99% purity), known to be a non-sensitiser and to result in a negative prediction with the LuSens test method. Other suitable negative controls may be used if historical data are available to derive comparable run acceptance criteria. Furthermore, in the LuSens test method a sufficient number of wells (e.g. 6 for the cytotoxicity pre-range dose finding test and 12 for the main luciferase test as described in the protocol (24)) containing blank medium controls are prepared consisting of untreated cells and culture medium only.

19. A concurrent positive control should also be tested in a sufficient number of wells within each repetition to demonstrate appropriate response of the test system (e.g. 2 for the cytotoxicity pre-range dose finding test and 5 for the main luciferase test as described in the protocol (24)). For the LuSens test method, 120 µM Ethylene Glycol Dimethacrylate (EGMDA, CAS No. 97-90-5, ≥ 99% purity) is used. The positive control is prepared using the same dilution steps as described for the master concentrations in paragraph 14 and as described in the test method's protocols (24). If the positive control concentration of 120 µM is too toxic or not able to induce luciferase ≥ 2.5 (see paragraph 31) due to e.g. a new laboratory facility or a new batch of EGMDA, the performing laboratory may run a range finder experiment with EGDMA (confirmed in at least two more runs) in order to set the concentration at which luciferase induction is ≥ 2.5 folds compared to solvent/vehicle control, and for which cell viability is ≥ 70%. Finally, other suitable positive controls, preferentially providing $EC_{1.5}$ values in the mid-range, may be used if historical data are available to derive comparable run acceptance criteria.

Application of the test chemical and control substances

20. For each test chemical and positive control substance, one experiment is needed to derive a prediction (positive or negative), consisting of at least two independent repetitions containing each three replicates (i.e. n=6). In case of discordant results between the two independent repetitions, a third repetition containing three replicates should be performed (i.e. n=9). Each independent repetition is performed on a different day with fresh stock solution of test chemicals and independently harvested cells. Cells may come from the same passage however.

21. After seeding as described in paragraph 13, cells are grown for 24 hours in the 96-wells microtiter plates. The medium is then removed and replaced with fresh culture medium (i.e. 150 µl DMEM containing serum but without antibiotics as described within the method's protocol (24)) to which 50 µl of the 25 fold diluted test chemical and control substances are added. At least one well per plate should be left empty (no cells and no treatment) to assess background values.

22. The treated plates are then incubated for about 48 hours at 37±1°C in the presence of 5% CO_2. Care should be taken to avoid evaporation of volatile test chemicals and cross-contamination between wells by test chemicals by e.g. covering the plates with a foil during incubation with the test chemicals.

© OECD 2018

Luciferase activity measurements

23. The following factors are critical to ensure appropriate luminescence readings:

- the choice of a sensitive luminometer,
- the use of a plate format with sufficient height to avoid light-cross-contamination,
- the use of a luciferase substrate with sufficient light output to ensure sufficient sensitivity and low variability; and
- an appropriate and stable background level.

Prior to testing, a control experiment setup as described in Annex 3 of this Appendix should be carried out to ensure that these three points are met.

24. After the 48 hour exposure time with the test chemical and control substances, cells are washed with a phosphate buffered saline, and the appropriate lysis buffer for luminescence readings added to each well for a sufficient time (e.g. 5-10 min in dark).

25. Plates with the cell lysate are then placed in the luminometer for reading using the specific program prescribed within the test method's protocol (24). In case alternative settings are used, e.g. depending on the model of luminometer used, these should be justified. Furthermore, a glow substrate may also be used provided that the quality control experiment of Annex 3 of this Appendix is successfully conducted.

Cytotoxicity Assessment

26. For the LuSens cell viability assay, medium is replaced after the 48 hour exposure time with fresh medium containing 0.5 mg/ml MTT (3-(4,5-dimethylthiazol-2-yl) -2,5 diphenyltetrazolium bromide, Thiazolyl blue tetrazolium bromide; CAS No. 298-93-1) and cells are incubated for 2 hours at 37±1°C in the presence of 5% CO_2. The MTT medium is then removed and cells are lysed by using an appropriate lysing agent for a sufficient amount of time (e.g. 10 % (w/v) SDS and 0.4% (v/v) acetic acid solution in DMSO for 5 min). After shaking, the absorption is then measured using the parameters described in the test method protocol (24).

DATA AND REPORTING

Data evaluation

27. The following parameters are calculated in the LuSens test method (see Annex 4 of this Appendix for the detailed equations):

- Fold luciferase activity induction at all concentrations of the tested chemical, positive control and negative control.
- Cellular viability (CV) at all concentrations of the tested chemical and for all controls to determine (by interpolation) the concentration value at which 75% of cell viability occurs (CV_{75}).

28. For each concentration showing a luciferase activity induction equal or higher (≥) than 1.5, statistical significance is determined (e.g. using a two-tailed Student's t-test) by comparing the luminescence values of the three replicate samples with the luminescence

© OECD 2018

values in the solvent/vehicle control wells to assess whether the luciferase activity induction is statistically significant ($p < 0.05$). Furthermore, it should be checked that no significant cytotoxic effects occur at these concentrations (i.e. that the cell viability is ≥ 70% at the concentrations leading to ≥ 1.5 fold luciferase induction).

29. It is recommended that data are visually checked with the help of graphs. If no clear dose-response curve is observed, or if the dose-response curve obtained is biphasic (i.e. crossing the threshold of 1.5 twice), the experiment should be repeated to verify whether this is specific to the test chemical or due to an experimental artefact. In case the biphasic response is reproducible in an independent experiment, the lower concentration, i.e., when the threshold of 1.5 is crossed the first time should be reported. However, a concentration delivering an $EC_{1.5}$ is not a requirement.

30. Finally, when in the LuSens test method a ≥ 1.5 fold luciferase activity induction is observed only at the lowest tested concentration (e.g. CV_{75}/2.07), re-testing should be conducted using at least one additional lower concentration.

Acceptance criteria

31. The following acceptance criteria should be met when using the LuSens test method. If any of the criteria listed below is not met, the data should be discarded and a new repetition should be performed.

- The average luciferase activity induction obtained with the positive control, 120 µM EGDMA (or comparable concentration – see paragraph 19) should be ≥ 2.5, and the positive control should have a relative cell viability ≥ 70% as compared to the solvent/vehicle control.
- The average luciferase activity induction obtained with the negative control, i.e., 5000 µM DL-Lactic acid, as well as the basal expression of untreated cells should be < 1.5 fold as compared to the average solvent/vehicle control.
- The average coefficient of variation of the luminescence reading for the solvent/vehicle controls (e.g. DMSO) should be below 20% in each repetition.
- At least three test concentrations should have cell viability of at least 70% relative to the solvent/vehicle controls. Moreover, in case a result is to be considered negative, at least one concentration should be cytotoxic, i.e. have a cell viability < 70%, or the maximum concentration of 2000 µM (or 2000 µg/ mL for substances with no defined MW) should have been tested.

32. In some cases, test chemicals may induce no cytotoxicity, in which cases the maximum concentration tested should be 2000 µM (or 2000 µg/ mL for test chemicals having undefined MW). If in the main luciferase test no concentration is cytotoxic, i.e. has a cell viability < 70%, and no luciferase induction is observed, then a second repetition should be performed using e.g. a 1.44 serial dilution factor based on the CV75 (i.e. starting with 1.44 x CV_{75}) instead of the 1.2 serial dilution factor used in the main luciferase test. If in the second repetition cytotoxicity and luciferase induction are still not observed, a third repetition should be run with the maximum concentration of 2000 µM (or 2000 µg/ mL for substances with undefined MW). This repetition should then be confirmed by performing a fourth repetition.

© OECD 2018

Interpretation of results and prediction model

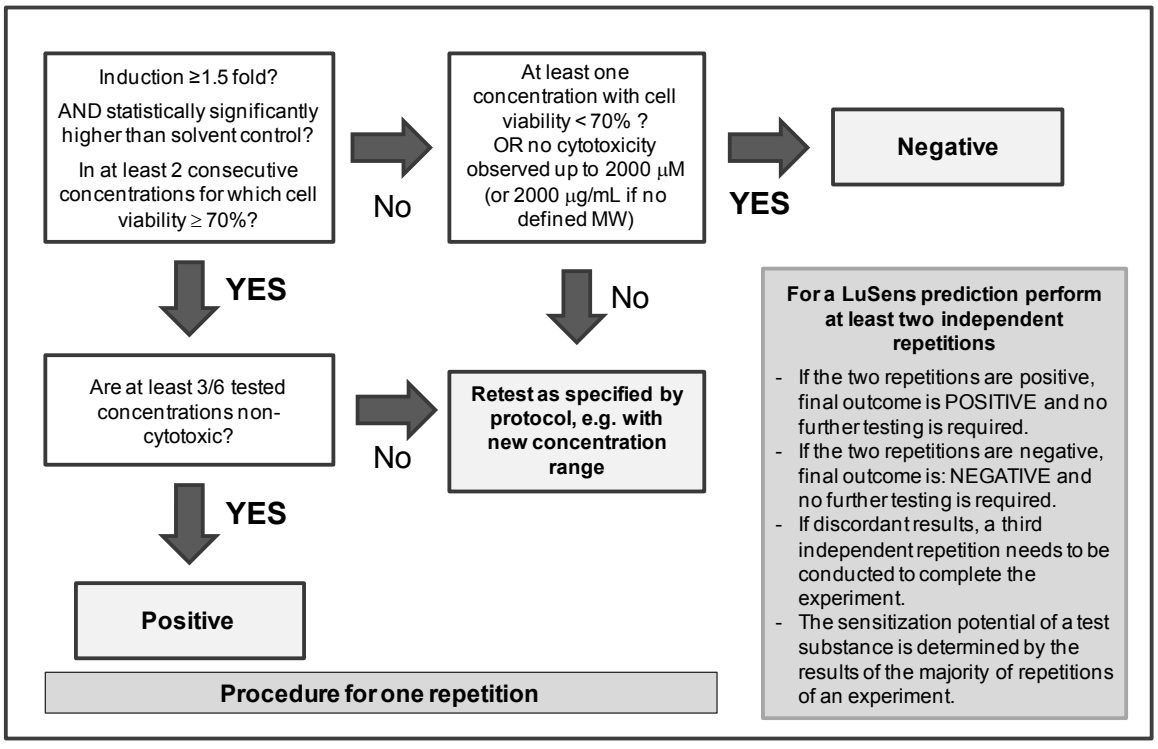
33. A LuSens prediction is considered positive if the following conditions are met in 2 of 2 or in the same 2 of 3 repetitions, otherwise the LuSens prediction is considered negative (Figure 1):

- the luciferase induction is above or equal to (≥) 1.5 fold and is statistically significant compared to the solvent control in at least 2 consecutive non-cytotoxic tested concentrations (i.e. cellular viability is equal or higher than (≥) 70%), whereby at least three tested concentrations should be non-cytotoxic (cellular viability equal or higher than (≥) 70%).

34. In addition, a negative result obtained with test chemicals that do not form a stable dispersion and were not tested up to 2000 µM (or 2000 µg/mL for test chemicals with no defined MW) and for which no cytotoxicity is observed in any of the tested concentration (see paragraph 31) should also be considered as inconclusive (see paragraph 4).

Figure 2. Overview of the criteria leading to a prediction in the LuSens test method.

A LuSens prediction should be considered in the framework of a Defined Approach or of an IATA and in accordance with the provision paragraph 4 and paragraphs 7 and 8 of the general introduction.



© OECD 2018

Test report

35. The test report should include the following information:

Test chemical

- Mono-constituent substance
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), SMILES or InChI code, structural formula, and/or other identifiers like batch/ lot number and expiry date;
  - Physical appearance, water solubility, DMSO solubility, molecular weight, and additional relevant physicochemical properties, to the extent available;
  - Statement on (in)solubility or stable dispersion in exposure media
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;
  - Treatment prior to testing, if applicable (e.g. warming, grinding);
  - Concentration(s) tested;
  - Storage conditions and stability to the extent available.
- Multi-constituent substance, UVCB and mixture:
  - Characterisation as far as possible by e.g. chemical identity (see above), purity, quantitative occurrence and relevant physicochemical properties (see above) of the constituents, to the extent available;
  - Physical appearance, water solubility, DMSO solubility and additional relevant physicochemical properties, to the extent available;
  - Statement of (in)solubility or stable dispersion in exposure media
  - Molecular weight or apparent molecular weight in case of mixtures/polymers of known compositions or other information relevant for the conduct of the study;
  - Treatment prior to testing, if applicable (e.g. warming, grinding);
  - Concentration(s) tested;
  - Storage conditions and stability to the extent available.

Controls

- Positive control
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), SMILES or InChI code, structural formula, and/or other identifiers;
  - Physical appearance, water solubility, DMSO solubility, molecular weight, and additional relevant physicochemical properties, to the extent available and where applicable;
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;

© OECD 2018

- Treatment prior to testing, if applicable (e.g. warming, grinding);
- Concentration(s) tested;
- Storage conditions and stability to the extent available;
- Reference to historical positive control results demonstrating suitable run acceptance criteria, if applicable.

- Solvent/vehicle control
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), and/or other identifiers;
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;
  - Physical appearance, molecular weight, and additional relevant physicochemical properties in the case other solvents/vehicles than those mentioned in this Appendix are used and to the extent available;
  - Storage conditions and stability to the extent available;
  - Justification for choice of solvent/vehicle for each test chemical.
- Negative control
  - Chemical identification, such as IUPAC or CAS name(s), CAS number(s), and/or other identifiers;
  - Purity, chemical identity of impurities as appropriate and practically feasible, etc;
  - Physical appearance, molecular weight, and additional relevant physicochemical properties in the case other negative controls than those mentioned in this Appendix are used and to the extent available;
  - Storage conditions and stability to the extent available;
  - Justification for choice of the negative control in the case other negative controls than those mentioned in the Test Guideline are used.

Test method conditions

- Name and address of the sponsor, test facility and study director;
- Description of test method used;
- Cell line used, its storage conditions and source (e.g. the facility from which they were obtained);
- Passage number and level of confluence of cells used for testing;
- Cell counting method used for seeding prior to testing and measures taken to ensure homogeneous cell number distribution (cf. paragraph 13);
- Luminometer used (e.g. model), including instrument settings, luciferase substrate used, and demonstration of appropriate luminescence measurements based on the control test described in Annex 3 of this Appendix;

© OECD 2018

- The procedure used to demonstrate proficiency of the laboratory in performing the test method (e.g. by testing of proficiency substances) or to demonstrate reproducible performance of the test method over time.

Test procedure

- Number of repetitions and replicates used;
- Test chemical concentrations, application procedure and exposure time used (if different than the one recommended)
- Description of evaluation and decision criteria used;
- Description of study acceptance criteria used;
- Description of any modifications of the test procedure.

Results

- Tabulation of fold luciferase induction activity and viability values (i.e.CV75 for the LuSens test method) obtained for the test chemical and for the positive control for each repetition;
- The mean values (i.e. arithmetic means of cell viability and luciferase activity induction) and SD calculated using data from all individual repetitions;
- An indication of the rating of the test chemical according to the prediction model;
- Coefficient of variation obtained with the luminescence readings for the solvent/vehicle control for each experiment;
- A graph depicting dose-response curves for induction of luciferase activity and viability;
- Description of any other relevant observations, if applicable.

Discussion of the results

- Discussion of the results obtained with the LuSens test method;
- Consideration of the test method results within the context of an IATA, if other relevant information is available.

Conclusion

© OECD 2018

Literature

1) OECD (2012). Series on Testing and Assessment No. 168. The Adverse Outcome Pathway for Skin Sensitisation Initiated by Covalent Binding to Proteins. Part 1: Scientific Evidence. Organisation for Economic Cooperation and Development, Paris. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2012)10/PART1&docLanguage=En

2) Natsch A. (2010). The Nrf2-Keap1-ARE Toxicity Pathway as a Cellular Sensor for Skin Sensitizers-Functional Relevance and Hypothesis on Innate Reactions to Skin Sensitizers. Toxicological Sciences 113, 284-292.

3) Emter R., Ellis G., Natsch A.(2010). Performance of a novel keratinocyte-based reporter cell line to screen skin sensitizers in vitro. Toxicology and Applied Pharmacology 245, 281-290.

4) Dinkova-Kostova A.T., Holtzclaw W.D., Kensler T.W. (2005). The role of Keap1 in cellular protective responses. Chem. Res. Toxicol. 18, 1779-1791.

5) Kansanen E., Kuosmanen S.M., Leinonen H., Levonen A.L. (2013). The Keap1-Nrf2 pathway: Mechanisms of activation and dysregulation in cancer. Redox Biol. 1, 45-49.

6) OECD (2015). Guidance Document No 213. Performance Standards for assessment of proposed similar or modified in vitro skin sensitisation ARE-NrF2 luciferase test methods. Series on Testing and Assessment. Available at: http://www.oecd.org/env/ehs/testing/series-testing-assessment-publications-number.htm

7) Ramirez T., Mehling A., Kolle S.N., Wruck C.J., Teubner W., Eltze T., Aumann A., Urbisch D., van Ravenzwaay B., Landsiedel R. (2014). LuSens: a keratinocyte based ARE reporter gene assay for use in integrated testing strategies for skin sensitization hazard identification. Toxicol. In Vitro 28, 1482-1497.

8) Ramirez T., Stein N., Aumann A., Remus T., Edwards A., Norman K.G., Ryan C., Bader J.E., Fehr M., Burleson F., Foertsch L., Wang X., Gerberick F., Beilstein P., Hoffmann S., Mehling A., van Ravenzwaay B., Landsiedel R. (2016). Intra- and inter-laboratory reproducibility and accuracy of the LuSens assay: A reporter gene-cell line to detect keratinocyte activation by skin sensitizers. Toxicol. In Vitro 32, 278-286.

9) EURL ECVAM (2018). The LuSens test method Validation Study Report. Accessible at: https://tsar.jrc.ec.europa.eu/test-method/tm2011-10

10) ESAC (2016). ESAC opinion on the BASF-coordinated Performance Standards-based validation of the LuSens test method for skin sensitisation testing. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC103706/esac_opinion_2016-04_lusens_final.pdf.

11) EURL-ECVAM (2014). Recommendation on the KeratinoSensTM assay for skin sensitisation testing, 42 pp. Available at: http://ihcp.jrc.ec.europa.eu/our_labs/eurl-ecvam/eurl-ecvam-recommendations/recommendation-keratinosens-skin-sensitisation.

12) Fabian E., Vogel D., Blatz V., Ramirez T., Kolle S., Eltze T., van Ravenzwaay B., Oesch F., Landsiedel R. (2013). Xenobiotic metabolizin enzyme activities in cells used for testing skin sensitization in vitro. Arch Toxicol 87, 1683-1969.

13) Jaworska J., Dancik Y., Kern P., Gerberick F., Natsch A. (2013). Bayesian integrated testing strategy to assess skin sensitization potency: from theory to practice. J. Appl. Toxicol. 33, 1353-1364.

© OECD 2018

14) Casati S., Aschberger K., Asturiol D., Basketter D., Dimitrov S., Dumont C., Karlberg A.T., Lepoittevin J.P., Patlewicz G., Roberts D.W., Worth A. (2016). Ability of non-animal methods for skin sensitisation to detect pre- and pro-haptens: Report and recommendations of an EURL ECVAM expert meeting. EUR 27752 EN. Available at : https://eurl-ecvam.jrc.ec.europa.eu/eurl-ecvam-status-reports/pre-prohapten-workshop-report.

15) Bauch C., Kolle S.N., Ramirez T., Eltze T., Fabian E., Mehling A., Teubner W., van Ravenzwaay B., Landsiedel R. (2012). Putting the parts together: combining in vitro methods to test for skin sensitizing potentials. Regul. Toxicol. Pharmacol. 63, 489-504.

16) Thorne N., Inglese J., Auld D.S. (2010). Illuminating Insights into Firefly Luciferase and Other Bioluminescent Reporters Used in Chemical Biology. Chemistry and Biology 17, 646-657.

17) OECD (2012). BG1Luc Estrogen Receptor Transactivation Test Method for Identifying Estrogen Receptor Agonists and Antagonists. OECD Guidelines for Chemical Testing No. 457. Organisation for Economic Cooperation and Development, Paris. Available at: [http://www.oecd.org/env/testguidelines].

18) ECETOC (2003). Contact sensitization: Classification according to potency. European Centre for Ecotoxicology & Toxicology of Chemicals (Technical Report No. 87).

19) Urbisch D., Becker M., Honarvar N., Kolle S.N., Mehling A., Teubner W., Wareing B., Landsiedel R. (2016). Assessment of Pre- and Pro-haptens Using Non-animal Test Methods for Skin Sensitization. Chem. Res. Toxicol. 29, 901-13.

20) Wasserman W.W., Fahl W.E. (1997). Comprehensive analysis of proteins which interact with the antioxidant responsive element: correlation of ARE-BP-1 with the chemoprotective induction response. Arch. Biochem. Biophys. 344, 387-396.

21) Ade N, Leon F, Pallardy M, Peiffer JL, Kerdine-Romer S, Tissier MH, Bonnet PA, Fabre I, Ourlin JC.(2009); HMOX1 and NQO1 genes are upregulated in response to contact sensitizers in dendritic cells and THP-1 cell line: role of the Keap1/Nrf2 pathway. Toxicol Sci. 2009 Feb;107(2):451-60.

22) Rob J. Vandebriel, Jeroen L. A. Pennings, Kirsten A. Baken, Tessa E. Pronk, Andre Boorsma, Ralph Gottschalk, Henk Van Loveren; Keratinocyte Gene Expression Profiles Discriminate Sensitizing and Irritating Compounds, Toxicological Sciences, Volume 117, Issue 1, 1 September 2010, Pages 81–89, https://doi.org/10.1093/toxsci/kfq182

23) Emter R., van der Veen J.W., Adamson G., Ezendam J., van Loveren H., Natsch A. (2013). Gene expression changes induced by skin sensitizers in the KeratinoSens™ cell line: Discriminating Nrf2-dependent and Nrf2-independent events. Toxicol. In Vitro 27, 2225-2232.

24) DB-ALM Protocol No. 184 (2017). LuSens Assay. Available at https://ecvam-dbalm.jrc.ec.europa.eu

25) Natsch A., Ryan C.A., Foertsch L., Emter R., Jaworska J., Gerberick G.F., Kern P. (2013). A dataset on 145 chemicals tested in alternative assays for skin sensitization undergoing prevalidation. Journal of Applied Toxicology 33, 1337-1352.

26) Basketter D.A., Alépée N., Ashikaga T., Barroso J., Gilmour N., Goebel C., Hibatallah J., Hoffmann S., Kern P., Martinozzi-Teissier S., Maxwell G., Reisinger K., Sakaguchi H., Schepky A., Tailhardat M., Templier M. (2014). Categorization of chemicals according to their relative human skin sensitizing potency. Dermatitis 25, 11-21.

© OECD 2018

APPENDIX IB - ANNEX 1: PROFICIENCY SUBSTANCES

In Vitro Skin Sensitisation: The ARE-Nrf2 Luciferase LuSens Test Method

Prior to routine use of a test method that adheres to this Appendix to Test Guideline 442D, laboratories should demonstrate technical proficiency by correctly obtaining the expected prediction for the 10 Proficiency Substances recommended in Table 1 and by obtaining the raw values that fall within the respective reference range for at least eight out of the ten proficiency substances. These Proficiency Substances were selected to represent the range of responses for skin sensitisation hazards. Other selection criteria were commercial availability, availability of high quality in vivo reference, and availability of high quality in vitro data from the LuSens test method.

Table 1: Recommended substances for demonstrating technical proficiency with the LuSens test method.

Proficiency Substances	CASRN	Physical Form	LLNA Prediction (1)	Human category (2)	LuSens		
					In Vitro Prediction (3)	$EC_{1.5}$ (µM) Reference Range (4)	CV_{75} (µM) Reference Range (4)
Salicylic acid	69-72-7	Solid	Non-sensitiser	Cat. 6	Negative	> 1000	> 2000
Glycerol	56-81-5	Liquid	Non-sensitiser	Cat. 6	Negative	> 1000	> 2000
Isopropanol	67-63-0	Liquid	Non-sensitiser	Cat. 5	Negative	> 1000	> 2000
Sulfanilamide	63-74-1	Solid	Non-sensitiser	Negative (Basketter et al. 1994)	Negative	> 1000	> 2000
Eugenol	97-53-0	Liquid	Sensitiser (weak)	Cat. 3	Positive	< 500	< 1000
Cinnamyl alcohol	104-54-1	Solid	Sensitiser (weak)	Cat. 3	Positive	< 170	> 420
2-Mercaptobenzothiazole	149-30-4	Solid	Sensitiser (moderate)	Cat. 3	Positive	< 800	< 2000
4-Methylaminophenol sulfate	55-55-0	Solid	Sensitiser (strong)	Cat. 3	Positive	< 30	< 50
Methyldibromo glutaronitrile	35691-65-7	Solid	Sensitiser (strong)	Cat. 2	Positive	< 25	< 50
2,4-Dinitro-chlorobenzene	97-00-7	Solid	Sensitiser (extreme)	Cat. 1	Positive	< 5	< 10

© OECD 2018

Notes: (1) The in vivo hazard (and potency) predictions are based on LLNA data (25). The in vivo potency is derived using the criteria proposed by ECETOC (18).
(2) According to Basketter and co-workers (26). Cat. 1 represents clear evidence of contact allergy, Cat. 2 a frequent cause of contact allergy, Cat. 3 a common cause of contact allergy, Cat. 4 an infrequent cause of contact allergy, Cat. 5 a rare cause of contact allergy, and Cat. 6 essentially absent evidence of contact allergy.
(3) An ARE-Nrf2 luciferase test method prediction should be considered in the framework of a Defined Approach or of an IATA and in accordance with the provisions of paragraphs 7 and 8 of the general introduction.
(4) Based on the historical observed values (7) (8). Although the EC 1.5 is not part of the LuSens prediction model, it can be calculated from the obtained data, and used to determine the ranges of LuSens response for the Proficiency Substances. The EC 1.5 values were calculated according to Appendix IA (paragraph 26).

© OECD 2018

APPENDIX IB - ANNEX 2: Comparison of the main protocol steps of the LuSens and the VRM KeratinoSensTM test methods

	VRM (KeratinoSens™)	LuSens
Preparation of the keratinocyte cultures		
Propagation	2 to 4 passages	1 to 3 passages
Cryopreserved storage	2 to 4 passages	3 passages
Cell passages before main experiment	At least 2	At least 5
Maximal passage number propagation from frozen stocks	25 passages	20 passages for cytotoxicity range finding test 15 passages for main luciferase test
Propagation medium	DMEM containing serum and Geneticin	DMEM containing serum, penicillin/streptomycin and puromycin
Cell confluence for testing	80-90%	
Harvest of cells prior to testing	1 day	
Plate format used for testing	96 well-plates	
Cell number seeded for testing	10 000 cells/well, except in the well that is used for measurement of background	
Number of replicates for each test chemical concentration (in each repetition)	3 wells (on independent plates) for luciferase measurement 1 well for cytotoxicity assessment	3 wells (in the same plate) for all tests i.e. the cytotoxicity range finder test and the main luciferase test (including 3 wells for luciferase measurement, and 3 wells for parallel cytotoxicity assessment)
Preparation of the test chemical and control substances		
Preparation	Same day of testing	
Solvent	DMSO, sterile water or media for those test items not soluble in DMSO	DMSO or media for those test items not soluble in DMSO
Stock concentration	200 mM	
Test items with no defined molecular weight	Stock solution prepared to a default concentrations (40 mg/mL or 4% (w/v))	Stock solution prepared to a default concentrations (200 mg /mL or 20% (w/v))
Final tested concentration range in 96 well-plate	12 concentrations (2 fold dilution) ranging from 0.98 to 2000 µM	Cytotoxicity range finder test: 12 concentrations (2 fold dilution) ranging from 0.98 to 2000 µM Main luciferase test: 6 concentrations (1.2 fold dilution) ranging from CV_{75}/2.074 to CV_{75}x1.2 µM
Solvent control	1% DMSO (18 replicates per repetition)	1% DMSO (12 replicates per repetition for cyototoxicity range finder test, and 24 replicates per repetition for main luciferase test)
Negative control	See solvent control	5000 M DL-Lactic acid (3 replicates per repetition for cyototoxicity range finder test, and 6 replicates per repetition for main luciferase test)
Positive control	Cinnamic aldehyde Four concentrations (2 fold dilution) ranging from 4 to 64 µM (3 replicates per repetition)	120 M EGDMA or alternative concentration that induced luciferase =2.5 folds, and for which cell viability is ≥ 70%

© OECD 2018

		(2 replicates per repetition for cytotoxicity range finder test, and 5 replicates per repetition for main luciferase test)
Medium control	Not applicable	6 replicates per repetition for cytotoxicity range finder test, and 12 replicates per repetition for main luciferase test
Blank control (no cells)	3 replicates per repetition	1 replicates per repetition
Application of the test chemical and control substances & endpoints assessed		
Number of repetitions for each test chemical concentration	At least two independent repetitions containing each three replicates (n='6),' and in case of discordant results, a third repetition should be performed (n='9).' Each repetition is conducted on a different day with freshly prepared test chemicals and independently harvested cells (but eventually having the same passage number)	
Cell treatment medium	150 µl culture DMEM containing serum but without antibiotics (i.e. Geneticin, penicillin/streptomycin and puromycin) to which 50 µl of the 25 fold test chemical and control substances are added	
Exposure time	48 hours at 37±1°C in the presence of 5% CO_2 Plates are covered with a foil to avoid evaporation of volatile test chemicals and cross-contamination between wells	
Luminescence activity measurement	After exposure, cells are washed with phosphate buffered saline, and the relevant lysis buffer for luminescence readings added to each well for 20 min at room temperature. Plates with the cell lysate are placed in the luminometer for reading which is programmed to: i) add the luciferase substrate to each well, ii) wait for 1 second, and iii) integrate the luciferase activity for 2 seconds.	After exposure, the relevant lysis buffer for luminescence readings added to each well for 5-10 min, under agitation in the dark. Luminescence is measured for 2 seconds using a luminometer. *Other conditions may apply depending on the luminometer used.*
Cytotoxicity assessment	After exposure, 5mg/ml MTT solution is added and cells are incubated 4h at 37±1°C in the presence of 5% CO_2 Cells are then lysed overnight (with 10% SDS solution), agitated and absorption measured at 600 nm	After exposure, 200 µL of MTT working solution (0.5mg/ml) are added and cells are incubated 2h at 37±1°C in the presence of 5% CO_2 Cells are lysed for 5 min (with 10% (w/v) SDS and 0.4% (v/v) acetic acid in a DMSO solution), and absorption measured at 570 and 690 nm
Endpoints evaluated	**I_{max}:** maximal average fold induction observed at any concentration tested **$EC_{1.5}$:** interpolated concentration for which there is a 1.5 fold induction of luciferase activity **IC_{50} / IC_{30}**: interpolated concentration at which 50% and 30% reduction of cell viability occurs respectively	**Fold luciferase activity induction** as an average of each tested concentration C**ellular viability** as an average of each tested concentration **CV_{75}:** interpolated concentration at which 75% cell viability occurs
Acceptance criteria		
Positive control luciferase activity	>1.5 fold statistically significant induction in at least one of the tested concentrations of the positive control (4 to 64 µM cinnamic aldehyde). $EC_{1.5}$ value of positive control should be between 2SDs of historical mean (e.g. 2 to30 µM in validation dataset) Average induction of 64 µM cinnamic aldehyde should be	= 2.5 fold induction with the positive control (e.g. 120 M EGDMA) relative to solvent control at a non-cytotoxic concentration, i.e., cell viability = 70% relative to solvent control

© OECD 2018

	between 2 and 8.	
Negative control luciferase activity	Not applicable	< 1.5 fold induction with the negative control (5000 µM DL-Lactic acid) relative to solvent control
Solvent control variability	Coefficient of variation = 20% (18 replicates)	Coefficient of variation = 20% (of at least 21 replicates)
Others	Not applicable	Mean basal expression of medium control (cells with medium only) should have < 1.5 fold luciferase activity induction relative to solvent control At least three test concentrations (of 6 in the main luciferase test) should be non-cytotoxic (cell viability = 70%). In addition, in case of a negative result, at least one tested concentration (of 6 in the main luciferase test) should be cytotoxic (cell viability < 70%)
Prediction model		
A prediction is considered positive whenthe following conditions are met in 2 of 2 or in 2 of 3 repetitions, otherwise the prediction is considered negative	1. Imax equal or higher than (≥) 1.5 fold and statistically significantly different to the solvent control (two-tailed, unpaired Student's T-test) 2.The cellular viability is higher than (>) 70% at the lowest concentration with induction of luciferase activity equal or above 1.5 fold (i.e. at the $EC_{1.5}$ determining concentration) 3.The $EC_{1.5}$ value is less than (<) 1000 µM (or < 200 µg/mL for test chemicals with no defined MW) 4. There is an apparent overall dose-dependent increase in luciferase induction	1. A luciferase induction above or equal to (≥) 1.5 fold as compared to the solvent control is observed in at least 2 consecutive non-cytotoxic tested concentrations (i.e. cellular viability is equal or higher than (≥) 70%) 2. At least three tested concentrations should be non-cytotoxic (cellular viability equal or higher than (≥) 70%).
Chemicals that do not form a stable dispersion	Negative result obtained with test chemicals that do not form a stable dispersion < 1000 µM (or < 200 µg/mL for test chemicals with no defined MW), should be considered inconclusive	Negative result obtained with test chemicals that do not form a stable dispersion and were not tested up to 2000 µM (or 2000 µg/mL for test chemicals with no defined MW) should be considered inconclusive

© OECD 2018

APPENDIX IB - ANNEX 3: QUALITY CONTROL OF LUMINESCENCE MEASUREMENTS

Basic experiment for ensuring optimal luminescence measurements in the LuSens test method

In order to ensure optimal luminescence measurements, when performing the assay for the first time, it is recommended to perform one or two runs of the LuSens test method using increasing concentrations of EGDMA as a test substance and using the plate layout as described below. By performing these repetitions, the following aspects should be considered:

- luciferase induction should be increased in a dose-dependent fashion (in wells A-C:1-6) after treatment with increasing concentrations of EDGMA;
- no dose-dependent increase in luciferase induction should be observed in wells D:1-6, and A-D: 7 (empty wells) in comparison to luminescence values in wells A-D: 8-12;
- the average percentage Standard Deviation of the variability in at least 21 solvent/vehicle control wells (F-G: 1-12) should be below 20% and should not show any "gradient-like" pattern.

Table 1: Plate setup of first training experiment

	1	2	3	4	5	6	7	8	9	10	11	12
A	EGDMA CV75/2.07	EGDMA CV75/1.73	EGDMA CV75/1.44	EGDMA CV75/1.2	EGDMA CV75	EGDMA CV75x1.2						
B	EGDMA CV75/2.07	EGDMA CV75/1.73	EGDMA CV75/1.44	EGDMA CV75/1.2	EGDMA CV75	EGDMA CV75x1.2						
C	EGDMA CV75/2.07	EGDMA CV75/1.73	EGDMA CV75/1.44	EGDMA CV75/1.2	EGDMA CV75	EGDMA CV75x1.2						
D												
E	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
F	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
G	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO	DMSO
H	DL-Lactic acid 5000 M						**EGDMA 120 M**					**Blank**

© OECD 2018

APPENDIX IB - ANNEX 4: CALCULATIONS USED IN THE LUSENS TEST METHOD

1. **The fold induction of luciferase activity** (I_{max}) is calculated in the LuSens test method by Equation 1, and the overall maximal fold induction (Imax) is calculated as the average of the individual repetitions.

Equation 1: $$Fold\ induction = \frac{(L_{sample} - L_{blank})}{(L_{solvent} - L_{blank})}$$

where

L_{sample} is the luminescence reading in the test chemical well

L_{blank} is the luminescence reading in the blank well containing no cells and no treatment

$L_{solvent}$ is the average luminescence reading in the wells containing cells and solvent control

2. **Viability** in the LuSens test method is calculated by Equation 2:

Equation 2: $$Viability = \frac{(V_{sample} - V_{blank})}{(V_{solvent} - V_{blank})} \times 100$$

where

V_{sample} is the MTT-absorbance reading in the test chemical well

V_{blank} is the MTT-absorbance reading in the blank well containing no cells and no treatment

$V_{solvent}$ is the average MTT-absorbance reading in the wells containing cells and solvent control

3. **The concentration at which cell viability is reduced to 75% (CV_{75})** is then calculated in the LuSens test method by linear interpolation according to Equation 3, and the overall the CV_{75} is calculated as the geometric mean of the individual replicates.

Equation 3: $$CV_{75} = (C_b - C_a) \times \left(\frac{75 - V_b}{V_b - V_a}\right) + C_b$$

where

C_a is the tested concentration in µM with cell viability just above 75%

C_b is the tested concentration in µM with cell viability just below 75%

V_a is the % viability obtained with C_a

V_b is the % viability obtained with C_b

© OECD 2018