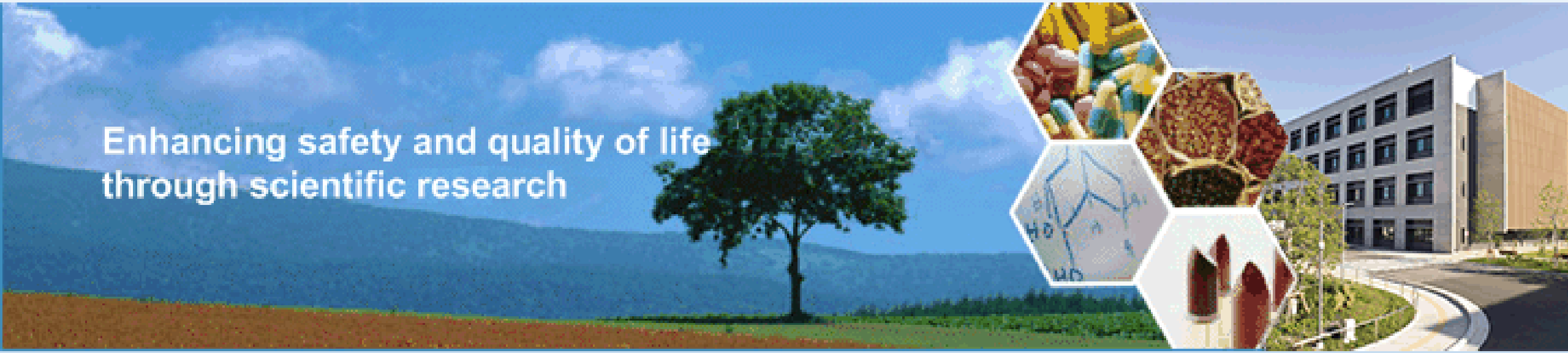
国立医薬品食品衛生研究所
National Institute of Health Sciences

Symposium on Streamlining Drug Discovery
British Embassy Tokyo/June 5, 2018



In Silico Approaches in Genetic Toxicology
-Progress and Future-

Masamitsu Honma, Ph.D.

Division of Genetics and Mutagenesis,
National Institute of Health Sciences,
Kanagawa, JAPAN

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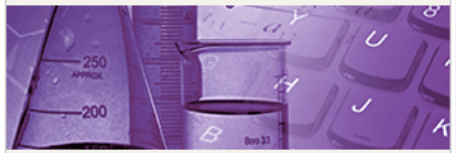

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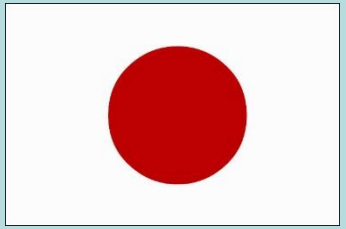
Global Management on Chemical Substances

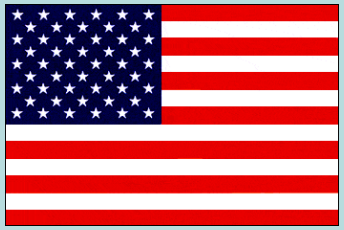
1974



Chemical Substances Control Low (**CSCL**)

Kashinhou

1977



TSCA

1981

EEC

2004

REACH

1988

CEPA

1991

TCCA

2015

KREACH

2003

C-NCSN

2010

C-REACH

Assessment for New Chemicals in “Kashinhou”

New Chemicals (2015)	Assessment
• High Volume; 360 Chemicals (>10 t/year)	◆ Biodegradability and Bioaccumulation (METI) ◆ Ecological Effect (ME) ◆ Human Health Effect (MHLW) ➢ Ames test (Mutagenicity) ➢ Chromosomal aberration test ➢ 28-days repeated dose study
• Low Volume; 1,648 Chemicals (>1 t/year)	◆ Biodegradability and Bioaccumulation (METI)
• Small Volume; 35,360 Chemicals (<1 t/year)	◆ Nothing

QSAR Tools Used in “Kashinhou” in Japan

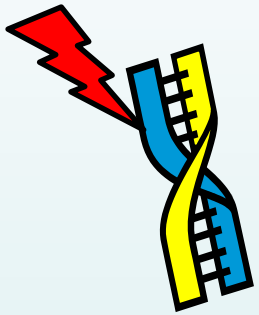
	Endpoints	QSAR Tools
Ministry of Economy, Trade and Industry (METI)	Biodegradation	BIOWIN5 BIOWIN6 CATABOL
	Bioaccumulation	BCFWIN CERI Model Baseline Model
Ministry of the Environment	Ecological Effect	TIMES ECOSAR KATE
Ministry of Health, Labour and Welfare (MHLW)	Human Health Effect (Ames Mutagenicity)	DEREK Nexus (Rule) CASE Ultra (Stat.) TIMES (Hybrid)

Great advantage of QSAR Approach for Toxicological Assessment

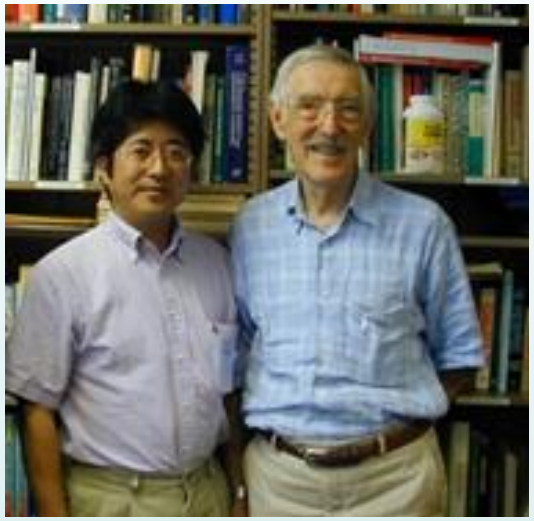
- High throughput screening for huge number of chemicals without cost and labor
- Test for unavailable chemicals (e.g., impurity, intermediates, flavoring chemicals)
- Strongly contribute to animal welfare

What Is Ames Test?

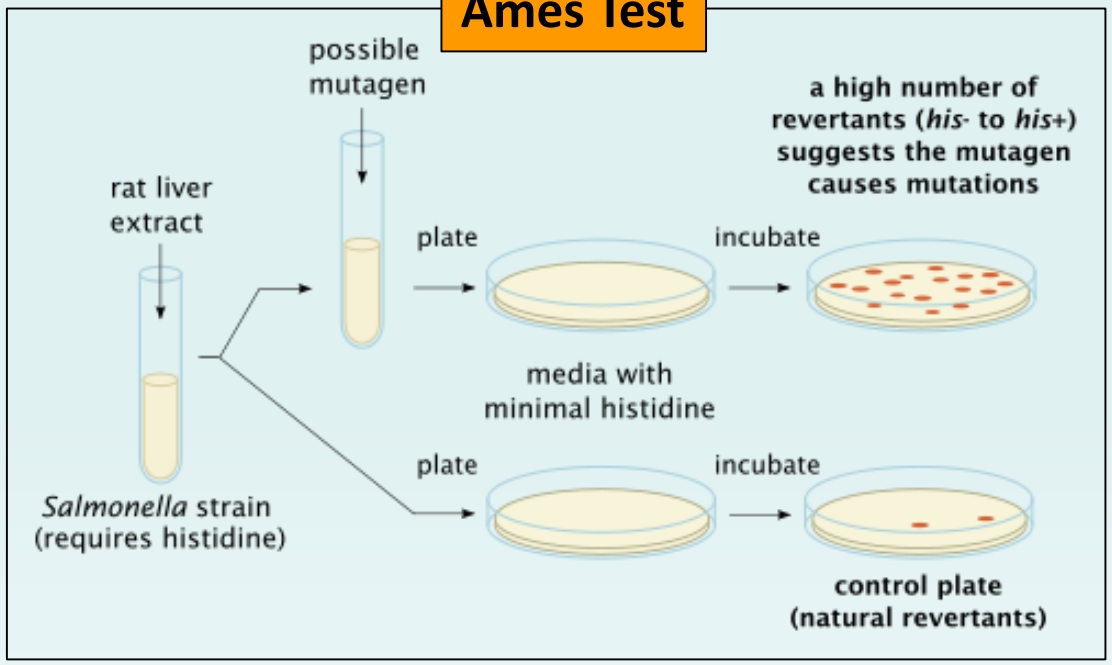
Genotoxic/mutagenic chemicals

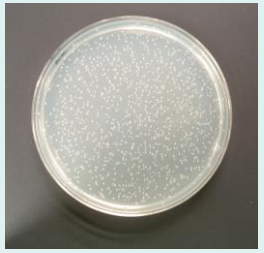


DNA Damage → Mutation → Cancer

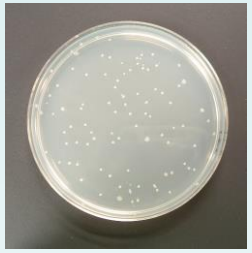


Ames Test





Mutants

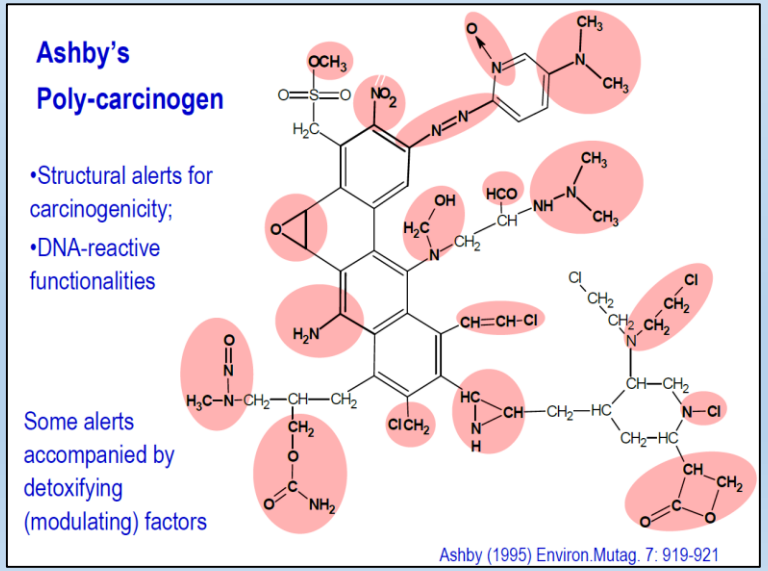


Wild-Type

Why Ames/QSAR?

- The electrophilic theory of chemical carcinogenesis was developed by James and Elizabeth Miller in the 1970s.
- Bruce Ames developed the Ames assay in 1972. It has a high positive predictivity for DNA-reactive chemical carcinogens based on the electrophilic theory. The Ames assay is an *in vitro* model of chemical carcinogenicity.

- Other reasons to develop QSAR models -----
  - Highly reproducible results among laboratories
  - Large number of data set
  - Binary results (positive or negative)



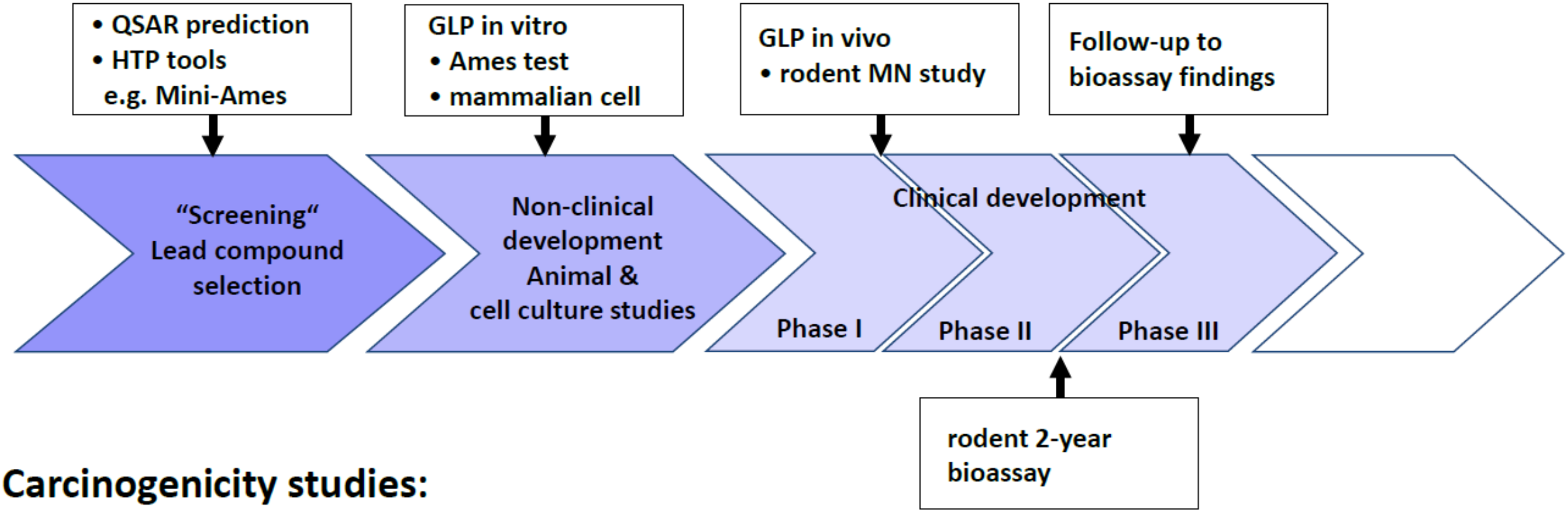
- QSAR model for Ames mutagenicity
  - Rule-Based Models
  - Statistical-Based Models

QSAR Used in Development of Pharmaceuticals

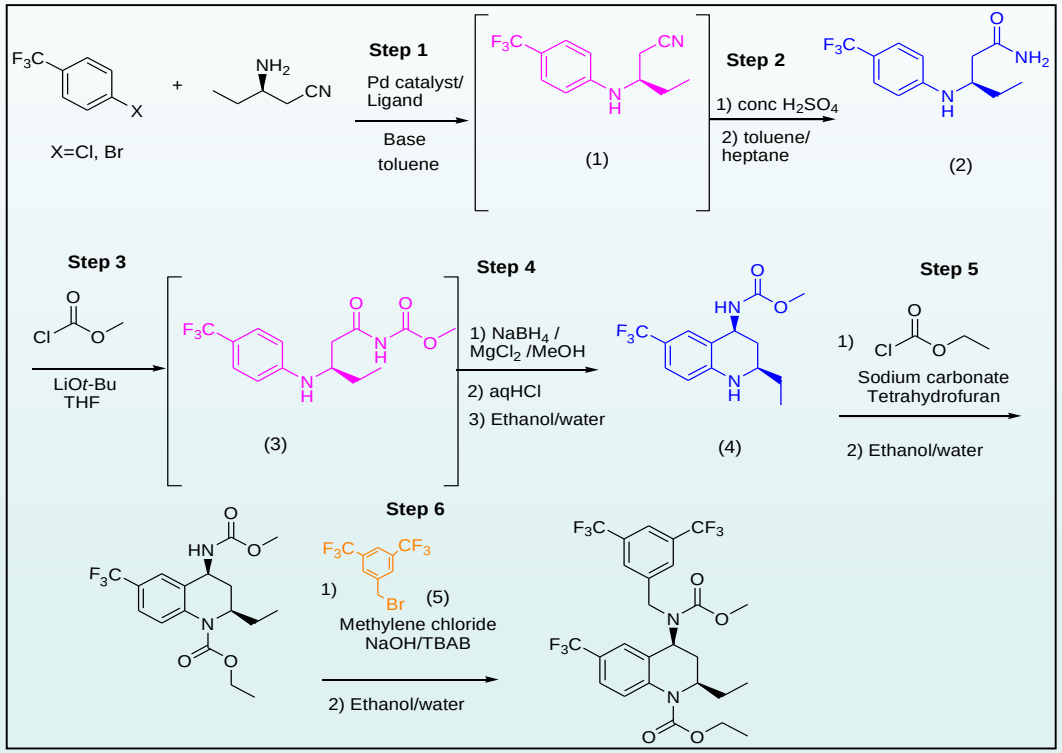
ICH
harmonisation for better health

Genotoxicity and Carcinogenicity Tests in Development of Pharmaceuticals

Genotoxicity studies:



Carcinogenicity studies:



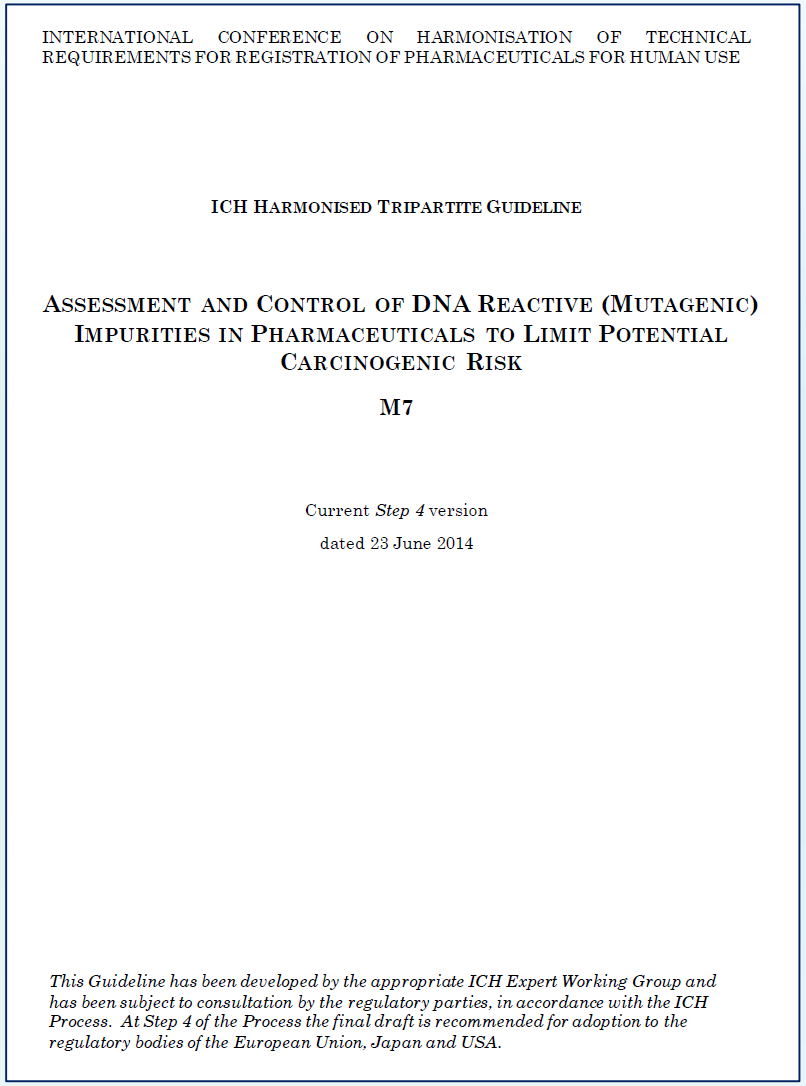
Synthetic Route of Drug Substances (Byproducts)

Degradation from Drug Substances (Degradants)

Impurities

Mutagenic or non-mutagenic?

QSAR Approach in ICH-M7



INTERNATIONAL CONFERENCE ON HARMONISATION OF TECHNICAL REQUIREMENTS FOR REGISTRATION OF PHARMACEUTICALS FOR HUMAN USE

ICH HARMONISED TRIPARTITE GUIDELINE

ASSESSMENT AND CONTROL OF DNA REACTIVE (MUTAGENIC) IMPURITIES IN PHARMACEUTICALS TO LIMIT POTENTIAL CARCINOGENIC RISK

M7

Current *Step 4* version

dated 23 June 2014

This Guideline has been developed by the appropriate ICH Expert Working Group and has been subject to consultation by the regulatory parties, in accordance with the ICH Process. At Step 4 of the Process the final draft is recommended for adoption to the regulatory bodies of the European Union, Japan and USA.

- **Two QSAR prediction methodologies that complement each other should be applied. One methodology should be expert rule based and the second methodology should be statistical based.**

- **The absence of structural alerts from two complementary QSAR methodologies (expert rule-based and statistical) is sufficient to conclude that the impurity is of no mutagenic concern, and no further testing is recommended.**

Performance of Four QSAR Models for Predicting Ames Mutagenicity

Data Source	QSAR Type	QSAR Tool	Sensitivity (%)	Specificity (%)	Concordance (%)
Hansen (Industrial chemicals) 2,647 compounds (67% positive)	Rule	DEREK	80.9	59.1	73.7
		Toxtree	85.2	53.1	74.6
	Statistical	Mcase	74.6	74.0	74.4
		LSMA	67.8	63.8	66.4
Roche (Pharmaceuticals) 2,335 compounds (13% positive)	Rule	DEREK	43.4	91.6	85.5
		Toxtree	42.9	77.5	73.1
	Statistical	Mcase	30.6	85.8	78.9
		LSMA	17.4	93.9	83.6

Hillebrecht A et al., Comparative Evaluation of *in Silico* Systems for Ames Test Mutagenicity Prediction: Scope and Limitations., *Chem Res Toxicol*, 24, 843–853, 2011)

How to Improve QSAR Prediction ?

- **New QSAR Algorithm/ Model**
  - AI, Deep-learning ?

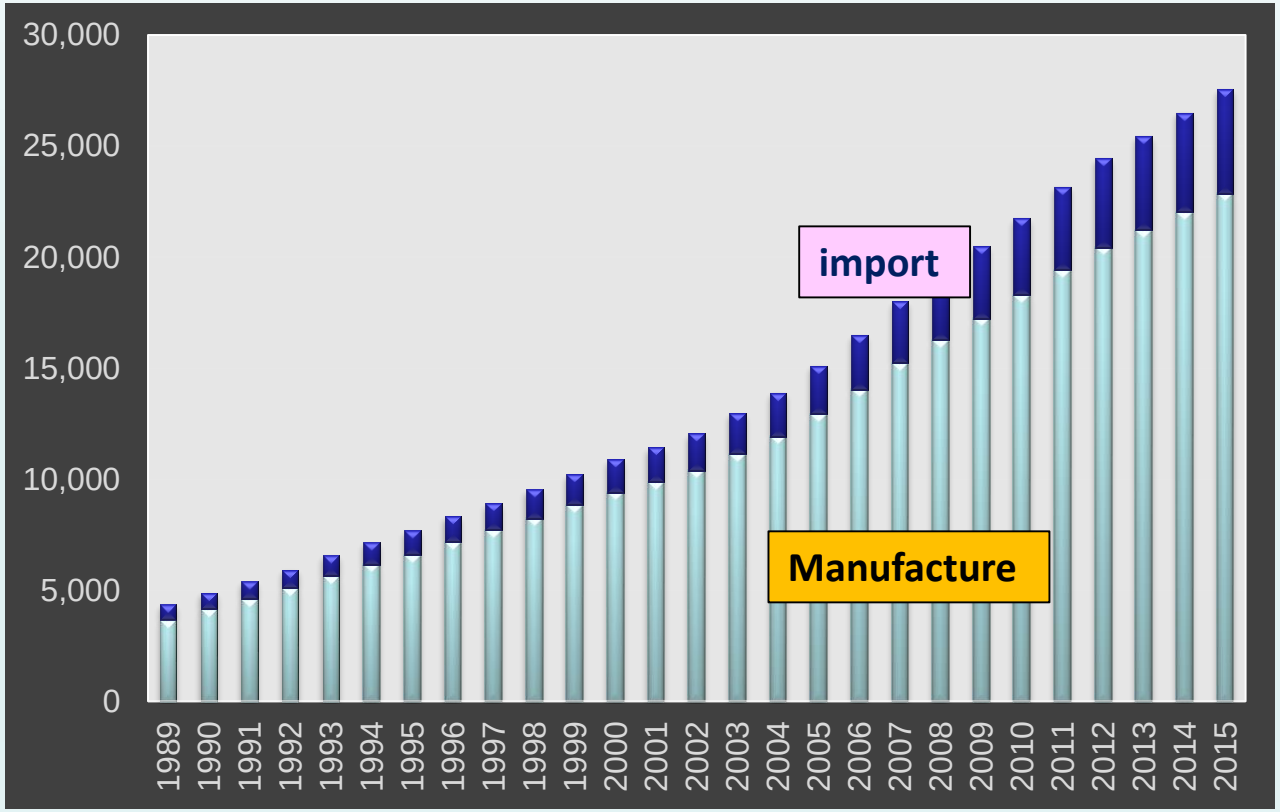
- **Training data set**
  - New
  - Many
  - Reliable

Ames Mutagenicity Data Sources in Major Public Domain

Database (name)	Information	Link
Benchmark Data Set for *In Silico* Prediction of Ames Mutagenicity (Hansen et. al., 2009)	Ames mutagenicity database for 6,500 compounds	http://doc.ml.tu-berlin.de/toxbenchmark/
Carcinogenic Potency Database (CPDB)	1,547 chemicals	http://toxnet.nlm.nih.gov/cpdb/cpdb.html
GAP – Genetic Activity Profile Database by US EPA and IARC (Latest update in 2000)	Data on approx. 300 chemicals from volumes 1-50 of the IARC Monographs and on 115	http://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=44472&CFID=726518&CFTOKEN=15601022
Existing Chemicals Examination (EXCHEM) database (Japan)	Ames mutagenicity for more than 360 HPV chemicals	http://dra4.nihs.go.jp/mhlw_data/jsp/SearchPageENG.jsp
Istituto superiore di Sanità database (ISSCAN)	More than 1,150 chemical compounds tested with the long-term carcinogenicity bioassay on rodents, mutagenicity data.	http://www.iss.it/meca/index.php?lang=1&anno=2013&tipo=25
National Toxicology Program (NTP) database	2,163 chemicals in genetic toxicity studies	ftp://157.98.192.110/ntp-cebs/datatype
Toxicity Reference Database (ToxRefDB)	Studies on 330 chemicals, many of which are active ingredients of pesticides	http://actor.epa.gov/toxrefdb/faces/SearchByEndpoint.jsp
TOXNET database : Carcinogenesis Research Information System database (CCRIS) and the Genetic Toxicology Databank (GENE-TOX)	CCRIS: over 9,000 chemical records with animal carcinogenicity, mutagenicity, tumor promotion, and tumor inhibition test results. GENE-TOX: on over 3,000 chemicals, from expert peer review of the open scientific literature.	http://toxnet.nlm.nih.gov/

Industrial Safety and Health Law “An-eihou” in Japan

Chemicals newly manufacturing produced or imported more than 100kg/year must be assessed its mutagenicity by Ames assay.



The permission of the use of the Ames data to improve QSAR models by Chemical Hazards Control Division, Industrial Safety and Health Department, Labor Standards Bureau in MHLW

Proposal of International Collaborative Studies to Improve Ames/QSAR models (QSAR2014, Milan, Italy, June 2014)

厚生労働省 Ministry of Health, Labour and Welfare

国立医薬品食品衛生研究所 National Institute of Health Sciences

To QSAR Builders

-1st Circular for Ames (Q)SAR Collaborative Study-

June, 2014

Ministry of Health, Labour and Welfare in Japan has collected and evaluated new Ames mutagenicity results. The National Institute of Health Sciences has the results of approximately 12,000 new chemicals. The Ames assays were conducted under GLP according to Industrial Safety and Health Act in Japan. We can now provide the Ames data to improve the reliability and applicability of your QSAR models for predicting Ames mutagenicity.

We first provide a list of 4,021 chemicals without the results of Ames mutagenicity assay (Excel and SD files). After calculating the Ames mutagenicity by your QSAR tools, you return the excel file with the results (positive, negative, and others). We evaluate the performance of your QSAR tool (sensitivity, specificity, and others). Then, we disclose the Ames results. You can integrate the Ames results into your QSAR model as learning sets. Next, we provide another 4,000 chemicals list. According to this procedure, we provide 12,000 chemical data totally, and you can integrate these Ames mutagenicity results into your QSAR model. We believe that this project strongly contributes to improve the QSAR models as well as to promote QSAR studies.

If you are interested in this project, please contact with me.

Masamitsu HONMA, Ph.D.
Director, Division of Genetics & Mutagenesis
National Institute of Health Sciences
1-18-1 Kamiyoga, Setagaya-ku,
Tokyo 158-8501, Japan
E-mail: honma@nihs.go.jp

Participants in Ames/QSAR Project

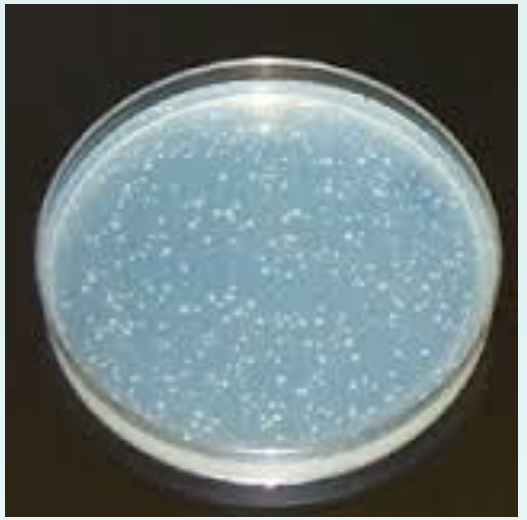
QSAR Venders	QSAR Model
1. Lhasa Limited (UK)	DEREK Nexus, SARAH
2. MultiCASE Inc (USA)	CASE Ultra rule-, statistical-based
3. Leadscope Inc (USA)	Leadscope rule-, statistical-based
4. Prous Institute (Spain)	Symmetry
5. Bourgas University (Bulgaria)	OASIS TIMES
6. Istituto Superiore di Sanita (Italy)	Toxtree
7. Istituto di Ricerche Farmacologiche Mario Negiri (Italy)	SARpy + VEGA + CAESER (consensus model)
8. Swedish Toxicology Science Research Center (Sweden)	AZAMES
9. FUJITSU KYUSHU SYSTEMS (Japan)	ADMEWORKS
10. IdeaConsult Ltd. (Bulgaria)	AMBIT
11. Molecular Networks GmbH and Altamira LLC (USA)	ChemiTunes
12. Sumilation Plus (USA)	Mut_Risk-0

Ames Mutagenicity of Challenging Chemicals

Class A : Strongly positive, in which the chemical generally induces more than 1,000 colonies/mg in at least one Ames strains in the presence or absence of rat S9.

Class B : Positive, in which the chemical induces colonies more than 2-fold of the negative control at least one Ames strains in the presence or absence of rat S9, but not in class A.

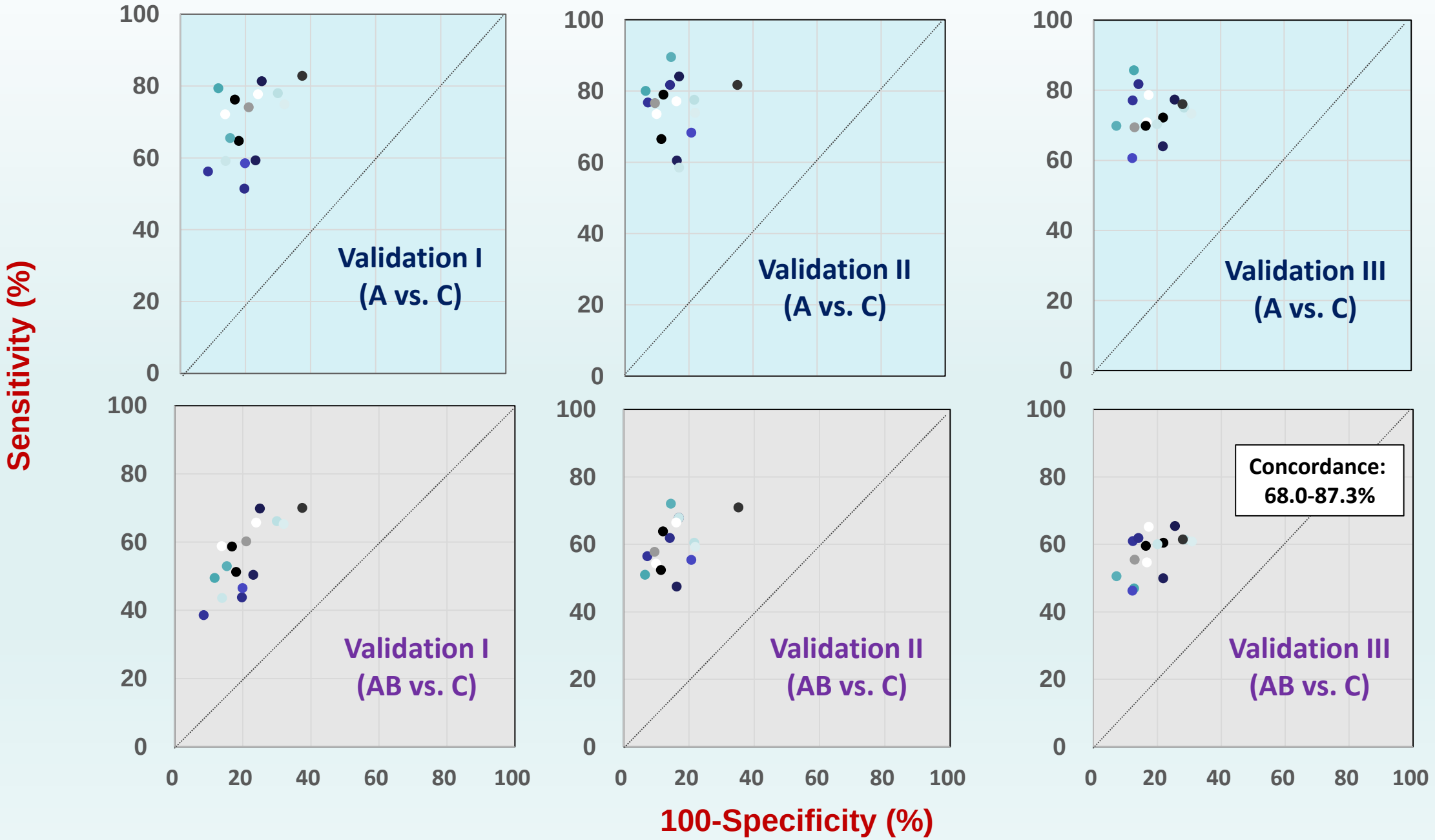
Class C : Negative, which is neither class A nor B.



Ames/QSAR Project (Phase I-III) Challenged Chemicals

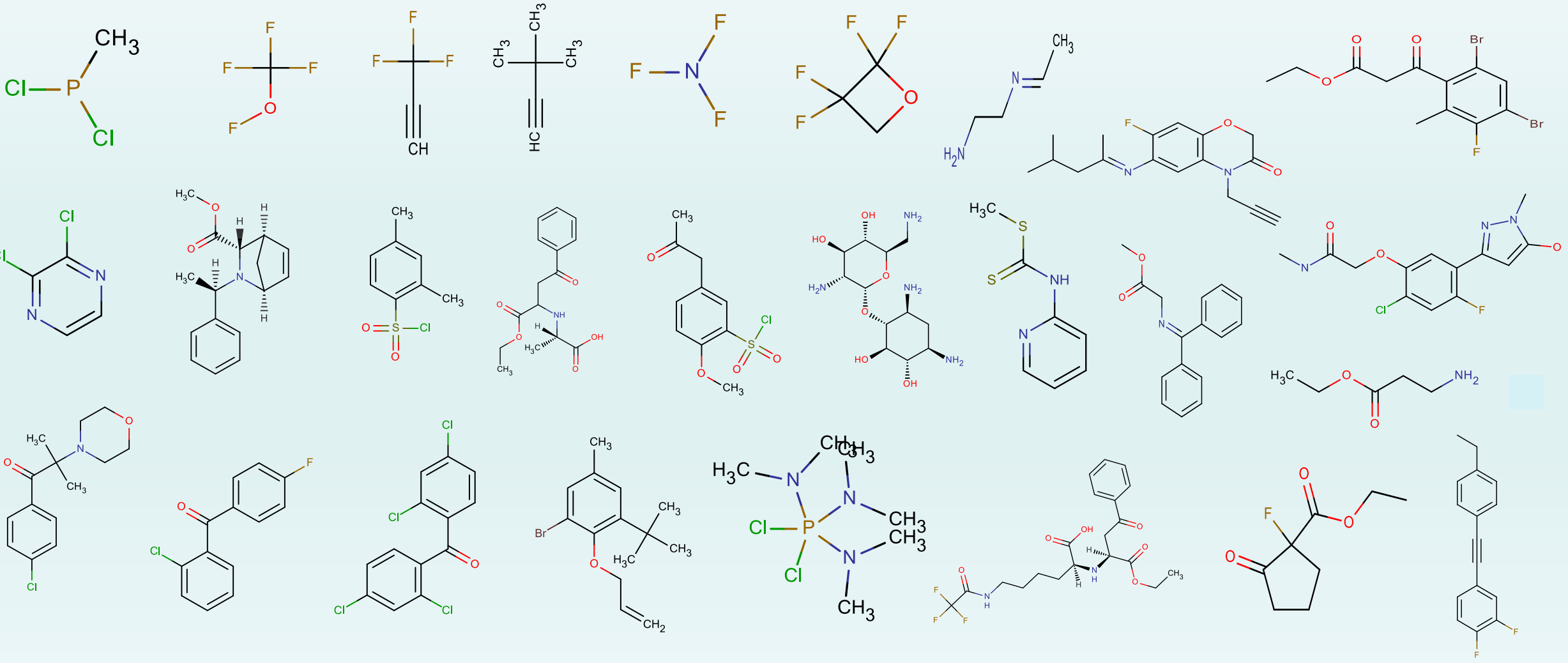
Category	Phase I (2014-2015)	Phase II (2015-2016)	Phase III (2016-2017)	Total (2014-2017)
Class A	183 (4.7%)	253 (6.6%)	236 (5.4%)	**672 (5.5%)**
Class B	383 (9.8%)	309 (8.1%)	393(8.9%)	**1,085 (8.9%)**
Class C	3,336 (85.5%)	3,267 (85.3%)	3,780 (85.7%)	**10,383 (85.6%)**
Total	3,902	3,829	4,409	**12,140**

ROC Graphs for Challenged QSAR Models' Validation



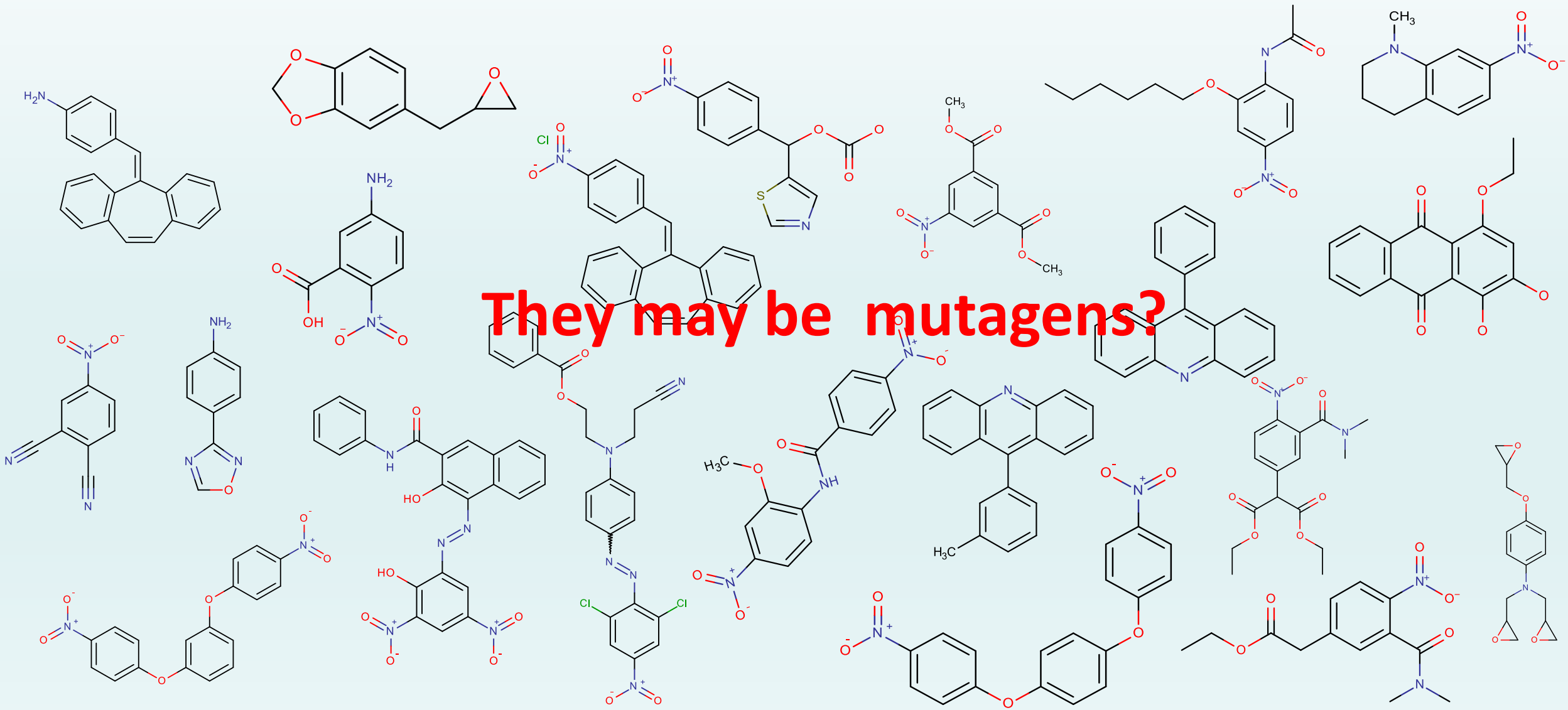
False Negatives

Class A chemicals, but negative call by almost QSAR tools



False Positive

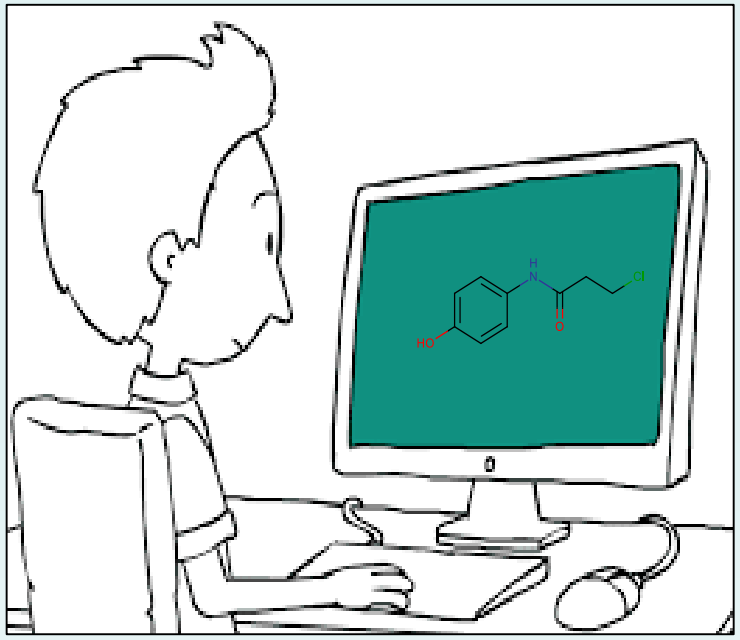
Class C chemicals, but positive call by almost QSAR tools

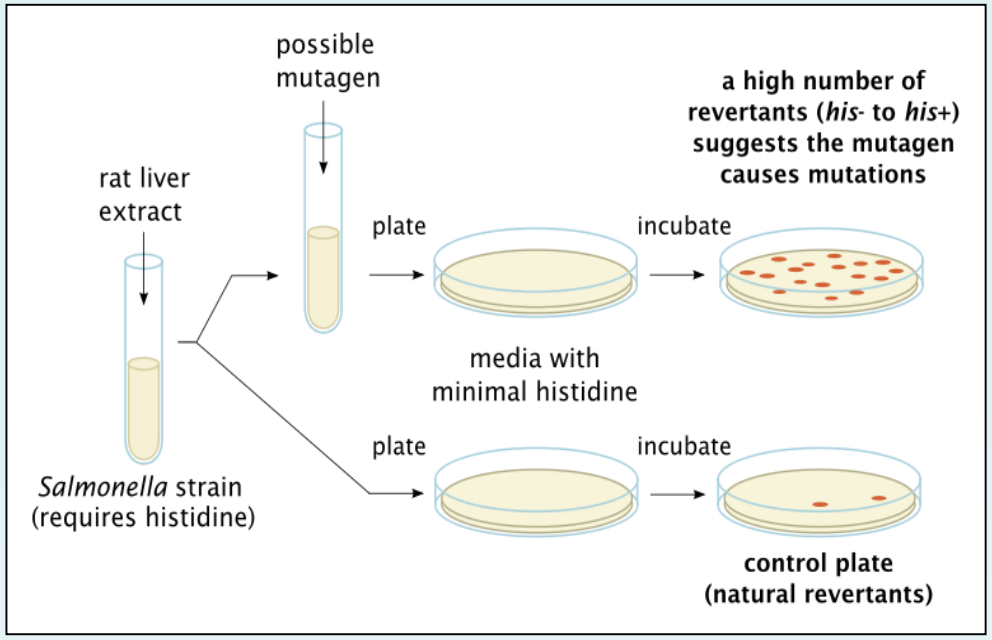


They may be mutagens?

Where is our goal?

Can we perfectly predict Ames mutagenicity by QSAR?





Inter-Laboratory Reproducibility of Ames Mutagenicity

-S9

Databases	Intersections	Concordance
GTP/NCI; TA 100	20 chemicals	85%
GTP/NTP; TA 100	39 chemicals	79%
GTP/NCI; TA 98	18 chemicals	88%
GTP/NTP; TA 98	21 chemicals	92%

82%

+S9

Databases	Intersections	Concordance
GTP/NCI; TA 100	15 chemicals	80%
GTP/NTP; TA 100	14 chemicals	(21%)*
GTP/NCI; TA 98	13 chemicals	90%
GTP/NTP; TA 98	23 chemicals	65%

GTP: Report of the U.S. Environmental Protection Agency Gene-Tox Program
NCI: Short-Term Testing Program in the National Cancer Institute (NCI), National Institutes of Health, US Department of Health and Human Services
NTP: NTP Program - P&G Inventory

*excluded for calculation

Analyzed Dr. Mekenyan in Bourgas "Prof. As. Zlatarov" University

What means Ames positive?

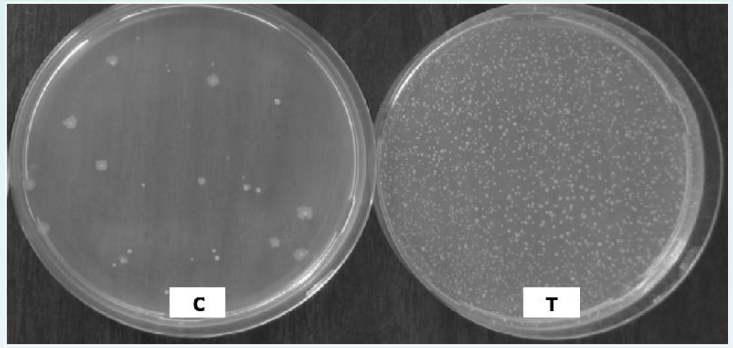
Class A : Strongly positive, in which the chemical generally induces more than 1,000 colonies/mg in at least one Ames strains in the presence or absence of rat S9.

Class B : Positive, in which the chemical induces colonies more than 2-fold of the negative control at least one Ames strains in the presence or absence of rat S9, but not in class A.

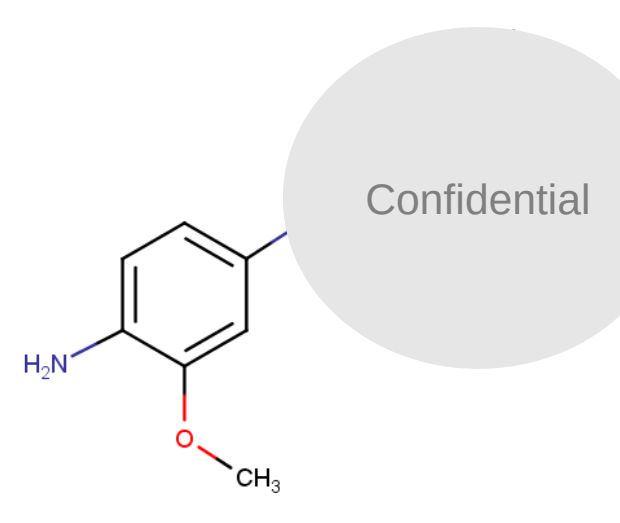
may contain false-positive.

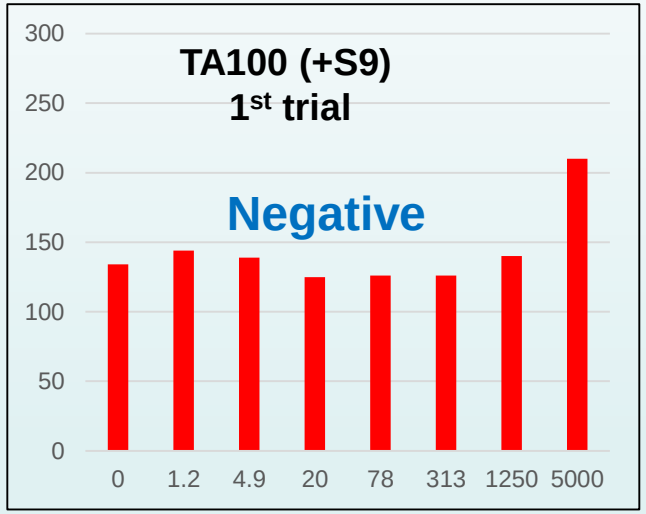
Class C : Negative, which is neither class A nor B.

may contain false-negative.

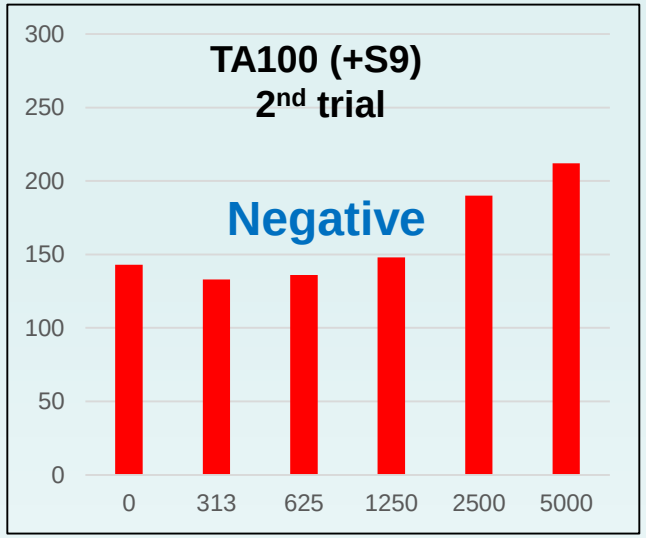


Is this Ames Positive?
-Example A-

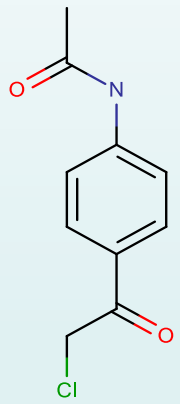




QSAR		Results
Derek NX		PLAUSIBLE
		Alert matched: 352 Aromatic amine or amide
CASE Ultra	PHARM_ECOLI	Negative
	PHARM_SALM	Inconclusive

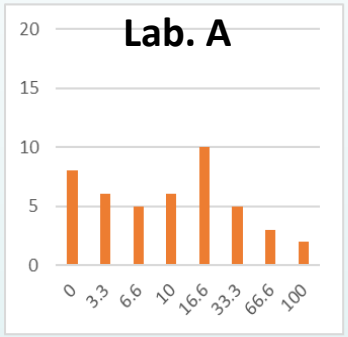


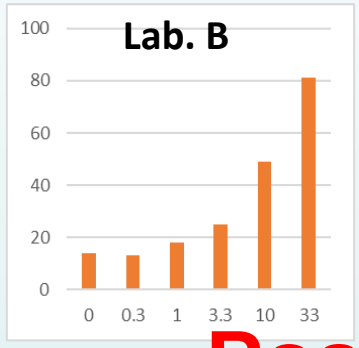
Is this Ames Positive?
-Example B-

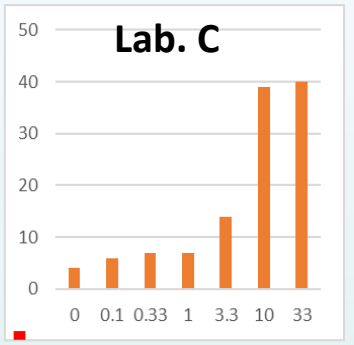


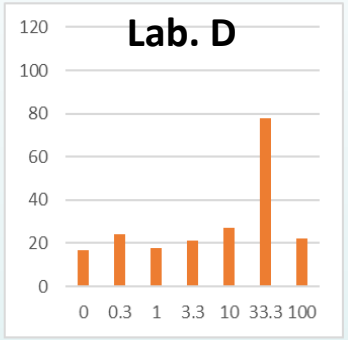
4'-(chloroacetyl) acaetanilde (Cas# 140-49-8)

TA1537 (-S9)

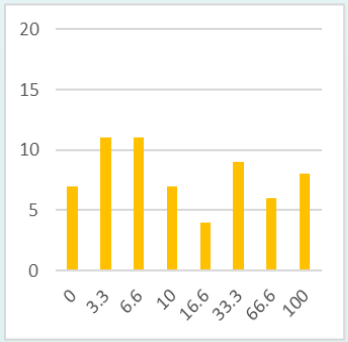


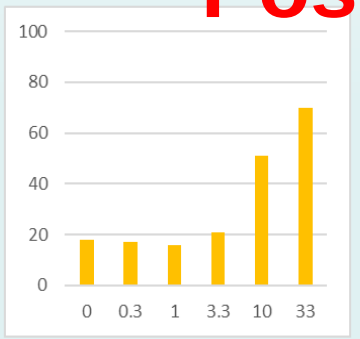


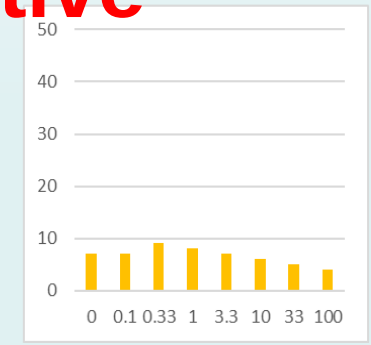


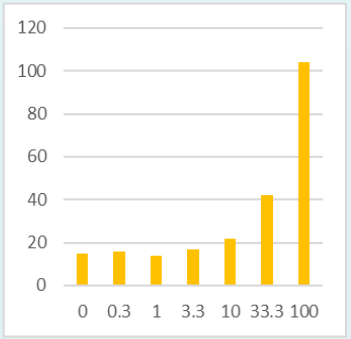


TA1537 (+S9)









Positive

QSAR		Results
Derek NX		INACTIVE
CASE Ultra	PHARM_ECOLI	Negative
	PHARM_SALM	Negative

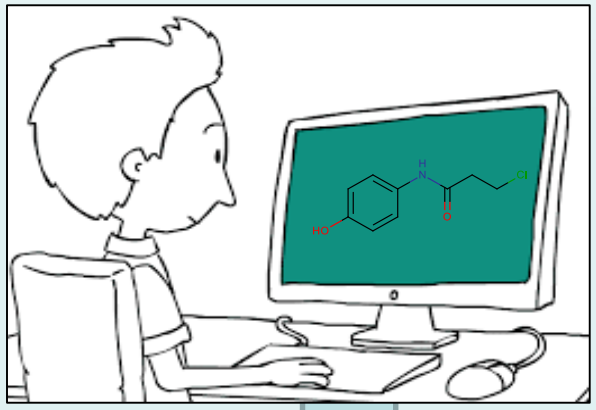
Dunkel et al., Environ Mutagen, 7, Suppl. 5, 1-248 (1985)

QSAR beyond Ames

Feed-Back

Re-modeling

Re-build Data Base



Cross-Talk

Molecular Mechanism

Mutagenic Potential

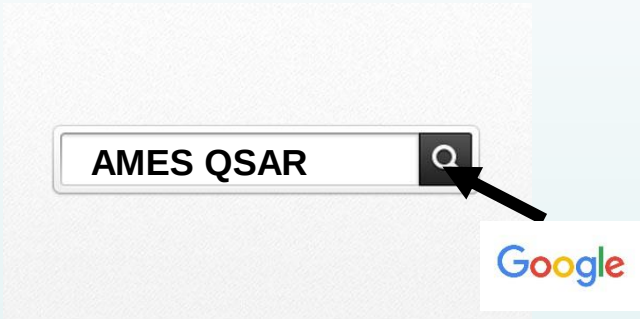
Integrated approach for Genotoxicity Assessment

QSAR is not only a tool for the prediction. It can support to judge the results of actual Ames test.

Summary

- A large number of highly reliable data sets are essential to allow the development and improvement of QSAR models.
- The Ames/QSAR international collaborative study is successfully ongoing. Its outcome gives a lot of benefits to QSAR vendors, QSAR users, and regulatory.
- The integrated approach with QSAR results increases the sensitivity and specificity of the Ames test. It can support to judge the Ames results with molecular mechanism.

Web-Site of AMES/QSAR International Collaborative Study



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AMES/QSAR International Collaborative Study

Robust Quantitative Structure–Activity Relationship (QSAR) models defining toxicological endpoints are desirable to enable regulatory authorities to identify chemicals possibly causing adverse effects without performing actual toxicological studies. Much effort has been invested in the development of QSAR models to predict Ames mutagenicity, among many toxicological endpoints, to exploit the large body of Ames data and the strong correlation between chemical structure and Ames mutagenicity. Ames results are important for decisions on the development of chemical products and pharmaceuticals and the assessment of chemical safety, given that a positive result corresponds to increased cancer risk from exposure to the chemical even at a low level. The ICH-M7 guideline (Assessment and control of DNA-reactive impurities in pharmaceuticals to limit potential carcinogenic risk) currently recommends two QSAR models (expert rule-based and statistical) to predict Ames mutagenicity for initially assessing DNA-reactive impurities in pharmaceuticals. This is the first international guideline addressing the use of QSAR in lieu of an actual toxicological study for human health assessment. Thus, QSAR models for Ames mutagenicity now require much greater prediction power to ensure the safety of chemicals. To increase this prediction power, experimental data sets as training data to build the models are important. Large numbers of highly reliable data sets will allow development and improvement of QSAR models with high predictive power.

The Division of Genetics and Mutagenesis, National Institute of Health Sciences (DGM/NIHS) has Ames mutagenicity data for approximately 12,000 new chemicals. The Ames assays were conducted according to the OECD TG471 guideline and Industrial Safety and Health Act in Japan under GLP-compliant conditions. We now provide these Ames data to QSAR builders/vendors to improve their QSAR models for predicting Ames mutagenicity with the permission of the Industrial Safety and Health Department of the Ministry of Health, Labor and Welfare (MHLW), Japan. The Ames/QSAR international collaborative study leaded by DGM/NIHS launched on 2014. Because most of the Ames data are confidential, the QSAR builders/vendors participating in the project must execute a confidentiality agreement. Twelve QSAR builders/vendors from USA, UK, Italy, Spain, Bulgaria, Sweden, and Japan are currently participating in this project (Table 1).

The next Ames/QSAR challenge program will start from the end of 2018. Not only QSAR vendors, but also academia and IT companies are welcome to join the challenge. Hopefully, new QSAR models using AI and deep-learning will challenge.

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