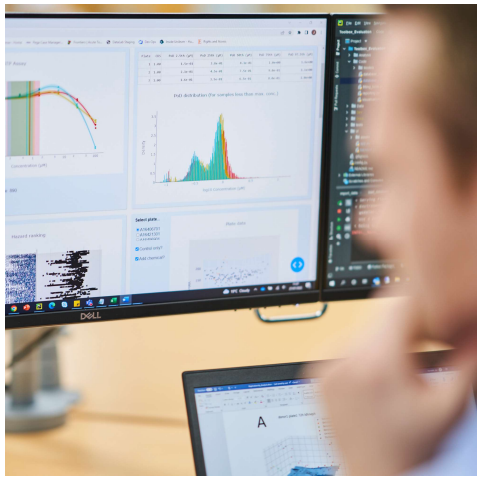
Use of New Approach Methodologies and Next Generation Risk Assessment for development and reproductive toxicity testing

Dr Predrag Kukic
Unilever Safety and Environmental Assurance Centre

Theme 2: Pharmacological and chemical safety – from modelling to interpretation



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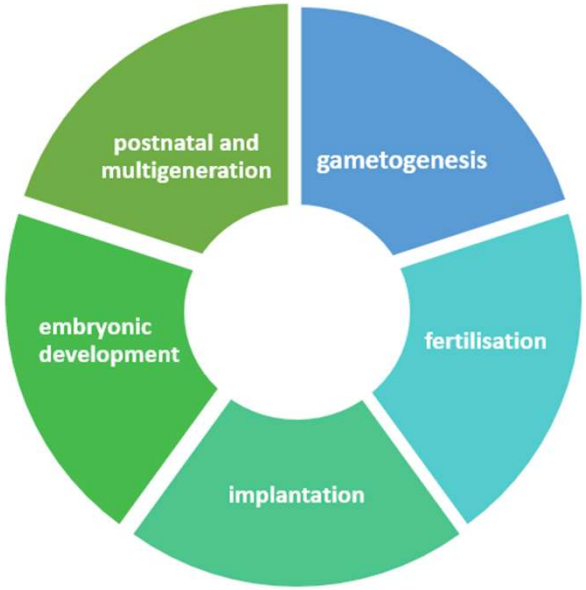
Outline

- **Unilever's approach to safety assessment**
- ***In vitro* methods and NGRA Frameworks for DART testing**
- **Biological relevance of the NGRA Framework for DART testing**
- **Case studies / fit for purpose validation, next steps**



DART endpoint

Unilever Policy & Approach

Safe & Sustainable Products without Animal Testing

What we believe

- **Every Unilever product must be safe for people and our environment**
- Non-animal testing to assess ingredient & product safety – there are a wide range of non-animal alternatives grounded in modern science and new technology

How we do it

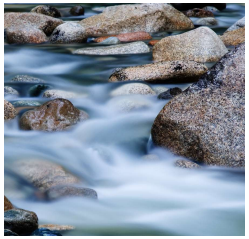
40+ years of developing non-animal safety science

70+ collaborations

600+ publications

seac.unilever.com



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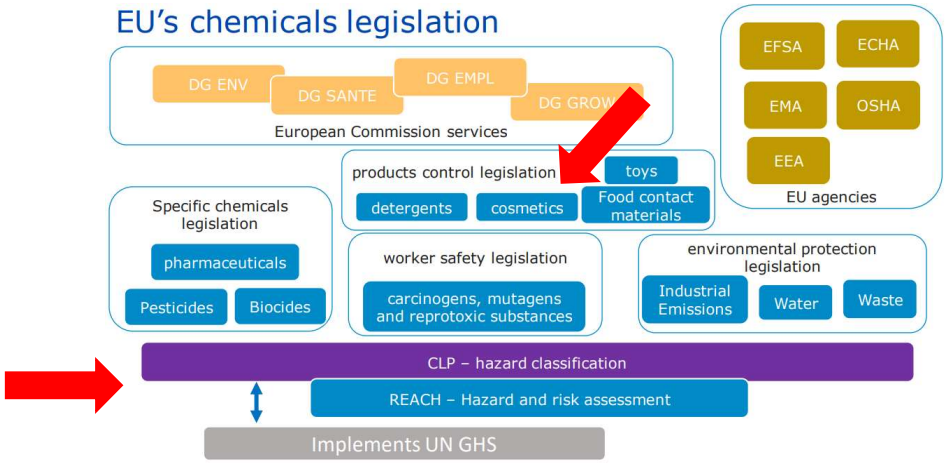
Cosmetics – brief overview of EU's chemical regulation

- In the European Union, selling cosmetic products **tested on animals is prohibited**. The ban applies to both the final formulation and the ingredients of the product (Cosmetics Regulation No 1223/2009)

- Those same chemical ingredients may, however, also need to be registered under REACH or their dossiers updated, which may involve animal testing. The standard information requirements for REACH often list animal tests.



Bercaru Offelia, ECHA workshop 2023

		10-100 tpa	100-1000 tpa	1000+ tpa
Study	Annex VII	Annex VIII	Annex IX	Annex X
Screening test for reproductive /developmental toxicity (OECD TG 421 or 422)		Required	Strongly recommended if no higher tier fertility study (such as OECD 443) is/will be available	
Prenatal developmental toxicity study (EU B.31, OECD TG 414)		May be proposed in case of (serious) concern[1] for prenatal developmental toxicity. However, it is strongly recommended to consider conducting a screening study in addition to the prenatal developmental toxicity[2] study	Required in one species; second species may be triggered[2]	Required in two species
Extended one-generation reproductive toxicity study (EU B.56, OECD TG 443)[3]		Recommended instead of the screening study in case of serious concern[1] for fertility	Required if triggered[4]	Required

A paradigm shift is underway as use of non-animal safety science increases & safety assessment frameworks evolve to embed NAMs

- Non-animal safety science is increasingly being used to make decisions on **consumer safety**, **safety of workers**, and safety of **people and non-human species** in the **environment**.

Regulatory Animal Testing of Chemicals is increasingly seen as unjustifiable / unethical by the majority of society

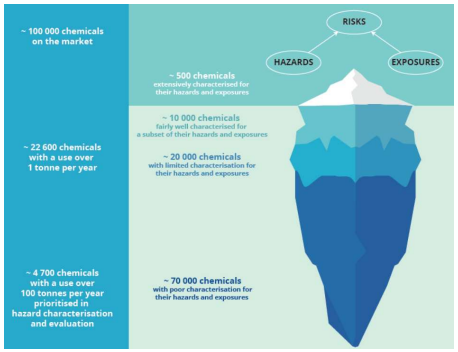
Aug 2021 – Aug 2022:
1.4M+ signatures

European Union
EUROPEAN CITIZENS' INITIATIVE

Save Cruelty Free Cosmetics

NAMs to fully replace the need for chemical regulatory animal testing

High throughput – more testing before the chemical is put on the market, data reuse, etc.



Potential to address information requirements for all substances in the market

Move to more sustainable sources of chemicals (e.g. bio-based) is transforming chemical innovation & use

Potential to ensure new chemicals are Safe & Sustainable by Design

Unilever

A paradigm shift is underway as use of non-animal safety science increases & safety assessment frameworks evolve to embed NAMs

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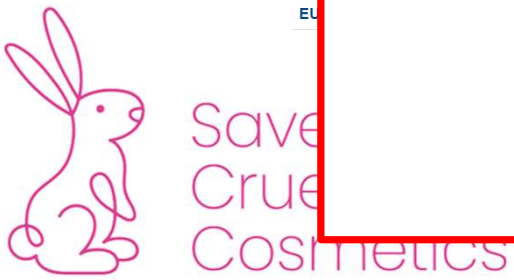

NAMs to fully replace the need for chemical regulatory animal testing

High throughput – more testing before the chemical is put on the market, data

Potential to address information requirements for all substances in the market

Human-relevant

Move to more sustainable sources of chemicals (e.g. bio-based) is

ming chemical innovation & use

Potential to ensure new chemicals are Safe & Sustainable by Design

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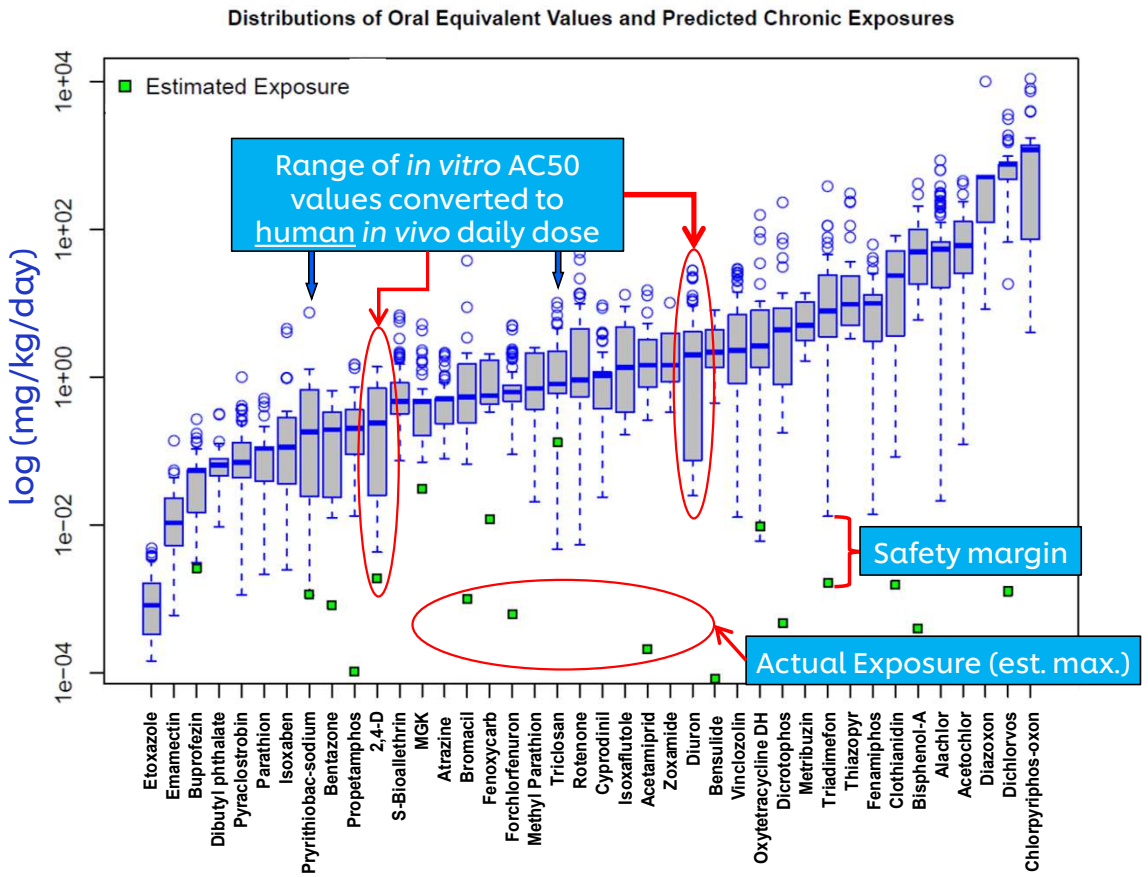
US EPA Next Generation Blueprint Tiered Testing Framework



Graph from Rusty Thomas EPA, with thanks. Rotroff *et al* (2010) Toxicological Sciences , **117**, 348-358

- NGRA is defined as **an exposure-led**, **hypothesis-driven** risk assessment approach that **integrates New Approach Methodologies (NAMs)** to assure safety without the use of animal testing
- If there is **no** bioactivity observed at consumer-relevant concentrations, there can be **no adverse health effects.**
- If there **is** bioactivity observed at consumer-relevant concentrations, **follow up testing** is required to establish if that could result in an adverse effect
- At no point does NGRA attempt to predict the results of high dose toxicology studies in animals.

US EPA Next Generation Blueprint Tiered Testing Framework

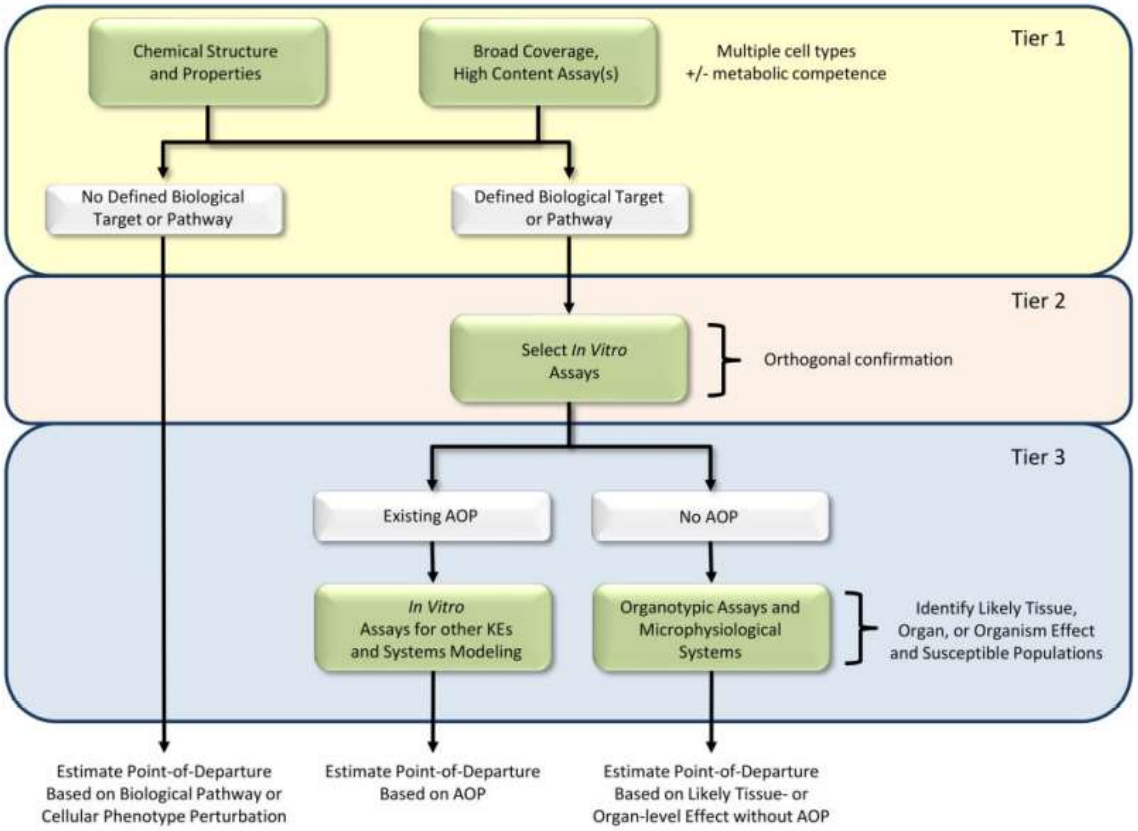


Figure 2. Tiered testing framework for hazard characterization. Tier 1 uses both chemical structure and broad coverage, high content assays across multiple cell types for comprehensively evaluating the potential effects of chemicals and grouping them based on similarity in potential hazards. For chemicals from Tier 1 without a defined biological target / pathway, a quantitative point-of-departure for hazard is estimated based on the absence of biological pathway or cellular phenotype perturbation. Chemicals from Tier 1 with a predicted biological target or pathway are evaluated Tier 2 using targeted follow-up assays. In Tier 3, the likely tissue, organ, or organism-level effects are considered based on either existing adverse outcome pathways (AOP) or more complex culture systems. Quantitative points-of-departure for hazard are estimated based on the AOP or responses in the complex culture system.

United States Environmental Protection Agency

OXFORD SOT Society of Toxicology
www.toxsci.oxfordjournals.org

TOXICOLOGICAL SCIENCES, 169(2), 2019, 317–332
doi: 10.1093/toxsci/kfz058
Advance Access Publication Date: March 5, 2019
Forum

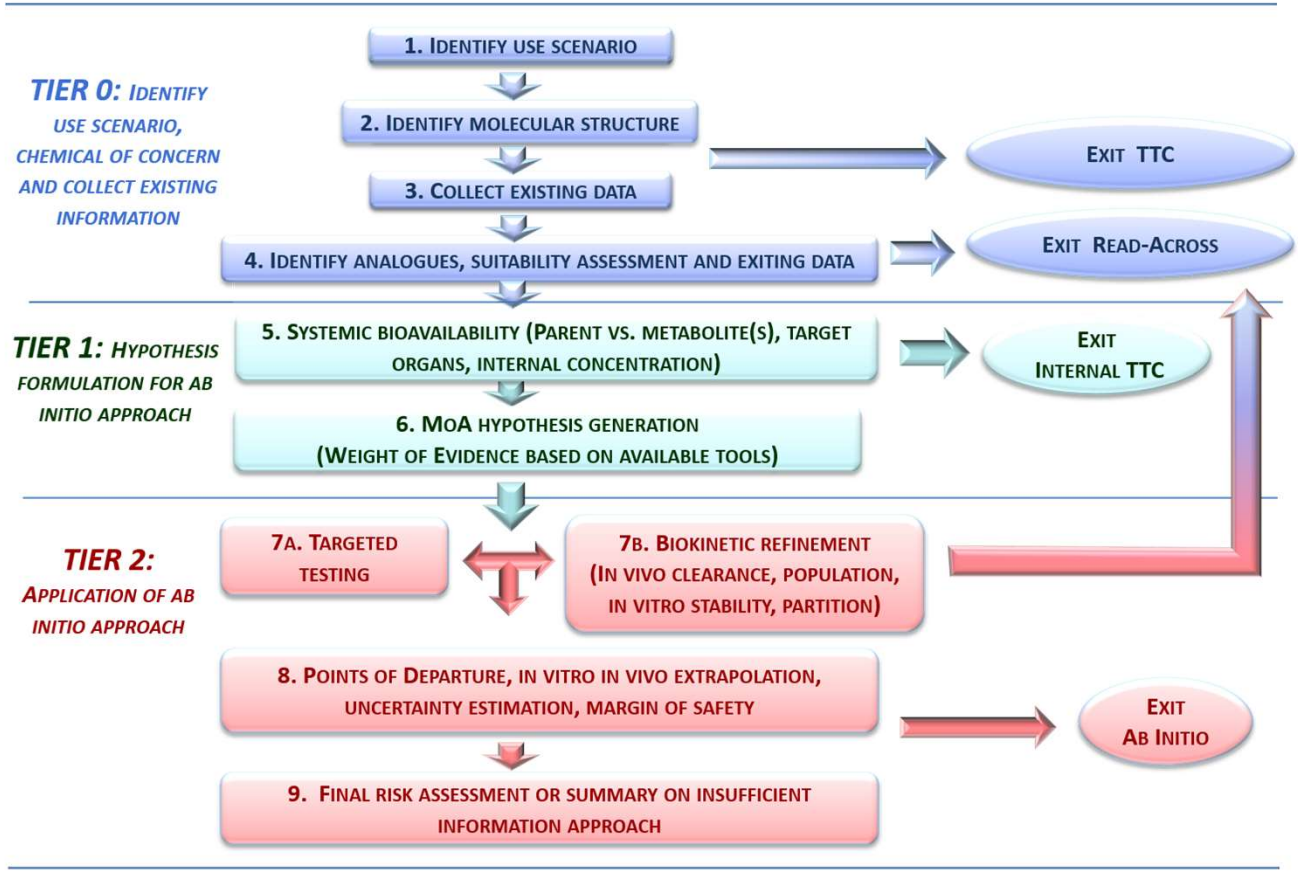
FORUM

The Next Generation Blueprint of Computational Toxicology at the U.S. Environmental Protection Agency

Russell S. Thomas,*,[1] Tina Bahadori,[†] Timothy J. Buckley,[‡] John Cowden,* Chad Deisenroth,* Kathie L. Dionisio,[‡] Jeffrey B. Frithsen,[§] Christopher M. Grulke,* Maureen R. Gwinn,* Joshua A. Harrill,* Mark Higuchi,[¶] Keith A. Houck,* Michael F. Hughes,[¶] E. Sidney Hunter, III,[¶] Kristin K. Isaacs,[‡] Richard S. Judson,* Thomas B. Knudsen,* Jason C. Lambert,[‖] Monica Linnenbrink,* Todd M. Martin,[‖] Seth R. Newton,[‡] Stephanie Padilla,[¶] Grace Patlewicz,* Katie Paul-Friedman,* Katherine A. Phillips,[‡] Ann M. Richard,* Reeder Sams,* Timothy J. Shafer,[¶] R. Woodrow Setzer,* Imran Shah,* Jane E. Simmons,[¶] Steven O. Simmons,* Amar Singh,* Jon R. Sobus,[‡] Mark Strynar,[‡] Adam Swank,[‡] Rogelio Tornero-Valez,[‡] Elin M. Ulrich,[‡] Daniel L. Villeneuve,[‖] John F. Wambaugh,* Barbara A. Wetmore,[‡] and Antony J. Williams*

*National Center for Computational Toxicology, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, [†]National Center for Environmental Assessment, U.S. Environmental Protection Agnecy, Washington, D.C. 20004, [‡]National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, [§]Chemical Safety for Sustainability National Research Program, U.S. Environmental Protection Agency, Washington, D.C. 20004, [¶]National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, [‖]National Center for Environmental Assessment, U.S. Environmental Protection Agency, Cincinnati, OH 45220,

FP7 (€200 mil) - Ab initio chemical safety assessment: Tiered testing to support human health safety assessment



SEURAT-1

- Read across
- Exposure-based waiving
- *In silico* tools

- Metabolism and metabolite identification
- Physiologically-based kinetic modelling
- *In chemico* assays
- 'Omics
- Reporter gene assays
- *In vitro* pharmacological profiling

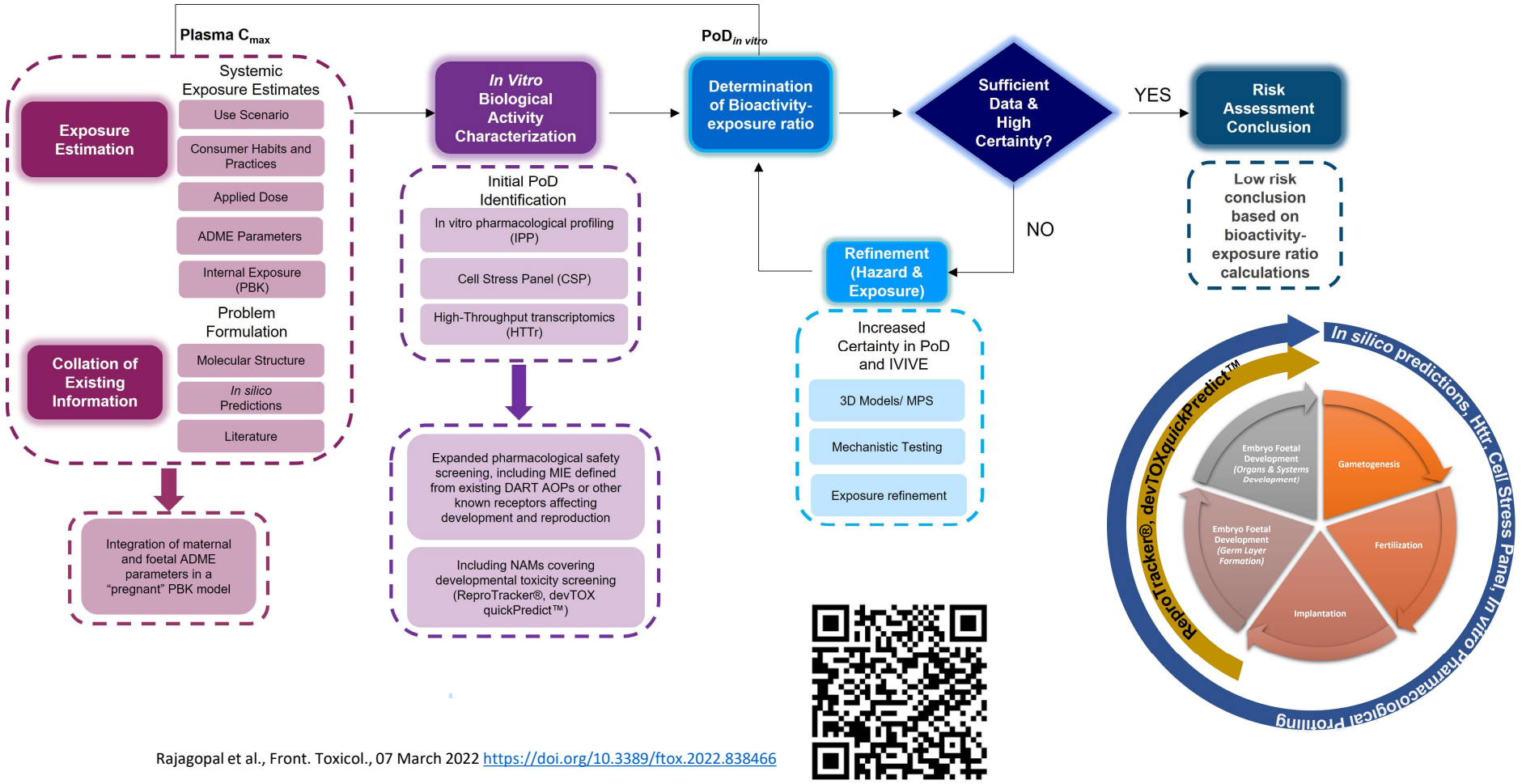
- 3D culture systems
- Organ-on-chip
- Zebrafish models
- Pathways modelling
- Human studies

Unilever

Berggren *et al.*, (2017) *Computational Toxicology* 4: 31-44

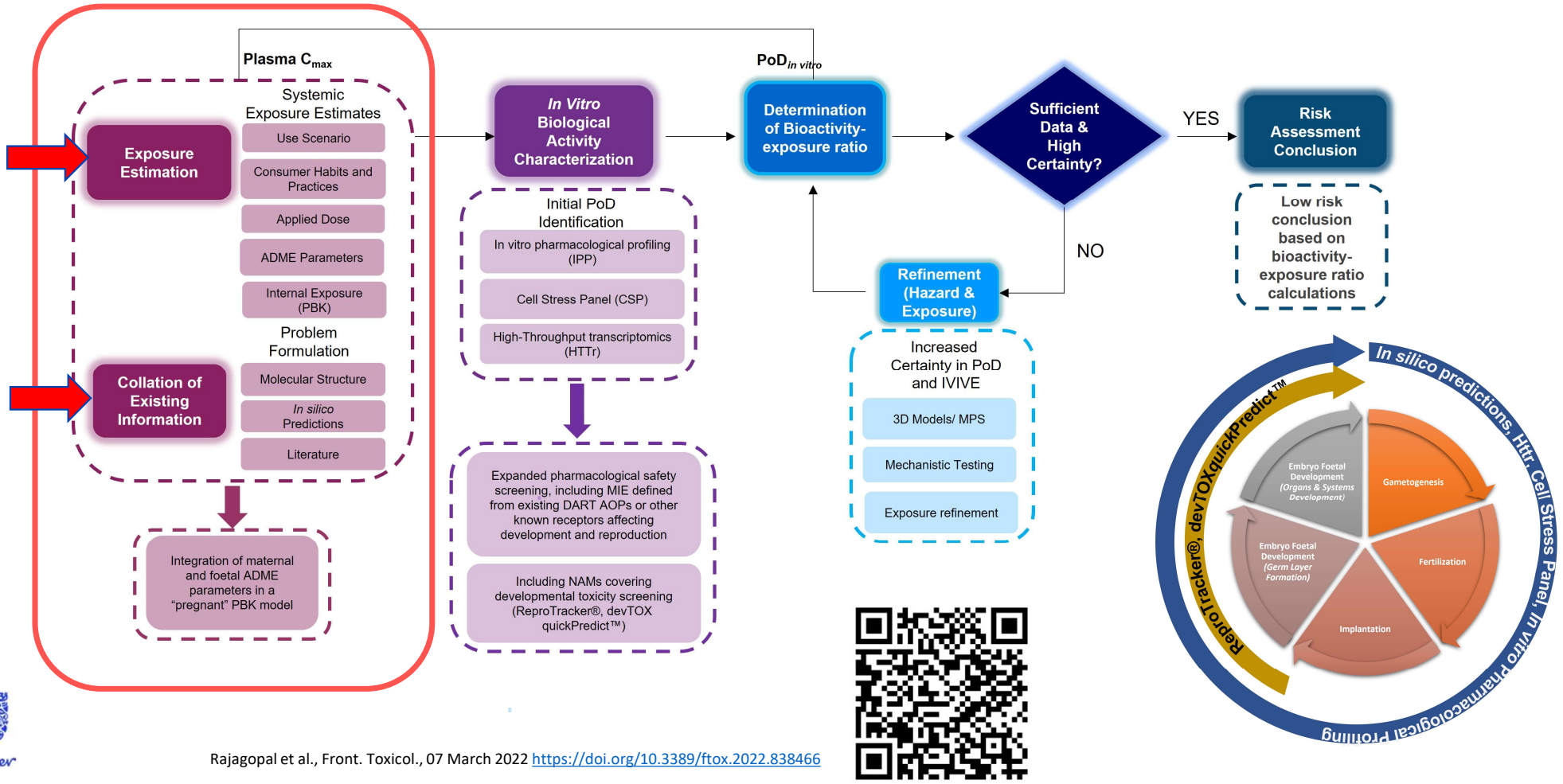
Unilever's NGRA Framework for DART

NGRA Framework for DART – tiered approach



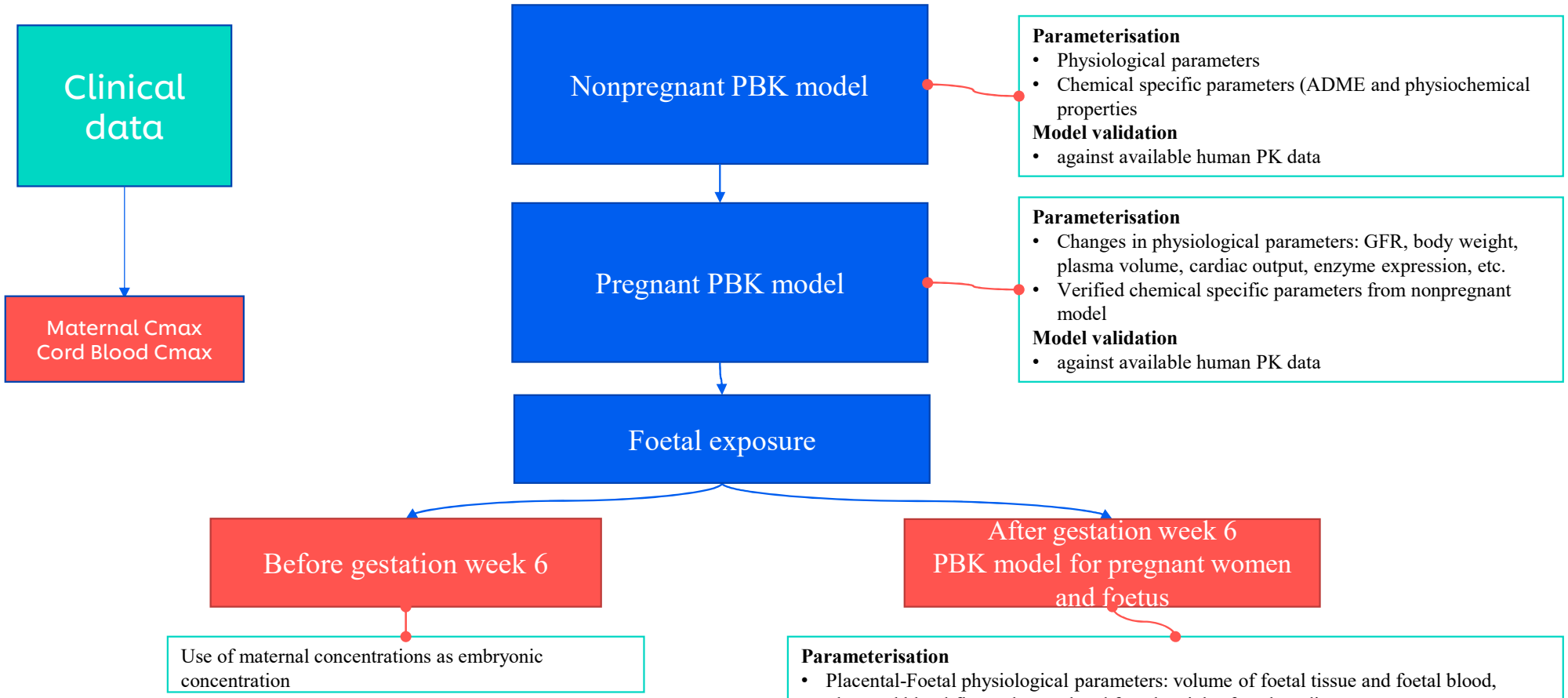
Rajagopal et al., Front. Toxicol., 07 March 2022 https://doi.org/10.3389/ftox.2022.838466

NGRA Framework for DART – exposure module



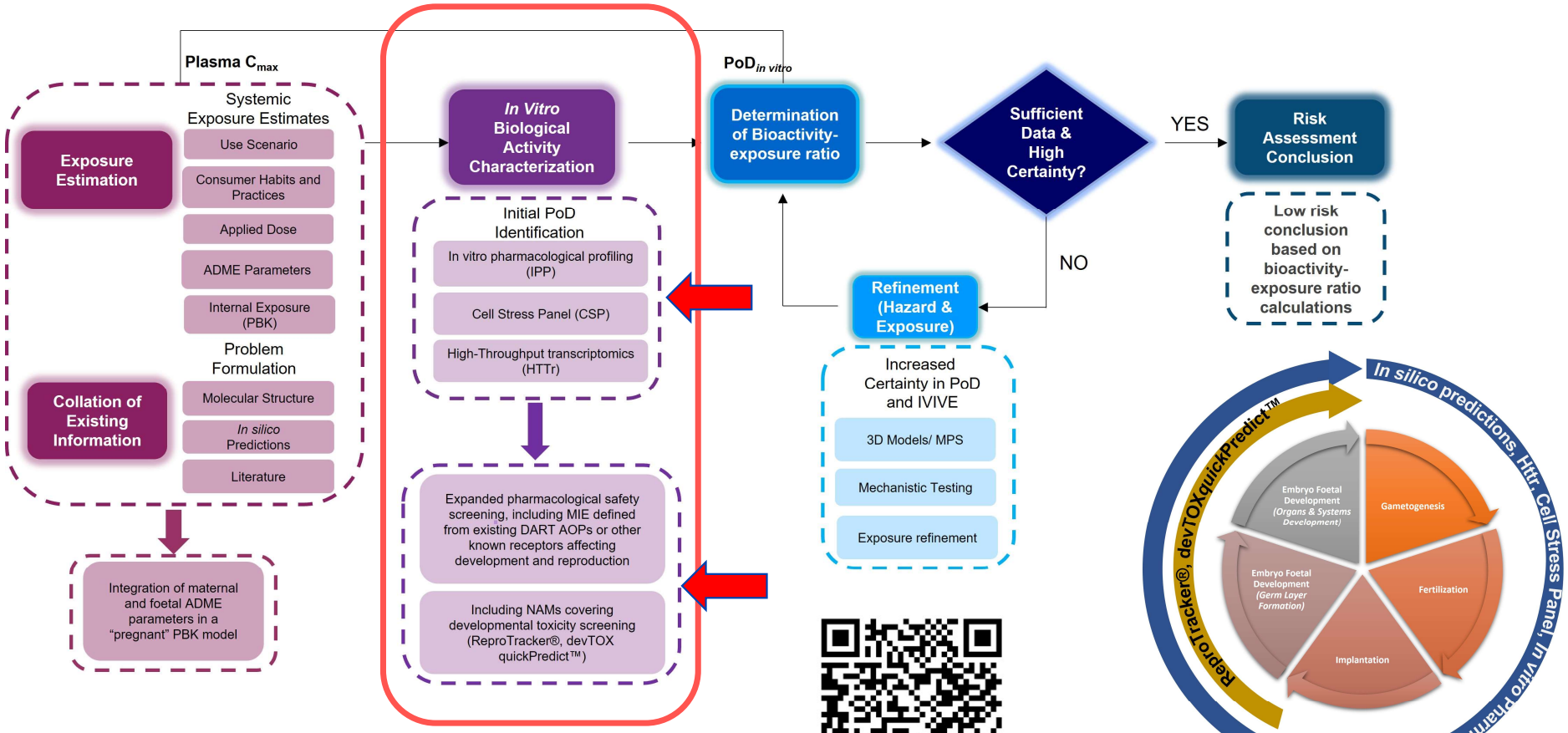
Rajagopal et al., Front. Toxicol., 07 March 2022 https://doi.org/10.3389/ftox.2022.838466

NGRA Framework for DART – exposure module



Rajagopal et al., Front. Toxicol., 07 March 2022
https://doi.org/10.3389/ftox.2022.838466

NGRA Framework for DART – bioactivity module

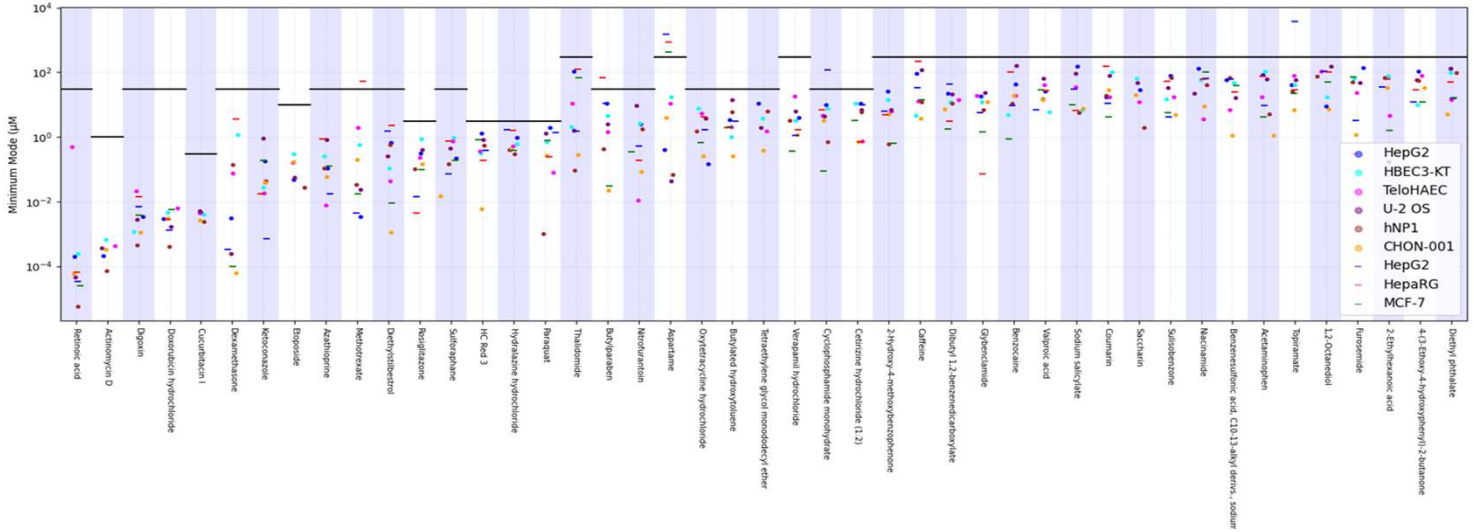


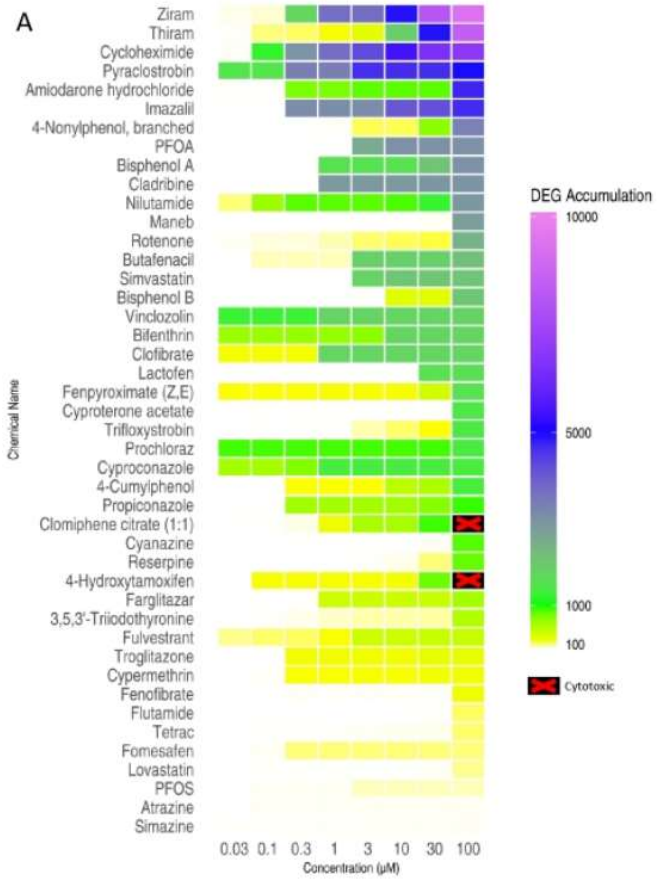
Rajagopal et al., Front. Toxicol., 07 March 2022 https://doi.org/10.3389/ftox.2022.838466

In vitro biological activity characterisation -High throughput transcriptomics

Harrill et al. Toxicol Sci (2021) 181(1):68-89

- Cells treated for 24h with 7 concentrations of each chemical to generate dose-response data (5 biological replicates).
- A number of cell lines chosen to cover a range of biological diversity





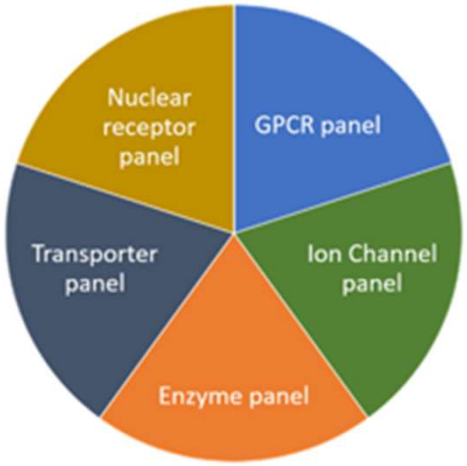
In vitro biological activity characterisation -*in vitro* pharmacological profiling

- The IPP panel contains 82 **targets** with known **safety liabilities** that were tested in binding, enzymatic, coactivator recruitment and luciferase assays.

- 63 of the targets have been associated with ***in vivo* adverse drug reactions** (Bowes *et al.*, 2012) and a further 19 targets implicated in **developmental and reproductive toxicity** were added to the panel based on a literature search.

  ER, AR, TR, CAR, LXR, AhR, PPARs, PXR, VDR, RARs, RXRs, …

  Aromatase, Steroid 5a-reductase, thyroperoxide, histone deacetylase, ..



eurofins | Cerep

PERSPECTIVES

A GUIDE TO DRUG DISCOVERY — OPINION

Reducing safety-related drug attrition: the use of *in vitro* pharmacological profiling

Joanne Bowes, Andrew J. Brown, Jacques Hamon, Wolfgang Jarolimek, Arun Sridhar, Gareth Waldron and Steven Whitebread

Abstract | *In vitro* pharmacological profiling is increasingly being used earlier in the drug discovery process to identify undesirable off-target activity profiles that could hinder or halt the development of candidate drugs or even lead to market withdrawal if discovered after a drug is approved. Here, for the first time, the rationale, strategies and methodologies for *in vitro* pharmacological profiling at four major pharmaceutical companies (AstraZeneca, GlaxoSmithKline, Novartis and Pfizer) are presented and illustrated with examples of their impact on the drug discovery process. We hope that this will enable other companies and academic institutions to benefit from this knowledge and consider joining us in our collaborative knowledge sharing.

safety testing of drug candidates and are designed to prevent serious ADRs from occurring in clinical studies.

The only *in vitro* pharmacology assay that is absolutely required by regulatory authorities is one that measures the effects of new chemical entities on the ionic current of native (I_{Kr}) or heterologously expressed human voltage-gated potassium channel subfamily H member 2 (KCNH2; also known as hERG)[3]. The mechanism by which blockade of hERG can elicit potentially fatal cardiac arrhythmias (torsades de pointes) following a prolongation of the QT interval is well characterized[3,4], and the seriousness of this ADR is one reason why this assay is a mandatory regulatory requirement. Receptor binding studies are also recommended as the first-tier approach for the assessment of the dependence potential of novel chemical entities[5].

However, current regulatory guidance does not describe which targets should constitute an *in vitro* pharmacological profiling panel and does not indicate the stage of the discovery process at which *in vitro* pharmacological profiling should occur.

Targets (gene)	Hit rate*		Main organ class or system	Effects	
	Binding	Functional or enzymatic		Agonism or activation	Antagonism or inhibition
G protein-coupled receptors					
Adenosine receptor A_{2A} (ADORA2A)	High	Low (agonist)	CVS, CNS	Coronary vasodilation; ↓ in BP and reflex; ↑ in HR; ↓ in platelet aggregation and leukocyte activation; ↓ in locomotor activity; sleep induction	Potential for stimulation of platelet aggregation; ↑ in BP; nervousness (tremors, agitation); arousal; insomnia
α_{1A}-adrenergic receptor (ADRA1A)	High	Low (agonist); high (antagonist)	CVS, GI, CNS	Smooth muscle contraction; ↑ in BP; cardiac positive ionotropy; potential for arrhythmia; mydriasis; ↓ in insulin release	↓ in smooth muscle tone; orthostatic hypotension and ↑ in HR; dizziness; impact on various aspects of sexual function
α_{2A}-adrenergic receptor (ADRA2A)	High	Low (agonist); medium (antagonist)	CVS, CNS	↓ in noradrenaline release and sympathetic neurotransmission; ↓ in BP; ↓ in HR; mydriasis; sedation	↑ in GI motility; ↑ in insulin secretion
β_1-adrenergic receptor (ADRB1)	Medium	NA	CVS, GI	↑ in HR; ↑ in cardiac contractility; electrolyte disturbances; ↑ in renin release; relaxation of colon and oesophagus; lipolysis	↓ in BP; ↓ in HR; ↓ in CO
β_2-adrenergic receptor (ADRB2)‡	High	Medium (agonist); medium (antagonist)	Pulmonary, CVS	↑ in HR; bronchodilation; peripheral vasodilation and skeletal muscle tremor; ↑ in glycogenolysis and glucagon release	↓ in BP

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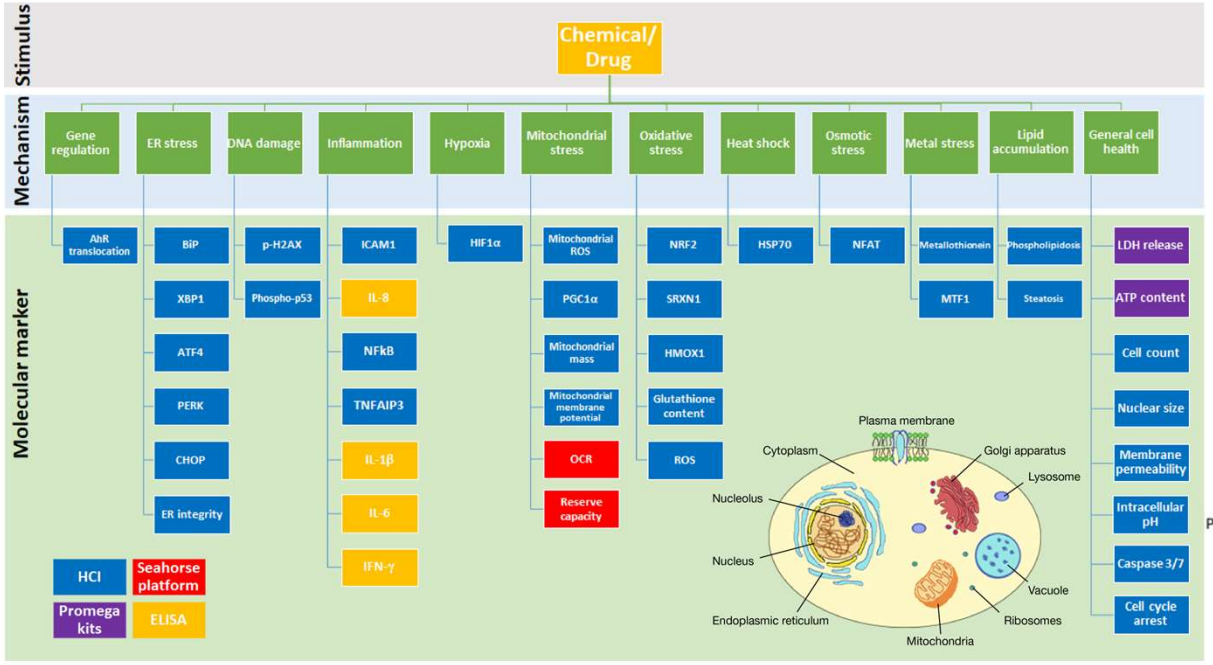
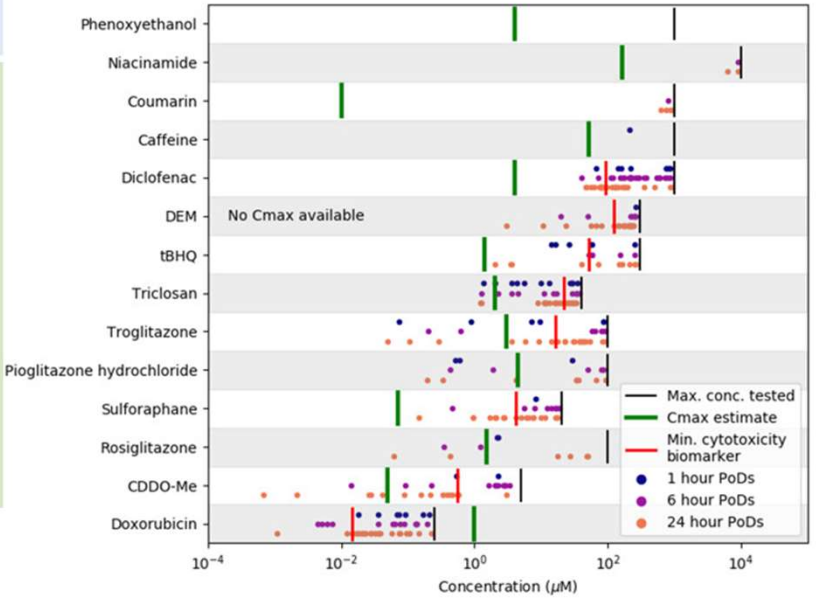
Bowes J, *et al.*, 2012 Reducing safety-related drug attrition: the use of in vitro pharmacological profiling. Nat Rev Drug Discov. 11(12):909-22.

In vitro biological activity characterisation
-Cell stress panel



cyprotex AN EVOTEC COMPANY



- 36 biomarkers, 3 cell lines (HepG2, HepaRG, MCF7), 3 timepoints, 8 concentrations

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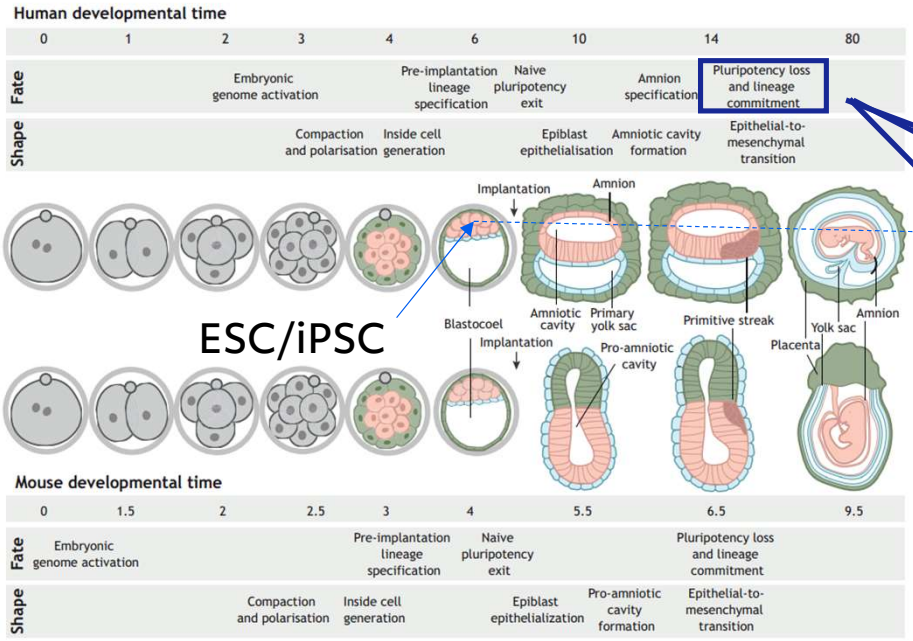
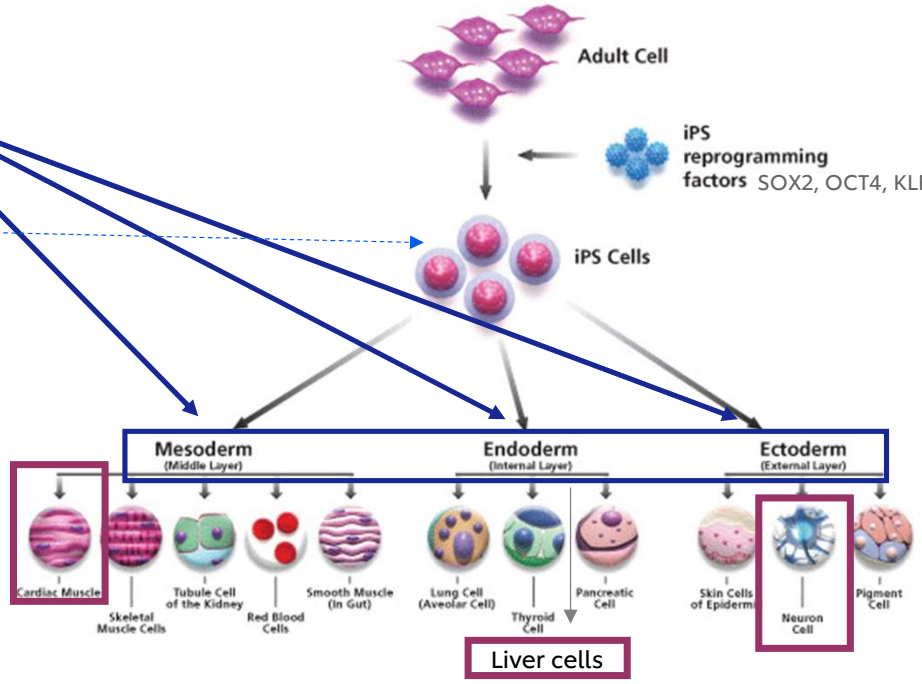
Induced pluripotent stem cells (iPSCs) to detect developmental toxicity



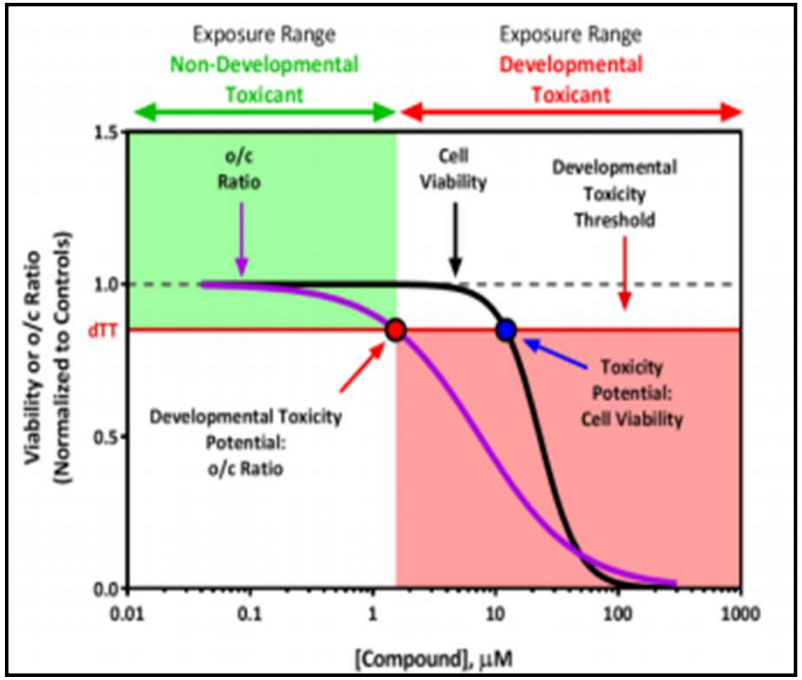
modified from Shahbazi, (2020) Development Jul 17;147(14):dev190629

Induced Pluripotent Stem Cell Differentiation Protocols | Sigma-Aldric



- iPSCs can be used as a surrogate for embryonic stem cells
- Assays have been developed to either use iPSCs directly (devToxquickPredict™ platform; Stemina) or the differentiation into heart, liver and neuronal cells (ReproTracker®; Toxys) as NAMs for developmental toxicity

In vitro biological activity characterisation – devTOX quickPredict™



Published in final edited form as:
Toxicol Sci. 2020 April 01; 174(2): 189–209. doi:10.1093/toxsci/kfaa014.

Profiling the ToxCast Library With a Pluripotent Human (H9) Stem Cell Line-Based Biomarker Assay for Developmental Toxicity

Todd J. Zurlinden[*], Katerine S. Saili[*], Nathaniel Rush[*], Parth Kothiya[*], Richard S. Judson[*], Keith A. Houck[*], E. Sidney Hunter[†], Nancy C. Baker[‡], Jessica A. Palmer[§], Russell S. Thomas[*], Thomas B. Knudsen[*,1]

[*]National Center for Computational Toxicology (NCCT)

[†]National Health and Environmental Effects Research Laboratory (NHEERL), Office of Research and Development (ORD), U.S. Environmental Protection Agency (USEPA), Research Triangle Park, North Carolina 27711

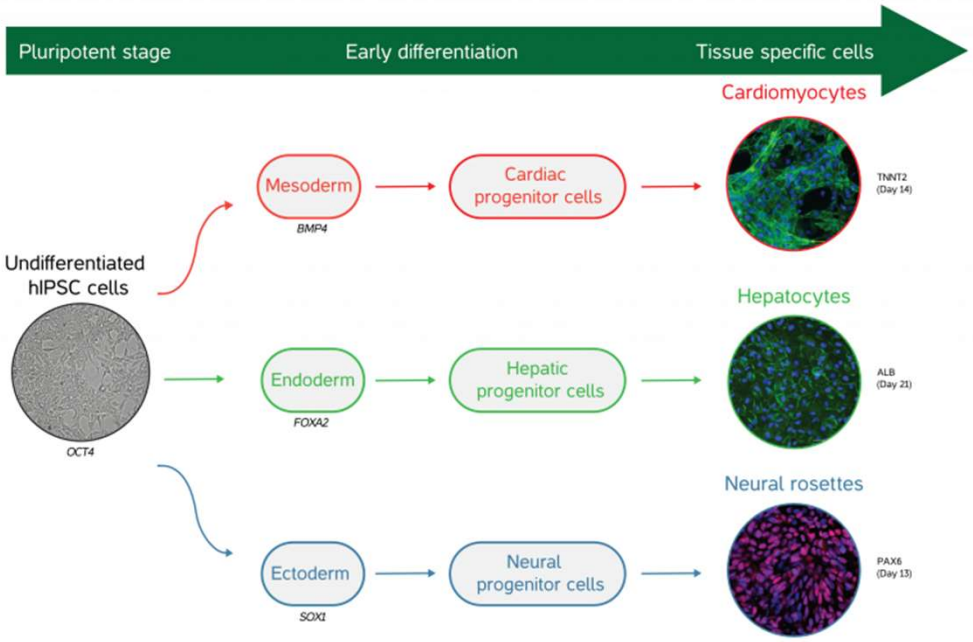
[‡]Leidos, Research Triangle Park, North Carolina 27711

[§]Stemina Biomarker Discovery, Inc, Madison, Wisconsin 53719

- **1065 chemicals tested, 19% showed a positive biomarker response**
- **biomarker performance in general reached accuracies of 79% to 82% with excellent to outstanding specificity (> 84%) but modest sensitivity (< 67%) when compared with in vivo animal models of human prenatal developmental toxicity**

Unilever

In vitro biological activity characterisation
– ReproTracker® assay



Model systems	Model accuracy (%)	References
ReproTracker	85%	A. Jamalpoor et al., submitted., 2021
Mouse EST	78%	A. Seiler et al., 2011
Whole Embryo Culture	68%	K. Augustine-Rauch et al., 2010
Micromass	70%	I. Wilk–Zasadna et al., 2009

Received: 18 November 2021 | Revised: 18 February 2022 | Accepted: 23 February 2022
DOI: 10.1002/bdr2.2001

RESEARCH ARTICLE

Birth Defects Research | Society for Birth Defects Research & Prevention | WILEY

A novel human stem cell-based biomarker assay for in vitro assessment of developmental toxicity

Amer Jamalpoor | Sabine Hartvelt | Myrto Dimopoulou | Tom Zwetsloot | Inger Brandsma | Peter I. Racz | Torben Osterlund | Giel Hendriks

Toxys B.V., Leiden Bio Science Park, Oegstgeest, The Netherlands

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Giel Hendriks, Toxys B.V., Leiden Bio Science Park, De Limes 7, 2342 DH, Oegstgeest, The Netherlands.
Email: g.hendriks@toxys.com

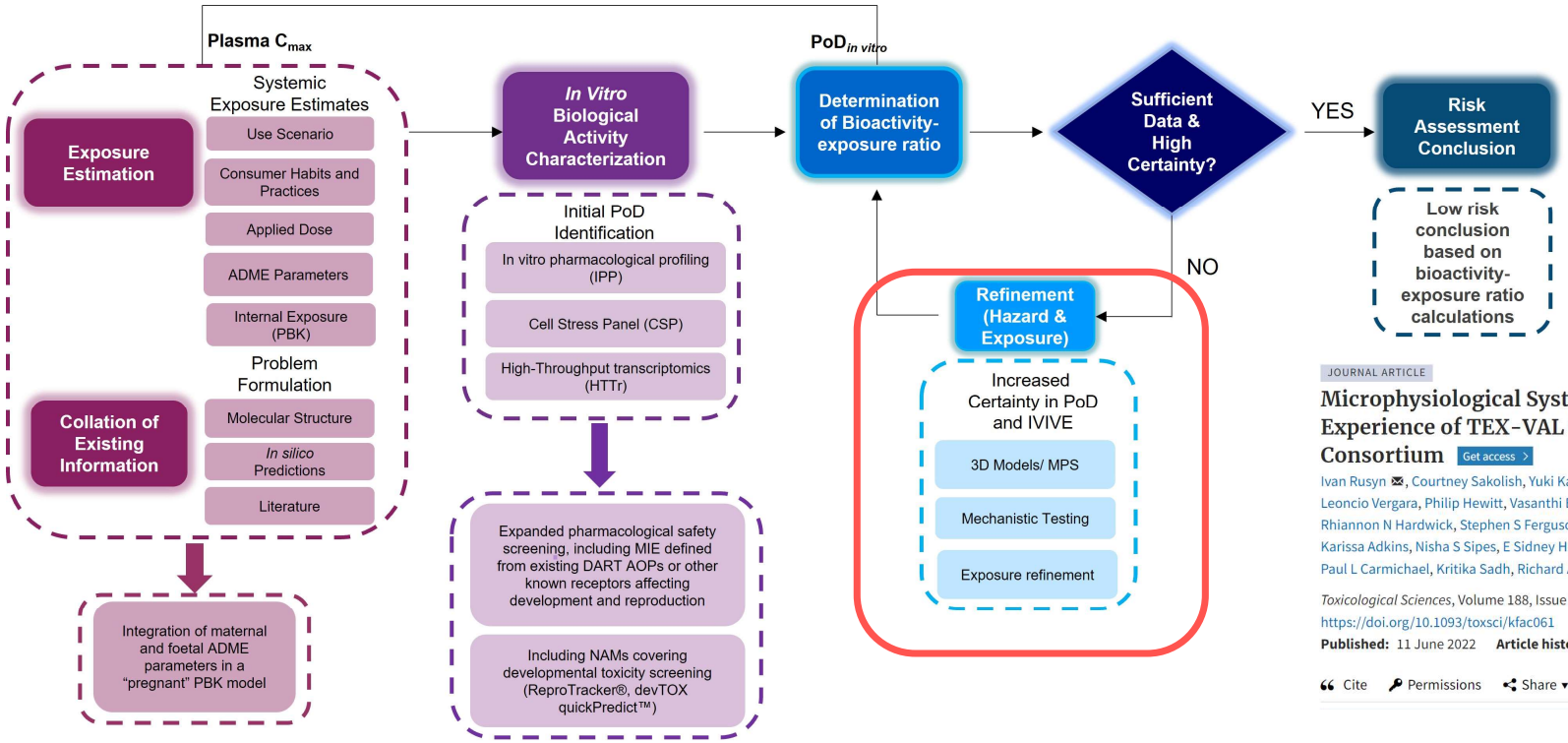
Funding information
EIT Health, Grant/Award Number: HS-2016-BENE-03; Netherlands Enterprise Agency

Abstract

Background: Testing for developmental toxicity according to the current regulatory guidelines requires large numbers of animals, making these tests very resource intensive, time-consuming, and ethically debatable. Over the past decades, several alternative in vitro assays have been developed, but these often suffered from low predictability and the inability to provide a mechanistic understanding of developmental toxicity.

Unilever

Refinement of Biological Activity and Exposure



- **Tex-Val: public-private collaboration established for testing of diverse microphysiological system**
- **Use of metabolically competent models (cell lines, alginate immobilization, etc)**

JOURNAL ARTICLE

Microphysiological Systems Evaluation: Experience of TEX-VAL Tissue Chip Testing Consortium Get access

Ivan Rusyn, Courtney Sakolish, Yuki Kato, Clifford Stephan, Leoncio Vergara, Philip Hewitt, Vasanthi Bhaskaran, Myrtle Davis, Rhiannon N Hardwick, Stephen S Ferguson, Jason P Stanko, Piyush Bajaj, Karissa Adkins, Nisha S Sipes, E Sidney Hunter, 3rd, Maria T Baltazar, Paul L Carmichael, Kritika Sadh, Richard A Becker

Toxicological Sciences, Volume 188, Issue 2, August 2022, Pages 143–152, https://doi.org/10.1093/toxsci/kfac061

Published: 11 June 2022 **Article history**

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JOURNAL ARTICLE FEATURED

The Alginate Immobilization of Metabolic Enzymes Platform Retrofits an Estrogen Receptor Transactivation Assay With Metabolic Competence FREE

Chad Deisenroth, Danica E DeGroot, Todd Zurlinden, Andrew Eicher, James McCord, Mi-Young Lee, Paul Carmichael, Russell S Thomas

Toxicological Sciences, Volume 178, Issue 2, December 2020, Pages 281–301, https://doi.org/10.1093/toxsci/kfaa147

Published: 29 September 2020

NGRA Framework for DART – Scientific and Technical challenges

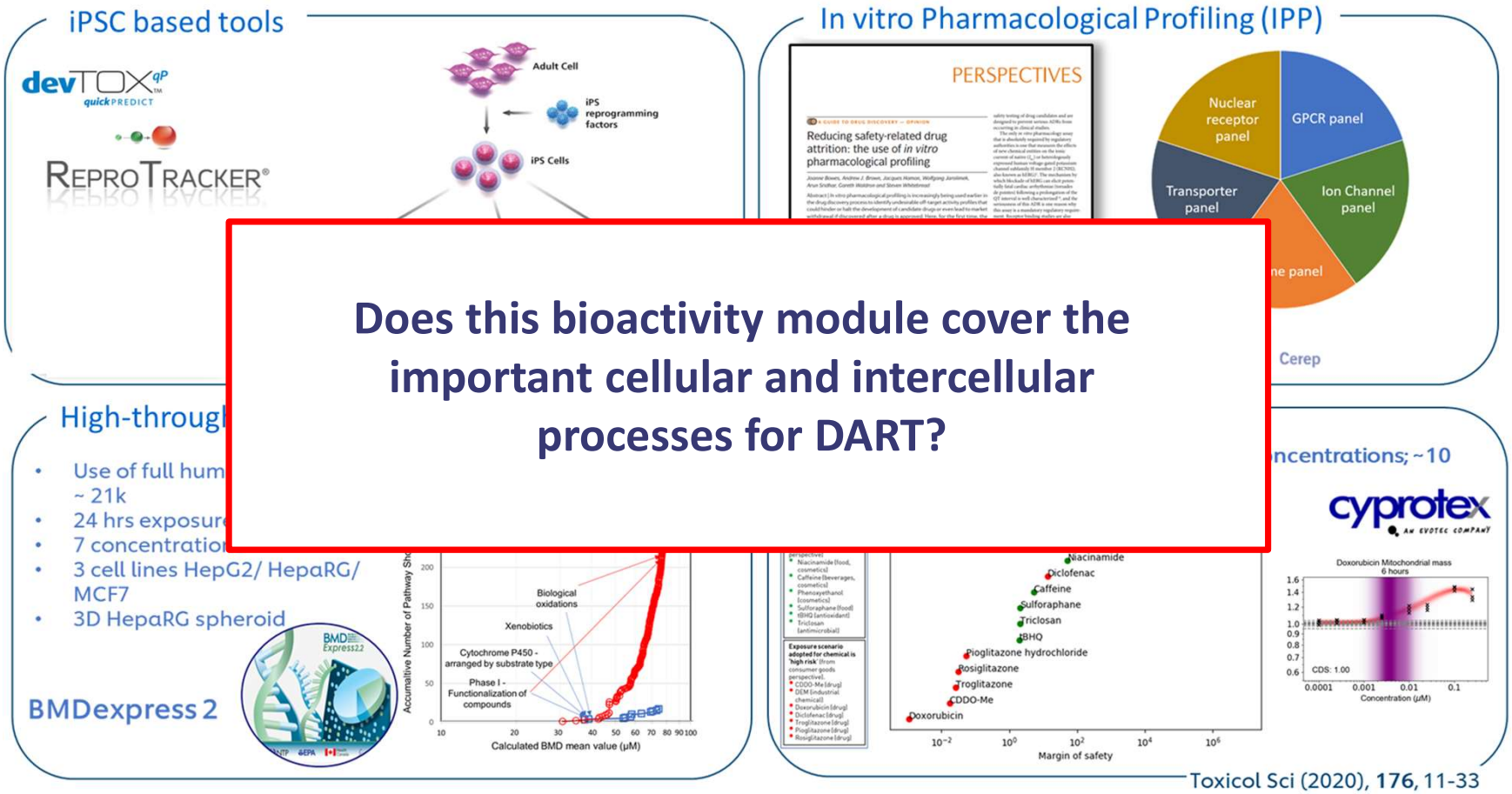
- Metabolic capacity of the framework (cell models, MPS, alginate technology, etc.)
- Spatio-temporal complexity of developmental and reproductive processes
- Short duration exposures and extrapolation to chronic effects
- Ability to generate reliable and consistent reproducible results (HTTr, cell line variability)
- Complex data interpretation and uncertainty analysis
- Coverage of important cellular and intercellular processes – biological relevance
- Chemical domain of applicability / case studies – need for a flexible and fit for purpose validation

Unilever

Biological relevance of the NGRA Framework for DART

Unilever

Coverage of important cellular and intercellular processes for DART

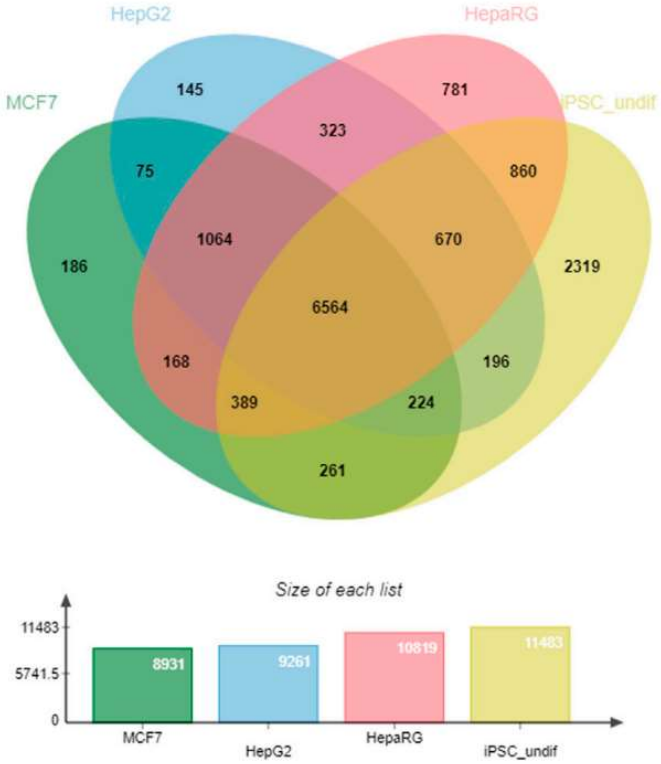


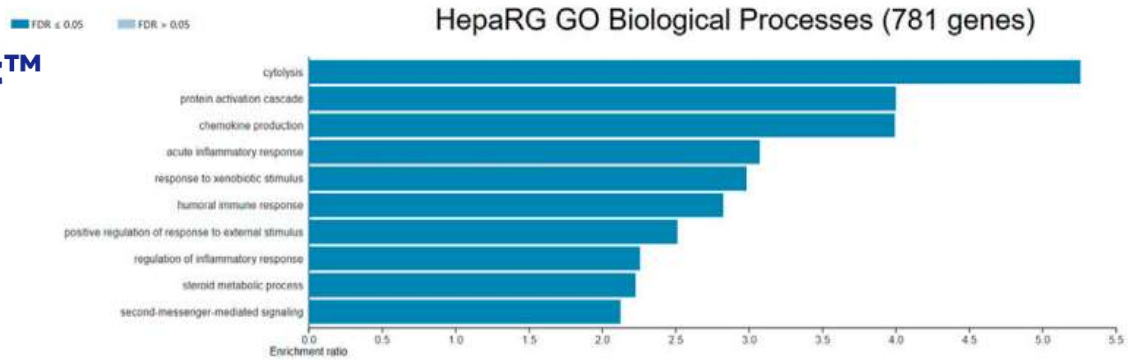
Toxicol Sci (2020), **176**, 11-33

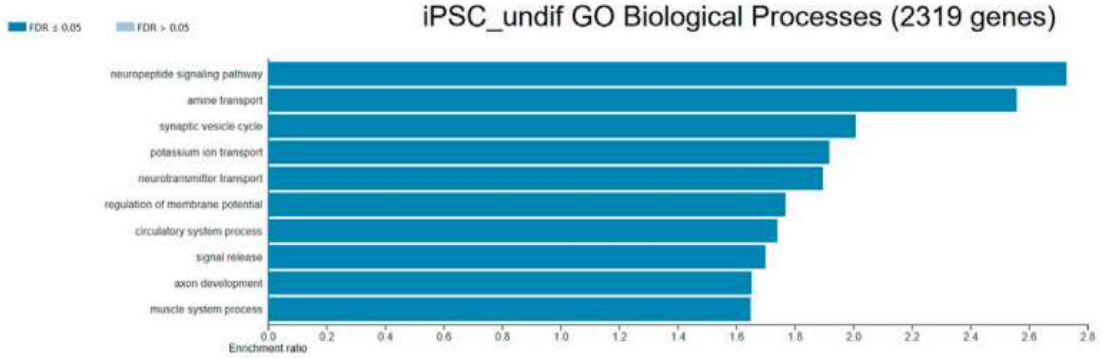
Unilever

Baseline expression of the cell lines within the NGRA DART

HepG2, MCF-7, HepaRG- Systemic Toolbox
hiPSCs- ReproTracker®, devTOXquickPredict™







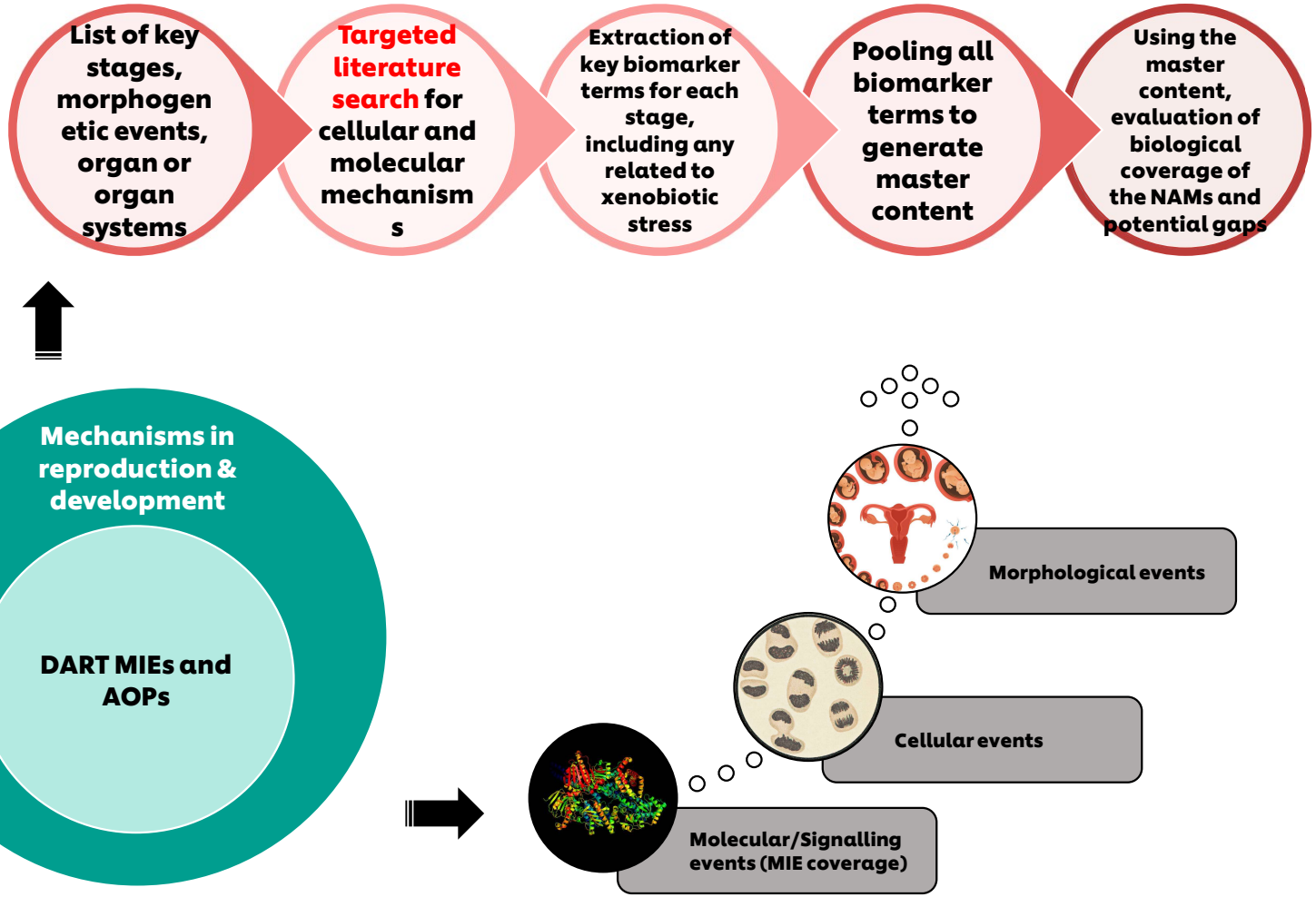
14,225 genes in total

Differentiated hiPSCs not included in this study but in scope for future work

Key Biomarkers for DART - Systematic literature search

AOPs based approach

- 11 DART-related Adverse Outcome Pathways (AOPs)
- At present, a decision framework based only on AOPs is not feasible. **However, AOPs can used as a knowledge base for enhancing a testing strategy**



Key Stages, Morphogenetic Events and Derivatives Organs & Systems in Human Reproduction and Development

Sex determination

Gametogenesis

Fertilization

Zygote formation

Implantation

Blastulation

Gastrulation

Placenta formation

Neurulation

Ectoderm formation and its derivatives

- Central nervous system
- Peripheral nervous system
- Autonomous nervous system
- Integumentary system

Mesoderm formation and its derivatives

- Somitogenesis
- Hematopoiesis
- Heart and circulatory system
- Immune system
- Spleen
- Urinary system and urethra
- Reproductive system – testis
- Reproductive system – ovary
- Skeletal system
- Limbs

Endoderm formation and its derivatives

- Digestive system
- Respiratory system
- Thymus
- Parathyroid
- Thyroid

Structures developing from mesenchyme or multiple germ layers

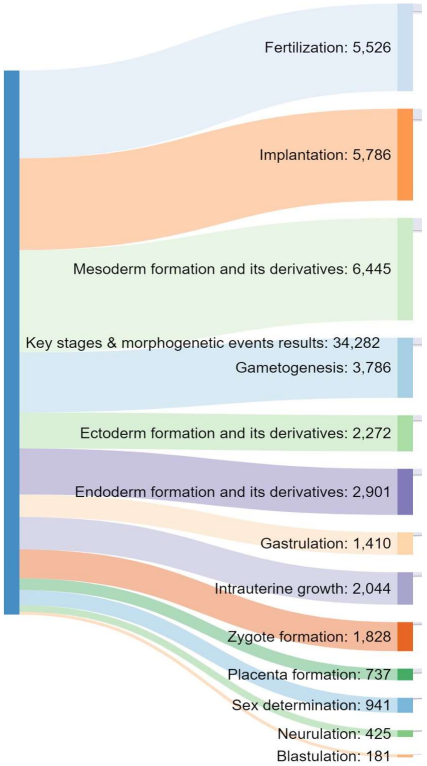
- Adrenal glands
- Eyes
- Ears
- Face and neck

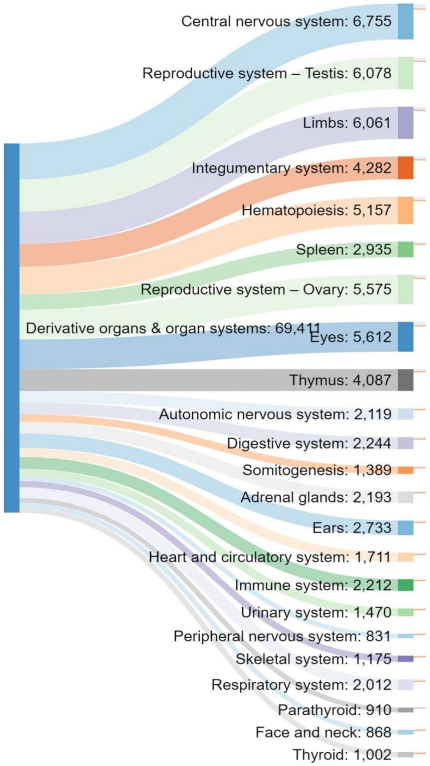
Intrauterine growth

Overview of Literature Search and Extraction of Key Markers Information

Literature search MeSH Ontology 37 million Articles

Validation and quality check of results; finalising the articles

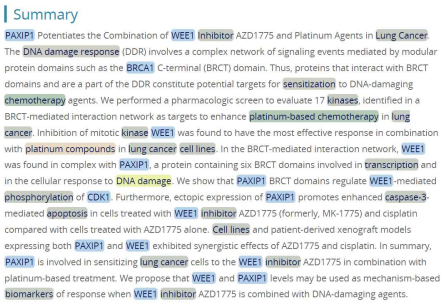




Pooling extractions, Thresholding of hit counts

Semantic enrichment using HGNC, miRNA and biological processes ontologies

Abstracts extracted and collated


Summary

PAXIP1 Potentiates the Combination of WEE1 Inhibitor AZD1775 and Platinum Agents in Lung Cancer. The DNA damage response (DDR) involves a complex network of signaling events mediated by modular protein domains such as the BRCA1 C-terminal (BRCT) domain. Thus, proteins that interact with BRCT domains and are a part of the DDR constitute potential targets for sensitization to DNA-damaging chemotherapy agents. We performed a pharmacologic screen to evaluate 17 kinases, identified in a BRCT-mediated interaction network as targets to enhance platinum-based chemotherapy in lung cancer. Inhibition of mitotic kinase WEE1 was found to have the most effective response in combination with platinum compounds in lung cancer cell lines. In the BRCT-mediated interaction network, WEE1 was found in complex with PAXIP1, a protein containing six BRCT domains involved in transcription and in the cellular response to DNA damage. We show that PAXIP1 BRCT domains regulate WEE1-mediated phosphorylation of CDK1. Furthermore, ectopic expression of PAXIP1 promotes enhanced caspase-3-mediated apoptosis in cells treated with WEE1 inhibitor AZD1775 (formerly, MK-1775) and cisplatin compared with cells treated with AZD1775 alone. Cell lines and patient-derived xenograft models expressing both PAXIP1 and WEE1 exhibited synergistic effects of AZD1775 and cisplatin. In summary, PAXIP1 is involved in sensitizing lung cancer cells to the WEE1 inhibitor AZD1775 in combination with platinum-based treatment. We propose that WEE1 and PAXIP1 levels may be used as mechanism-based biomarkers of response when WEE1 inhibitor AZD1775 is combined with DNA-damaging agents.

Query run: ("CNS") AND (embryonic development OR fetal development) AND (cell physiology OR nervous system physiology) OR (signalling OR pathway OR gene OR protein) AND (human OR mammalian) NOT (infections)

34,308 articles on key stages and morphogenetic events

69,299 articles on organs and organ systems development

103,607 total articles

Overview of Literature Search and Extraction of Key Markers Information

Extract Genes

Vocabulary based on Hugo Gene Nomenclature Committee standard list of genes

Download Abstracts of Selected articles

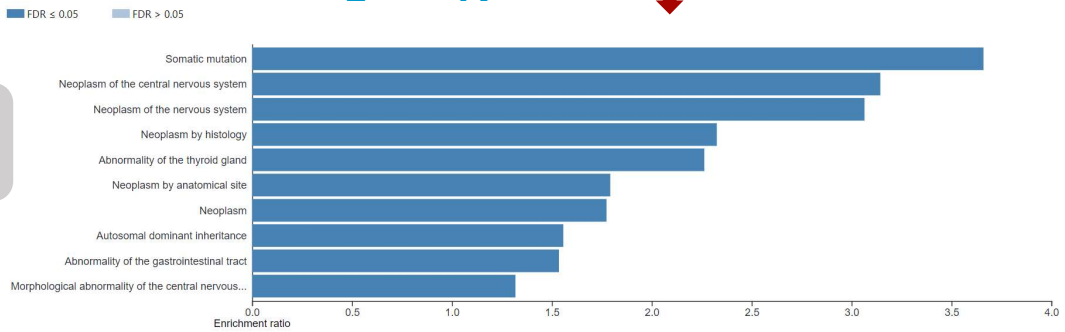
Extract Cellular & Molecular Mechanisms

Extract miRNA

CNS - 6757 Abstracts

	A	B	C
1	Gene symbol	Name	HitCount
2	GFAP	glial fibrillary acidic protein	554
3	SHH	sonic hedgehog	505
4	WNT1	Wnt family member 1	441
5	BDNF	brain derived neurotrophic factor	379
6	AQP1	aquaporin 1 (Colton blood group)	360
7	NES	nestin	346
8	FGF2	fibroblast growth factor 2	345
9	IGF1	insulin like growth factor 1	341
10	GNRH1	gonadotropin releasing hormone 1	334
11	TH	tyrosine hydroxylase	329
12	NGF	nerve growth factor	327
13	CSPG4	chondroitin sulfate proteoglycan 4	295
14	MBP	myelin basic protein	294
15	PAX6	paired box 6	288
16	TGFB1	transforming growth factor beta 1	267
17	EGF	epidermal growth factor	232
18	TP53	tumor protein p53	193
19	INS	insulin	189
20	INSR	insulin receptor	186
21	NCAM1	neural cell adhesion molecule 1	182
22	TNF	tumor necrosis factor	180
23	CDKN2A	cyclin dependent kinase inhibitor 2A	176
24	APP	amyloid beta precursor protein	173
25	TNC	tenascin C	166
26	OLIG2	oligodendrocyte transcription factor 2	163
27	SOX2	SRY-box 2	163
28	CTNNB1	catenin beta 1	158
29	IL6	interleukin 6	154
30	RTN4	reticulon 4	142
31	VIP	vasoactive intestinal peptide	142

902 genes/proteins



Human Phenotype Ontology

Pooled List of DARS biomarkers

3551 DARS Genes

	A	B	C
1	Gene symbol	Name	HitCount
2	CGA	glycoprotein hormones, alpha polypeptide	11924
3	SHH	sonic hedgehog	6622
4	WNT1	Wnt family member 1	6428
5	TGFB1	transforming growth factor beta 1	6056
6	IGF1	insulin like growth factor 1	4556
7	INS	insulin	4395
8	GNRH1	gonadotropin releasing hormone 1	3943
9	CTNNB1	catenin beta 1	3912
10	VEGFA	vascular endothelial growth factor A	3777
11	SRY	sex determining region Y	3479
12	POMC	proopiomelanocortin	3454
13	EGF	epidermal growth factor	3396
14	KIT	KIT proto-oncogene receptor tyrosine kinase	3380
15	POU5F1	POU class 5 homeobox 1	3307
16	CD4	CD4 molecule	3152
17	PAX6	paired box 6	3124
18	LIF	LIF, interleukin 6 family cytokine	3070
19	BMP4	bone morphogenetic protein 4	3027
20	CD34	CD34 molecule	3027
21	ESR1	estrogen receptor 1	2946
22	SOX9	SRY-box 9	2649
23	TNF	tumor necrosis factor	2620
24	TP53	tumor protein p53	2520
25	PTHLH	parathyroid hormone like hormone	2436
26	AMH	anti-Mullerian hormone	2431
27	NR5A1	nuclear receptor subfamily 5 group A member 1	2341
28	IGF2	insulin like growth factor 2	2290
29	LEP	leptin	2058
30	AKT1	AKT serine/threonine kinase 1	1977
31	FGF2	fibroblast growth factor 2	1912

474 DARS Biological Processes

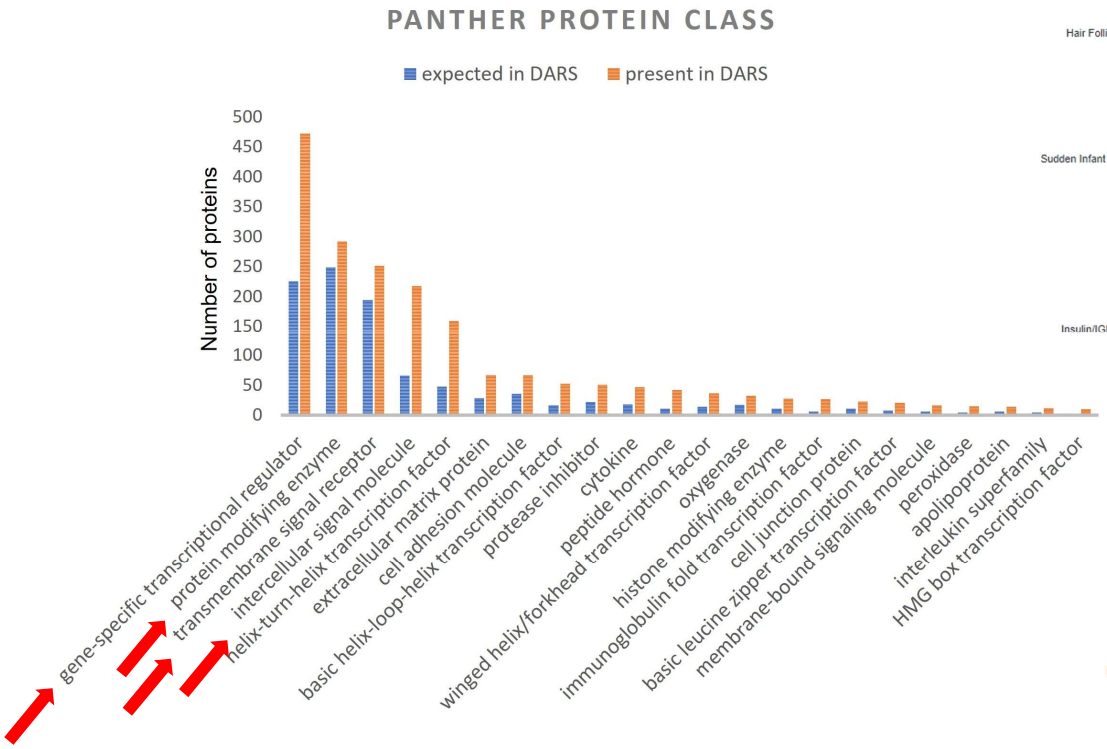
	A	B	C
1	HitID	Name	HitCount
2	GO_0023052	signaling	21733
3	GO_0007049	cell cycle	3228
4	GO_0008219	cell death	2514
5	GO_0006306	DNA methylation	2440
6	GO_0001837	epithelial to mesenchymal transition	2422
7	GO_0016310	phosphorylation	2372
8	GO_0030154	cell differentiation	2262
9	GO_0048468	cell development	2248
10	GO_0001556	oocyte maturation	1973
11	GO_0022008	neurogenesis	1567
12	GO_0006412	translation	1541
13	NCIT_C17741	Oxidative Stress	1449
14	GO_0048477	oogenesis	1243
15	GO_0001171	reverse transcription	1235
16	GO_0016477	cell migration	1209
17	GO_0007165	signal transduction	1146
18	GO_0030218	erythrocyte differentiation	1134
19	GO_0016049	cell growth	1041
20	GO_0006914	autophagy	1021

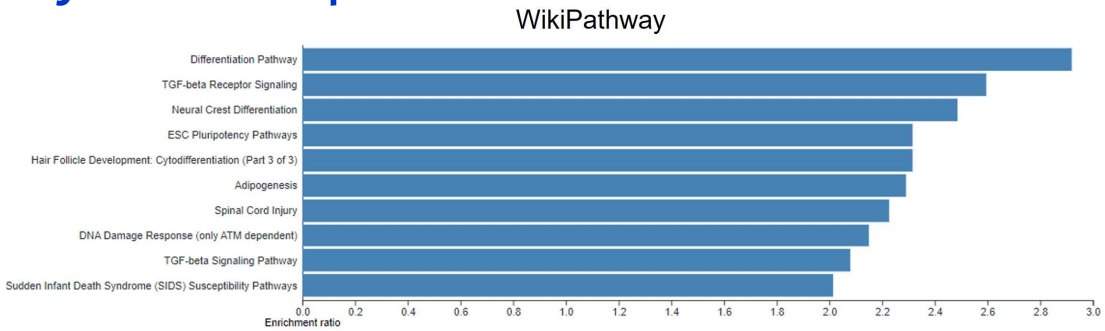
338 DARS miRNA

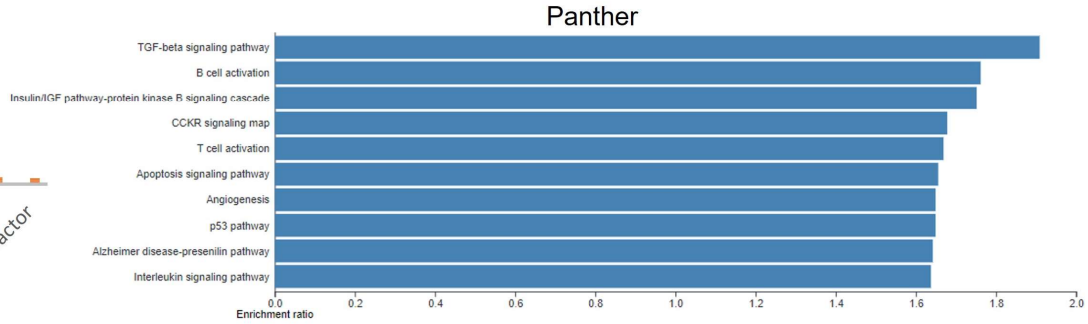
	A	B
1	HitID	HitCount
2	LET7	155
3	MIR-21	127
4	MIR-145	85
5	MIR-125B	73
6	MIR-17	73
7	MIR-17-92	65
8	MIR-1	64
9	MIR-302	62
10	MIR-124	56
11	MIR-29B	55
12	MIR-34C	52
13	MIR-34A	51
14	MIR-130B	51
15	MIR-375	49
16	MIR-200C	46
17	MIR-24	45
18	MIR-29A	44
19	MIR-429	41
20	MIR-223	41

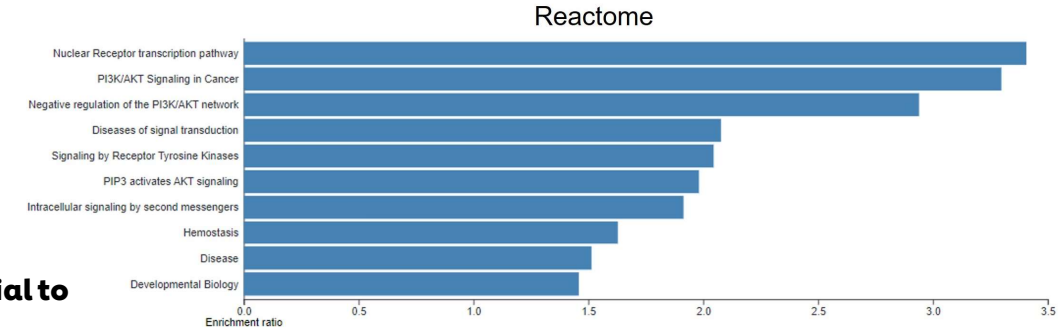
Unilever

Protein classes and signalling pathways over-represented in DARS biomarkers





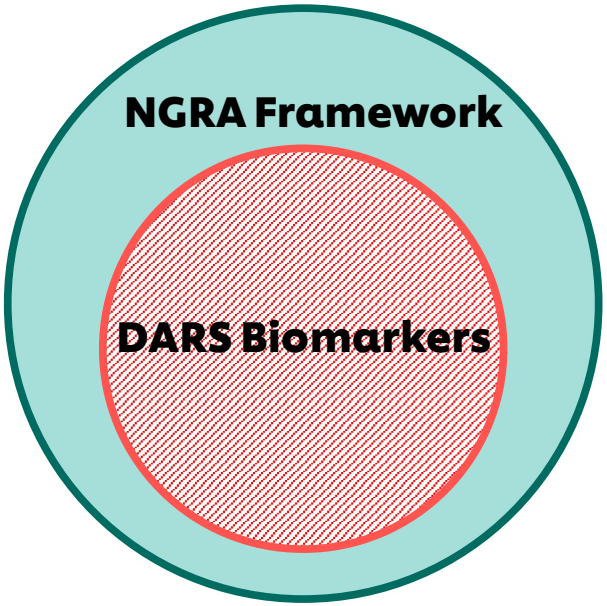




DARS BP: Signalling, cell cycle, cell death, DNA methylation, epithelial to mesenchymal transition, phosphorylation, cell differentiation, cell development, oocyte maturation and neurogenesis
DARS miRNA: LET-7, MIR-21 and MIR-145

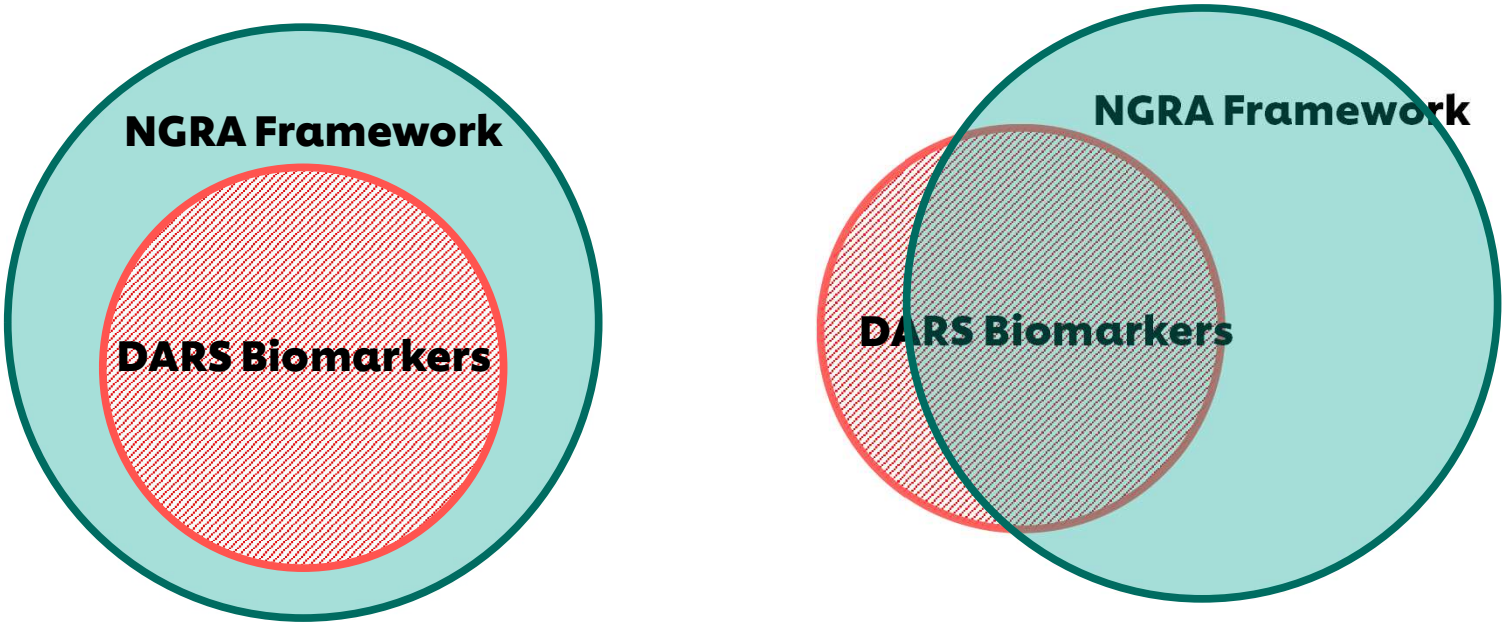
Rajagopal et al., Front. Toxicol., 2022

Biological coverage of the DARS biomarkers by the DART NGRA



Expectation

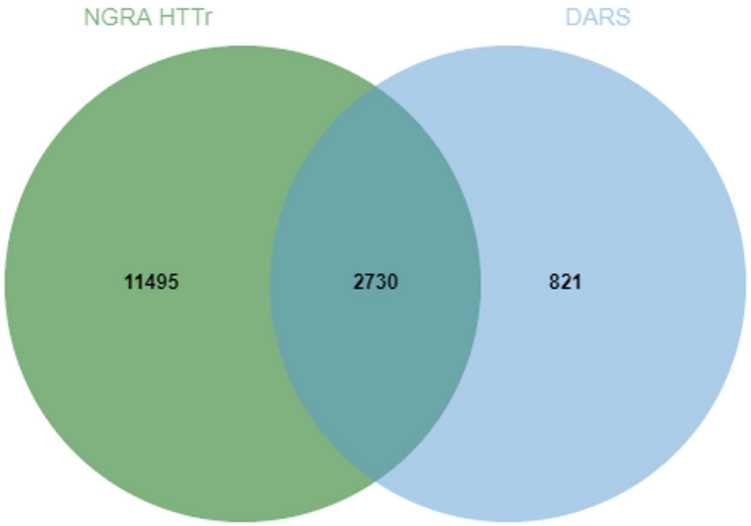
Biological coverage of the DARS biomarkers by the DART NGRA

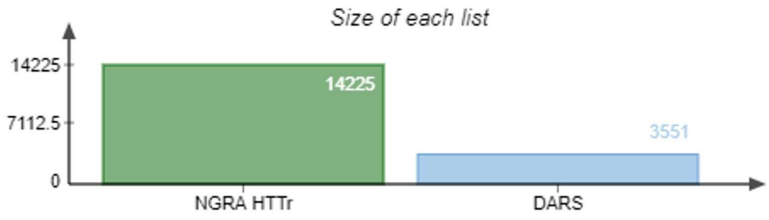


Expectation *versus* **Reality**

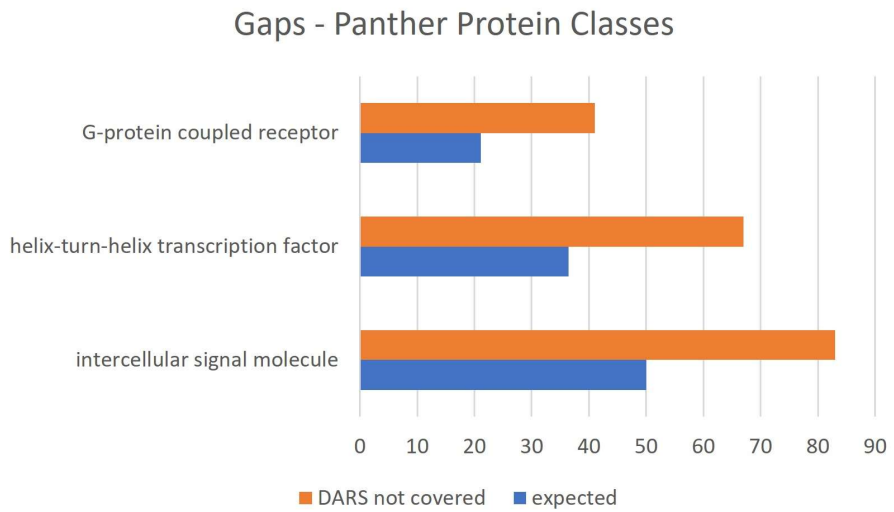
Biological coverage of the DARS biomarkers by the DART NGRA

Coverage





Gaps



- **41 GPCRs (6 present in IPP)**
- **60 HTH transcription factors (mainly homeobox transcription factors)**
- **Intercellular signal molecules (chemokines, cytokines, growth factors, neurotropic factors, peptide hormones)**

Biological coverage of the DARS biomarkers by the DART NGRA

Coverage

General cellular & functional processes- cell survival, cytotoxicity

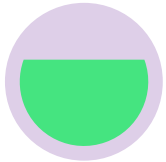
Receptor or enzyme activity- IPP covers about 13%

Signalling pathways- DARS genes

Specific differentiation- ReproTracker®

Specific cellular processes- devTOXQuickPredict™

Cellular stress- Cell stress panel assays

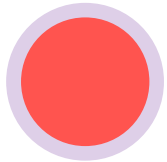


Gaps

Specific cellular processes- E.g. cytokine secretion or myelination or androgen biosynthesis

Specific functional processes- E.g. sperm motility or axon guidance or lymphocyte migration

Receptor or enzyme activity- E.g. receptor tyrosine kinases or receptor serine/threonine kinases or GPCRs



Weight of evidence

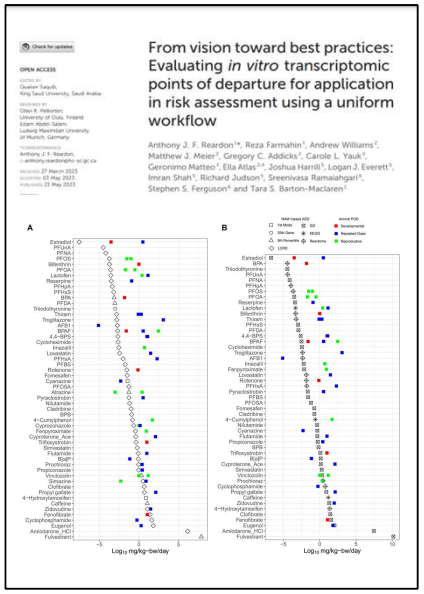
Integrating data from different NAMs

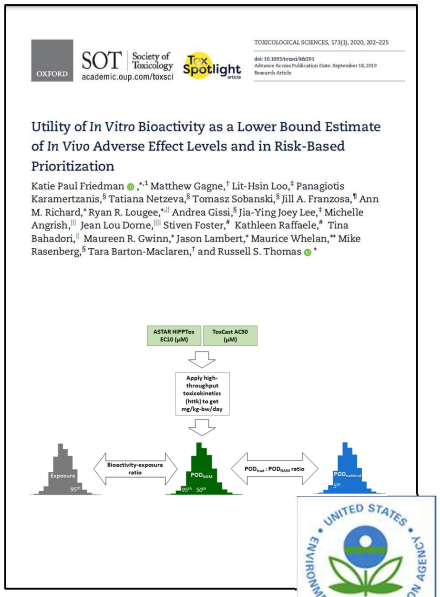
MIE -> KEs -> Adverse effects E.g. ADORA 2A binding, inhibition of PI3Kinase-AKT signalling, T cell development

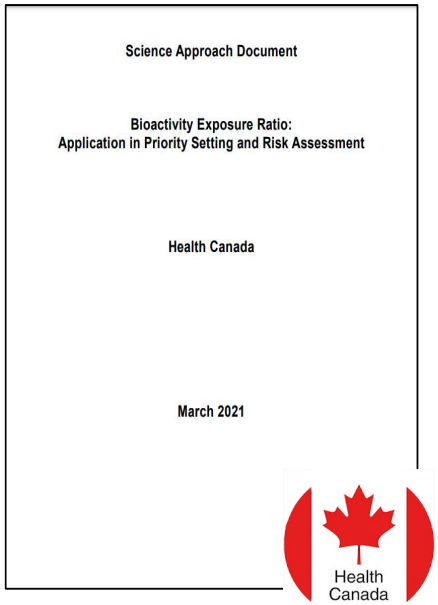
Rajagopal et al., Front. Toxicol., 2022

Case studies / fit for purpose validation, next steps

Examples of ongoing or completed case studies for NAM/NGRA BER based risk assessment or prioritisation


From vision toward best practices: Evaluating *in vitro* transcriptomic points of departure for application in risk assessment using a uniform workflow


Utility of *In Vitro* Bioactivity as a Lower Bound Estimate of *In Vivo* Adverse Effect Levels and in Risk-Based Prioritization

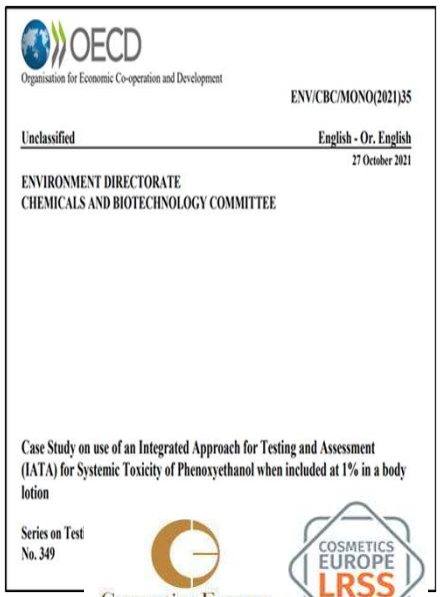

Science Approach Document

Bioactivity Exposure Ratio:
Application in Priority Setting and Risk Assessment

Health Canada

March 2021

https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/science-approach-document-bioactivity-exposure-ratio-application-priority-setting-risk-assessment.html


OECD

Organisation for Economic Co-operation and Development

ENV/CBC/MONO(2021)35

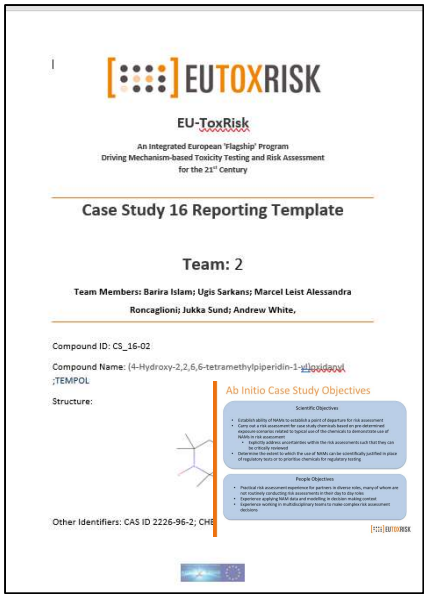
Unclassified — English - Or. English

27 October 2021

ENVIRONMENT DIRECTORATE
CHEMICALS AND BIOTECHNOLOGY COMMITTEE

Case Study on use of an Integrated Approach for Testing and Assessment (IATA) for Systemic Toxicity of Phenoxyethanol when included at 1% in a body lotion

Series on Test
No. 349


EUTOXRISK

EU-ToxRisk

An Integrated European 'flagship' Program
Driving Mechanism-based Toxicity Testing and Risk Assessment
for the 21st Century

Case Study 16 Reporting Template

Team: 2

Team Members: Barira Islam; Ugis Sarkans; Marcel Leist Alessandra Roncaglioni; Jukka Sund; Andrew White,

Compound ID: CS_16-02

Compound Name: (4-Hydroxy-2,2,6,6-tetramethylpiperidin-1-yl)oxidanyl ;TEMPOL

Structure:

Ab Initio Case Study Objectives

Other Identifiers: CAS ID 2226-96-2; CHE

Health Canada

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Cosmetics Europe
the personal care association

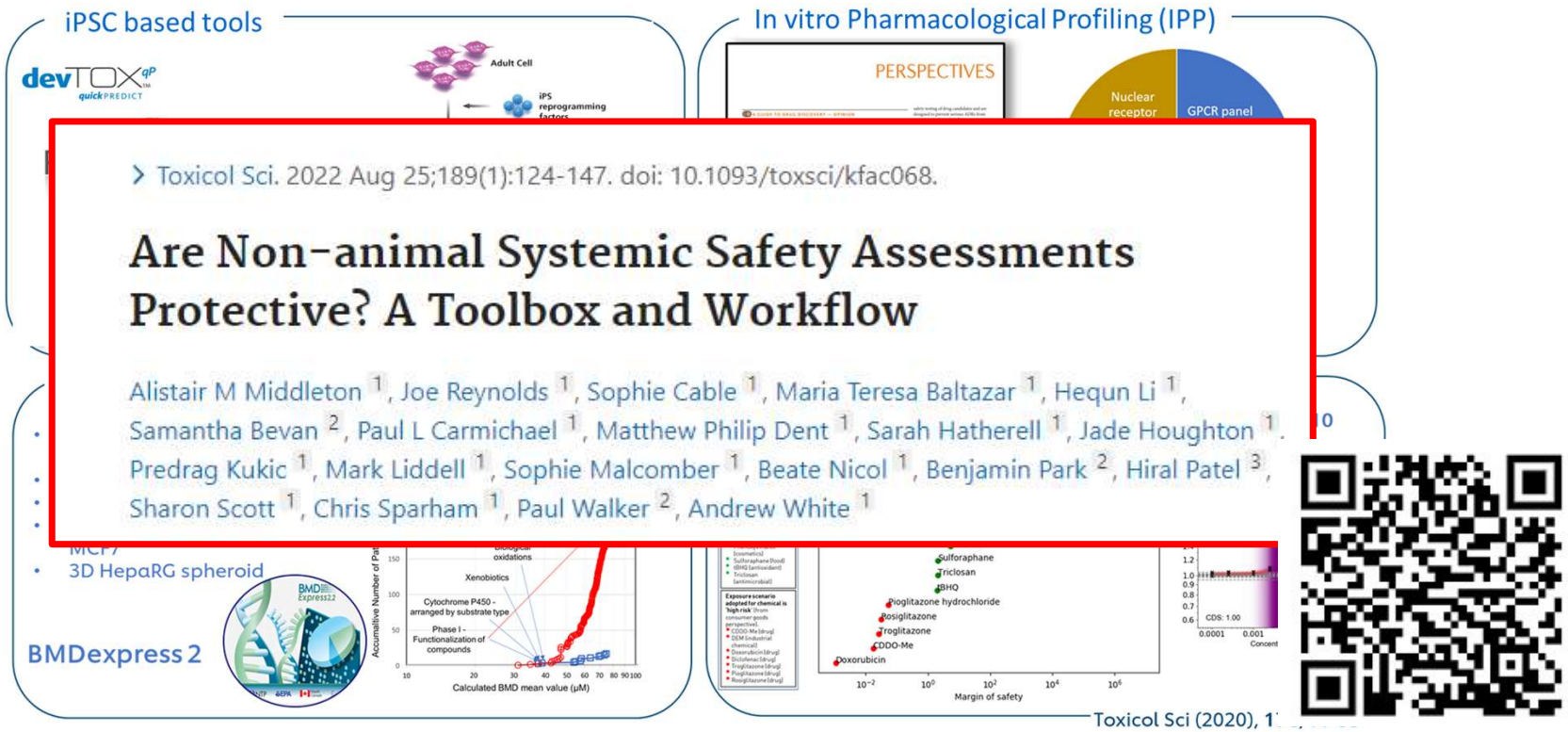
COSMETICS EUROPE LRSS

RISK HUNT3R

Unilever

Is the NGRA Framework protective – fit for purpose validation

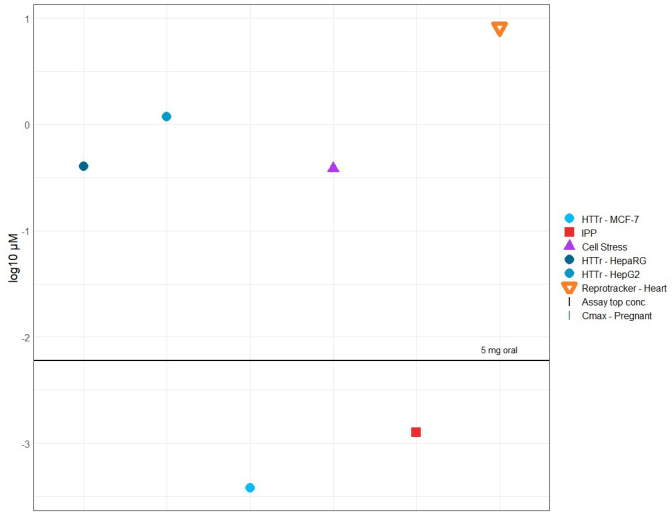
- Aim: evaluate protectiveness of the NGRA Framework for DART for a given chemical-exposure scenario
- Each chemical-exposure scenario is classified as “high” or “low” risk for pregnancy
- For each chemical-exposure scenario we generate NAM data using NGRA Framework



Is the NGRA Framework protective – examples

Exposure Scenario: Oral 0.5 mg tablet daily during pregnancy = risk for pregnancy

Diethylstilbesterol

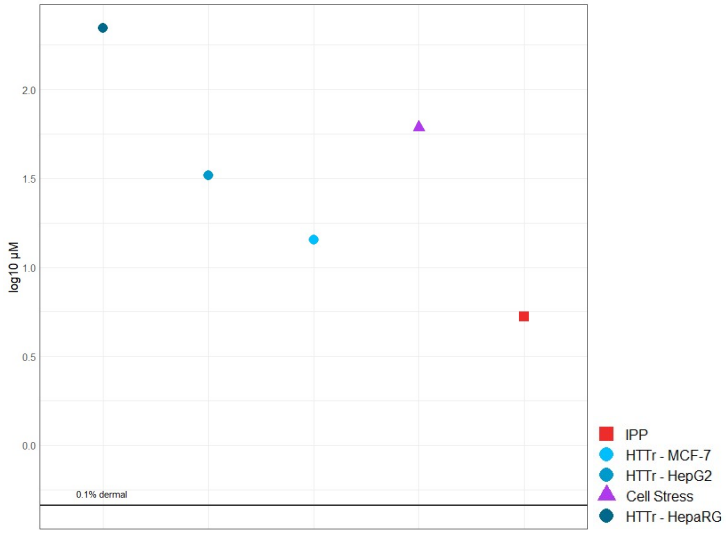


Outcome: Bioactivity detected at or below the plasma Cmax = <u>risk for pregnancy</u>

The lowest PoD is coming from HTTR data from MCF7 cells expressing the Estrogen receptor, and from IPP (ER binding)

Exposure Scenario: Daily dermal application of 0.1% caffeine in a body lotion = low risk for pregnancy

Caffeine



Outcome: Bioactivity across the DART toolbox occurring at much higher concentrations than the plasma C_{max} = <u>low risk for pregnancy</u>

The lowest PoD coming from IPP ADORA2A

Is the NGRA Framework protective – examples

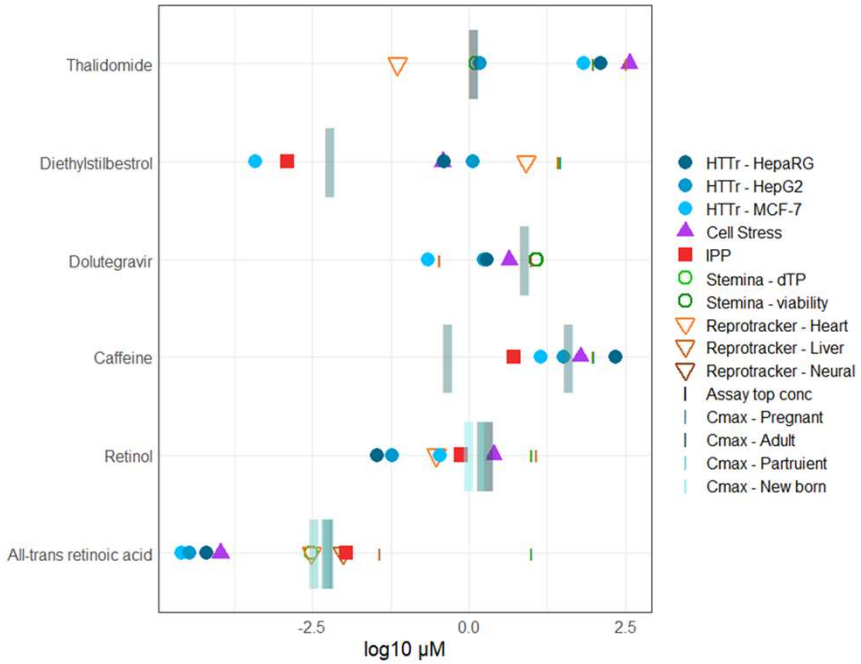
50mg oral application of Thalidomide, high risk, causing dev. toxicity.

5mg oral application of DES, high risk, causing estrogen activity/ED

50mg oral application of Dolutegravir, high risk, causing dev. toxicity

Dermal application of 0.1% caffeine in body lotion (lower Cmax), or oral uptake at recommended TDI of 200mg per days (higher Cmax) of caffeine, both low risk risk.

Uptake of vitamin A/retinol or retinol equivalents in normal diet, low risk. Cmax concentration of retinol and all-trans retinoic acid (metabolite of retinol) were measured in blood of adult, pregnant and parturient woman as well as in newborns[3].



Lowest PoD for Thalidomide is below Cmax value, the toolbox has correctly identified Thalidomide as high risk with lowest PoD coming from ReproTracker® assay.

Lowest PoD for DES is below Cmax value, the toolbox has correctly identified DES as high risk, lowest POD coming from MCF7 HTTr and estrogen receptor binding (IPP).

Lowest PoD for Dolutegravir is below Cmax value of exposure scenario, the toolbox has correctly identified it as high risk. Refinement for hazard classification as dev. Toxicant would be needed, if requested, as there are indications on dev. tox. but above Cmax values. Cell models like gastroloid systems can detect effects at relevant conc.[4]

Cmax for dermal application of caffeine is below lowest PoD, the toolbox has correctly identified it as low risk. For oral uptake of caffeine, the lowest PoD is below Cmax values indicating risk. Refinement for risk assessment would be needed.

Lowest PoD for retinol as well as all-trans retinoic acid is below Cmax values indicating high risk. Further tools would be needed to refine between bioactivity versus adversity of the compound .

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Is the NGRA Framework protective – examples

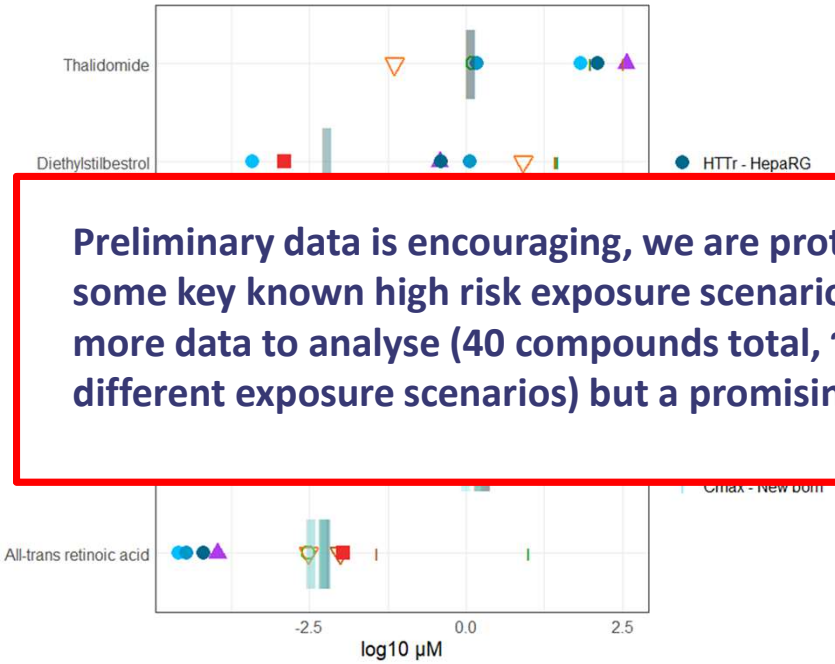
50mg oral application of Thalidomide, high risk, causing dev. toxicity.

5mg oral application of DES, high risk, causing estrogen activity/ED

50mg oral application of Dolutegravir, high risk, causing dev. toxicity

Dermal application of 0.1% caffeine in body lotion (lower Cmax), or oral uptake at recommended TDI of 200mg per days (higher Cmax) of caffeine, both low risk risk.

Uptake of vitamin A/retinol or retinol equivalents in normal diet, low risk. Cmax concentration of retinol and all-trans retinoic acid (metabolite of retinol) were measured in blood of adult, pregnant and parturient woman as well as in newborns[3)].



Preliminary data is encouraging, we are protective for some key known high risk exposure scenarios. Lots more data to analyse (40 compounds total, ~60+ different exposure scenarios) but a promising start!

Lowest PoD for Thalidomide is below Cmax value, the toolbox has correctly identified Thalidomide as high risk with lowest PoD coming from ReproTracker® assay.

Lowest PoD for DES is below Cmax value, the toolbox has correctly identified DES as [illegible]OD coming from MCF7 HTTr and estrogen receptor binding (IPP).

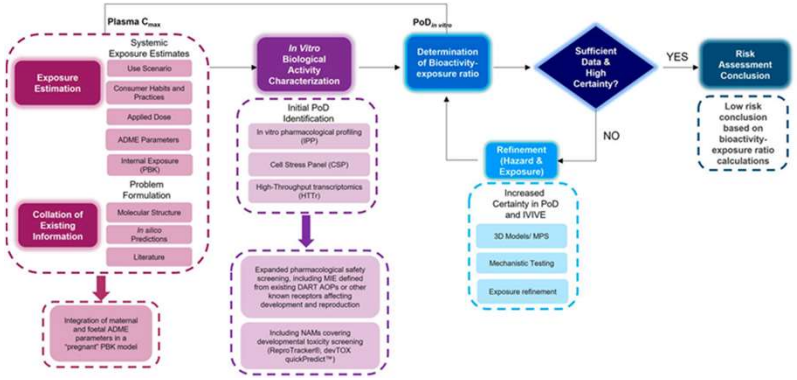
[illegible]lutegravir is below Cmax value of exposure scenario, the toolbox [illegible]ified it as high risk. Refinement for hazard classification as dev. needed, if requested, as there are indications on dev. tox. but [illegible]s. Cell models like gastroloid systems can detect effects at

[illegible]pplication of caffeine is below lowest PoD, the toolbox has [illegible]d it as low risk. For oral uptake of caffeine, the lowest PoD is below [illegible]ating risk. Refinement for risk assessment would be needed.

[illegible]Lowest PoD for retinol as well as all-trans retinoic acid is below Cmax values indicating high risk. Further tools would be needed to refine between bioactivity versus adversity of the compound .

Next Steps

- Evaluation of DART NGRA across many chemistries
- ReproTracker assay
  - Development and evaluation of an osteoblast differentiation protocol



Rajagopal et al., Front. Toxicol., 2022

- Identification and filling of existing gaps (placenta transfer measurements, DNT, DIT, endocrine disruptors, multigenerational effects, studying epigenetics in germline development, advanced cell models for refinement)
- CLP/GHS hazard classification with NAMs

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Acknowledgments

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