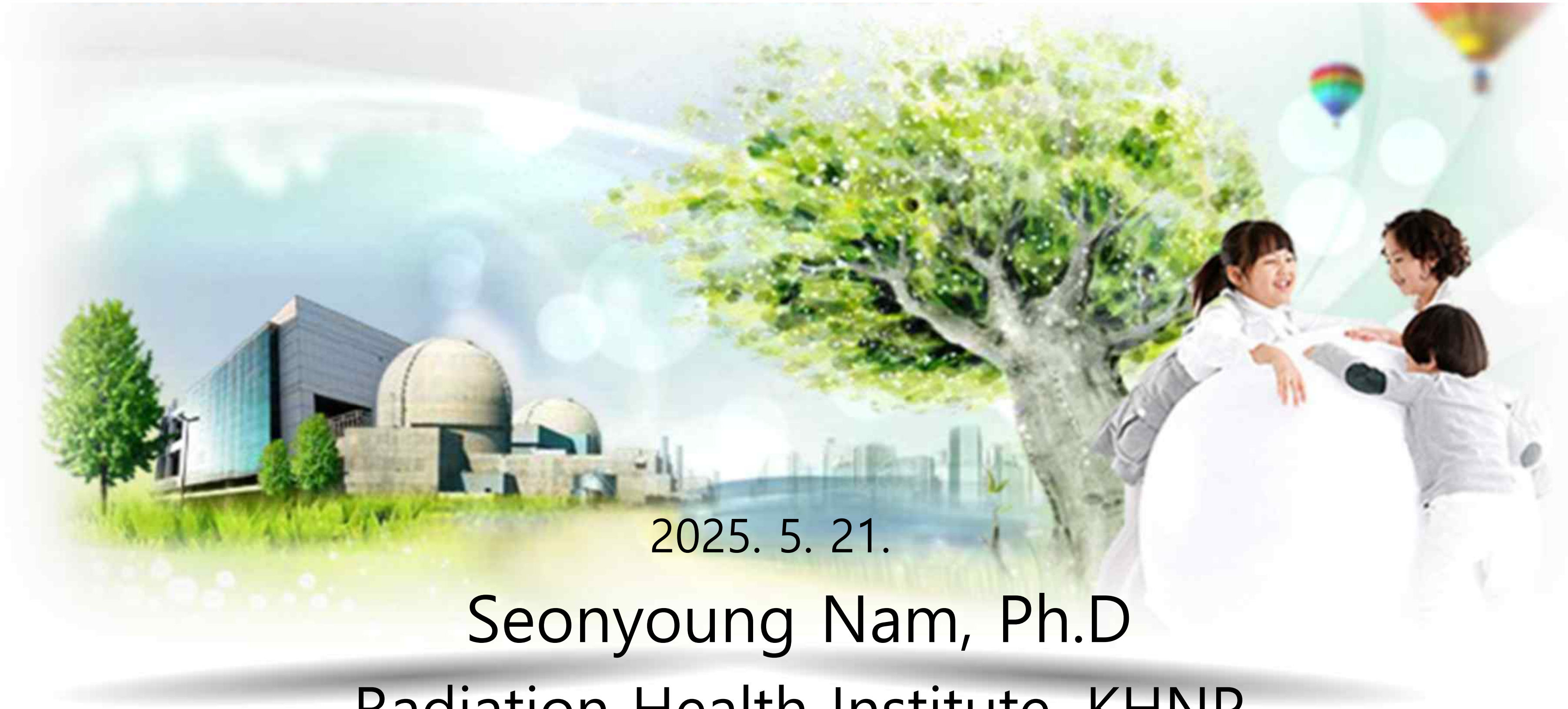
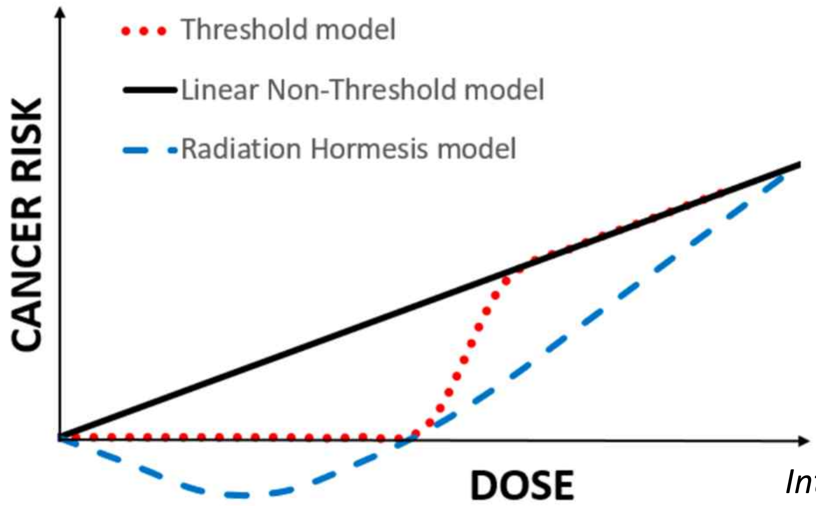
A view on the LNT model based on radiobiological studies



2025. 5. 21.

Seonyoung Nam, Ph.D
Radiation Health Institute, KHNP

Dose-response models for the effects of low dose radiation



Int. J. Mol. Sci. 2020, 21, 6650

Dose-Response:
An International Journal
July-September 2018:1-24

It Is Time to Move Beyond the Linear No-Threshold Theory for Low-... Radiation Protection

John J. Cardarelli II[1] and Brant A. Ulsh[2]

European Heart Journal (2012) **33**, 292–295
doi:10.1093/eurheartj/ehr288

EDITORIAL

Biological effects of low-dose radiation: of harm and hormesis

Tommaso Gori and Thomas Münzel*

Department of C...

International Journal of *Molecular Sciences*

Review

Overview of Biological, Epidemiologi... Evidence of Radiation Hormesis

Yuta Shibamoto [1,*] and Hironobu Nakamura [2,3]

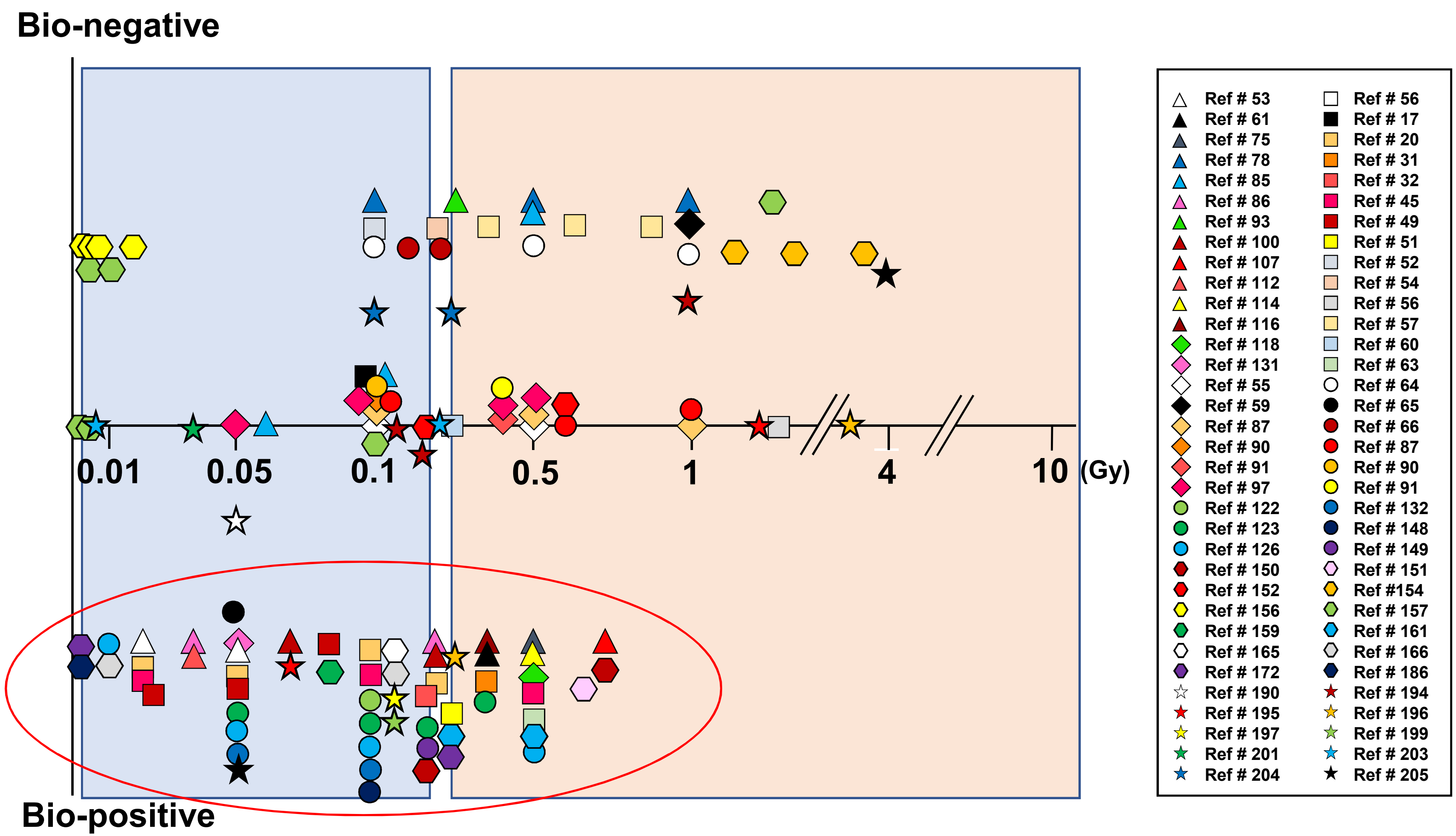
1 Department of Radiology, Nagoya City University Graduate School of M...
Nagoya 467-8601, Japan

Journal of Environmental Radioactivity 192 (2018) 32–47

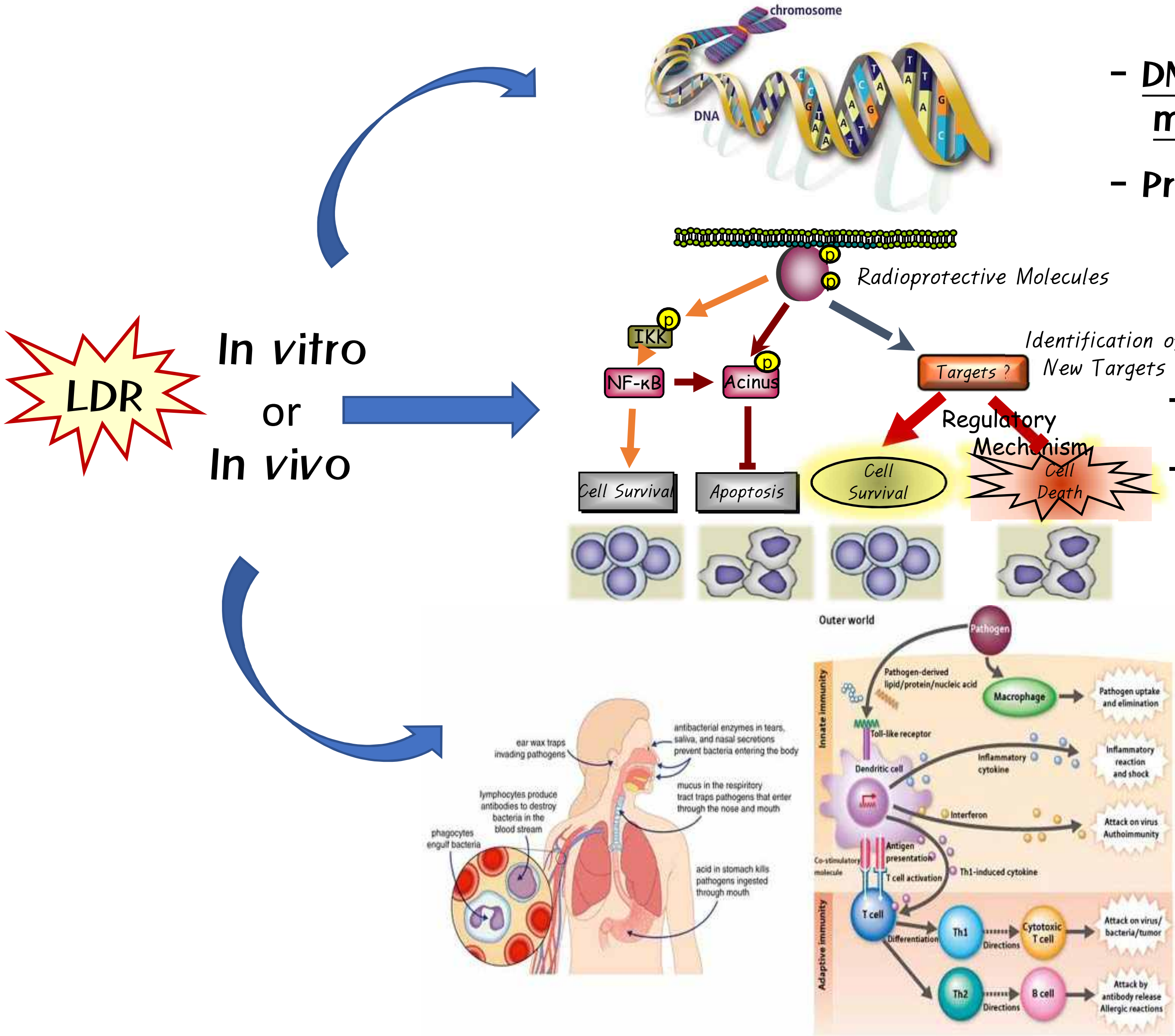
Low dose or low dose rate ionizing radiation-induced health effect in the human

Feng Ru Tang[a,*], Konstantin Loganovsky[b]

Radiation effect on biological response (Ref 2011-2018)



Study on biological response of low dose radiation



- DNA damage/repair mechanism
- Protein synthesis

- Antioxidative function
- Cell survival and death

- Immune responses
- Adaptive response
- Radioprotective bystander effects

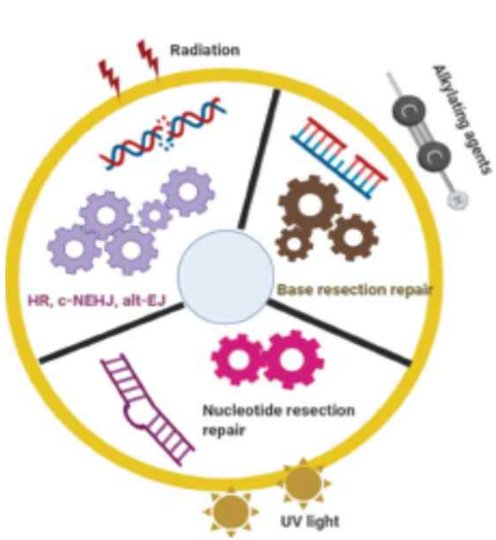
Molecular and Cellular Phenotypes of LDR

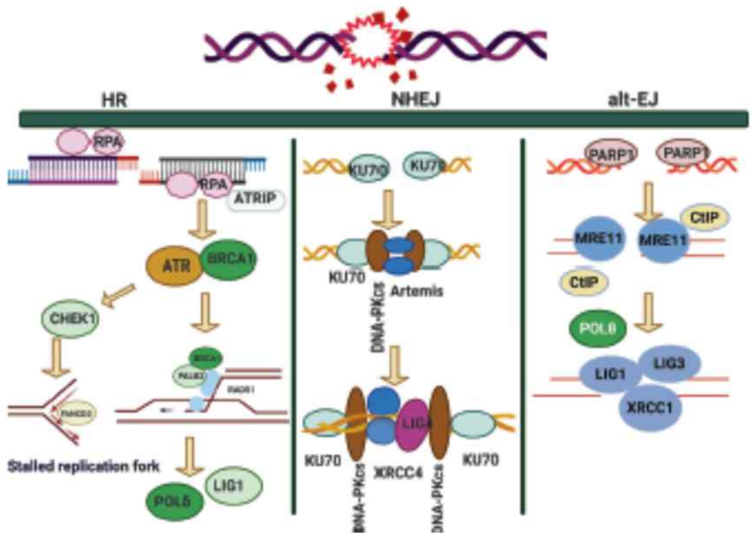
DNA damage repair mechanism

- **<u>One million DNA alterations per cell per day</u>** from natural endogenous oxidative metabolism and environmental exposures, **<u>which is efficiently repaired</u>** *(Lodish et al., 2004; Branzei et al., 2008; Tharmalingam et al., 2019)*

  - 10,000 oxidative damages/cell/day
  - 10,000 apurination or apyrimidination damages/cell/day
  - 55,200 single stranded breaks(SSBs)/cell/day
  - 10~50 double strand breaks(DSB)/cell cycle

"Environmental gear selection" : DNA damage repair pathway evolution





Huang and Zhou, 2021

Molecular and Cellular Phenotypes of LDR

DNA damage repair mechanism

- DNA damage by LDR seems to be cell type and strain specific *(Tubiana et al., 2009; Asaithamby et al., 2009; Rothkamm et al., 2003)*
- DNA damage at a very low dose rate is unnoticeable compared to controls
- Molecular mechanisms utilized by LDR to prevent cells

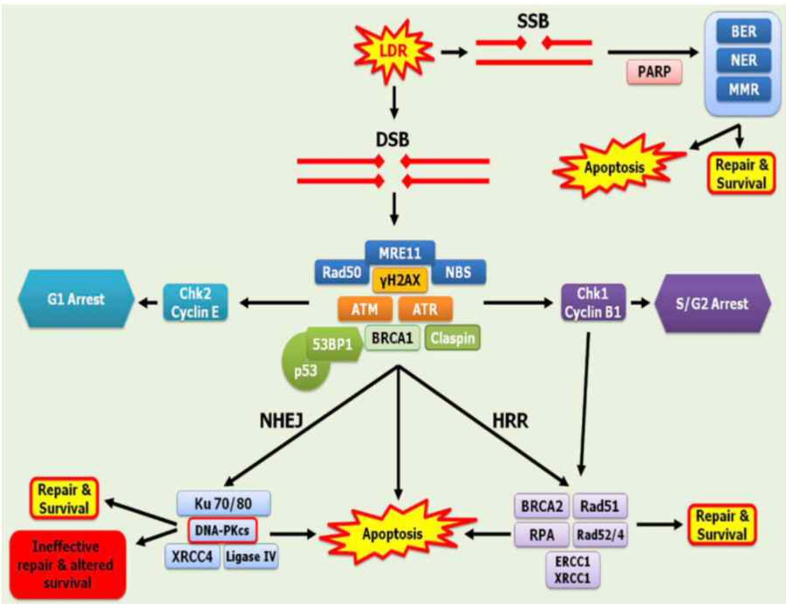


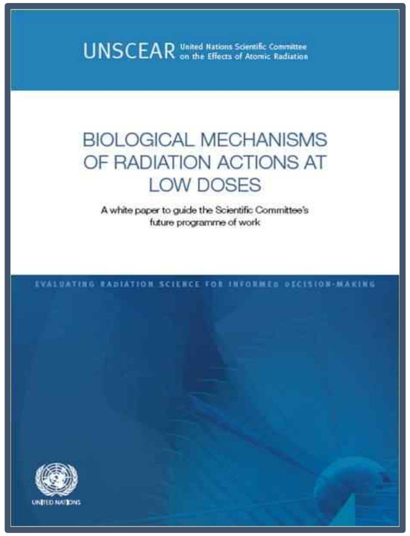
Fig. Repair/removal of LDR induced DNA damage

- Repair of damaged DNA
- Removal of damaged cells via apoptosis
- Cell cycle arrest

(Tharmalingam et al., 2019)

"The ratio of metabolic DNA damage to radiation-induced DNA damage by 1 mGy/year natural background radiation : ~ about 10 million"

Genomic instability
: the biological effect of Radiation



Genomic instability on LDIR is still controversial.

It has been reported that NO genomic instability under 100 mGy of radiation.

Dose (mGy)	Cells with abberations	Aberrations/ cell	Chromosome: chromatid aberrations
0	4/908	0.004	3:1
1.7	0/132	0	-
5	1/146	0.007	0:1
12.1	3/346	0.009	0:3
25	0/205	0	-
50	1/464	0.002	1:0
100	3/611	0.006	2:1
500	1/384	0.003	1:0
1000	6/571	0.011	1:5
3000	12/730	0.016	2:10

Cytogenetic aberrations in coded metaphase preparations obtained from mouse bone marrow 30 days post-irradiation

Radiat. Res. (2011) 175(3):322-327

DNA damage in peripheral blood mononuclear cells of individuals from high level natural radiation areas of Kerala

Jain et al., 2016

- 91 random volunteers
- Level of background radiation : 1.0 mGy/y to 45.0 mGy/y
- gamma-H2AX assay to estimate DNA DSBs in PBMCs of individuals

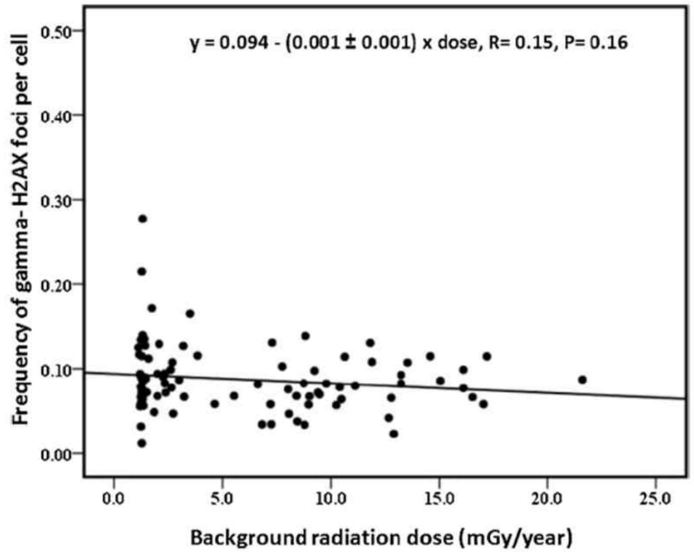


Fig. Distribution of γ-H2AX foci for background radiation dose

Table 1
Distribution of gamma-H2AX foci per cell with respect to age and background dose level among HLNRA and NLNRA individuals. HLNRA: High Level Natural Radiation area, NLNRA: Normal Level Natural Radiation area. LDG: Low Dose group, HDG: High dose group. S. D: standard deviation.

Area	Background dose groups (mGy/year)	Number of individuals studied	Mean Age ± S.D (Age range in years)	Mean background dose ± S.D (dose range in mGy/year)	Frequency of gamma-H2AX foci ± S.E. (range)
NLNRA	≤1.50	30	35.5 ± 6.35 (25–50)	1.28 ± 0.086 (1.1–1.50)	0.095 ± 0.009 (0.01–0.28)
HLNRA	LDG (1.51–5.0)	20	34.2 ± 5.7 (25–44)	2.63 ± 0.76 (1.57–4.64)	0.096 ± 0.008 (0.05–0.17)
	HDG (>5.00–21.6)	41	37.1 ± 8.03 (18–59)	11.04 ± 3.57 (5.53–21.60)	0.078 ± 0.004 (0.02–0.14)
HLNRA (Total)	>1.50	61	36.1 ± 7.43 (18–59)	8.28 ± 4.96 (1.57–21.60)	0.084 ± 0.004 (0.02–0.17)

Molecular and Cellular Phenotypes of LDR

Antioxidative function

- **<u>Low dose radiation</u>** stimulates protection from oxidative damage. LDR promotes adaptive responses that **<u>upregulate antioxidative systems</u>** *(Scott and Tharmalingam, 2019; Tharmalingam et al., 2019).*
- LDR reduced ROS production due to enhanced **<u>expression of antioxidative enzymes</u>** *(Nabil et al., 2016).*

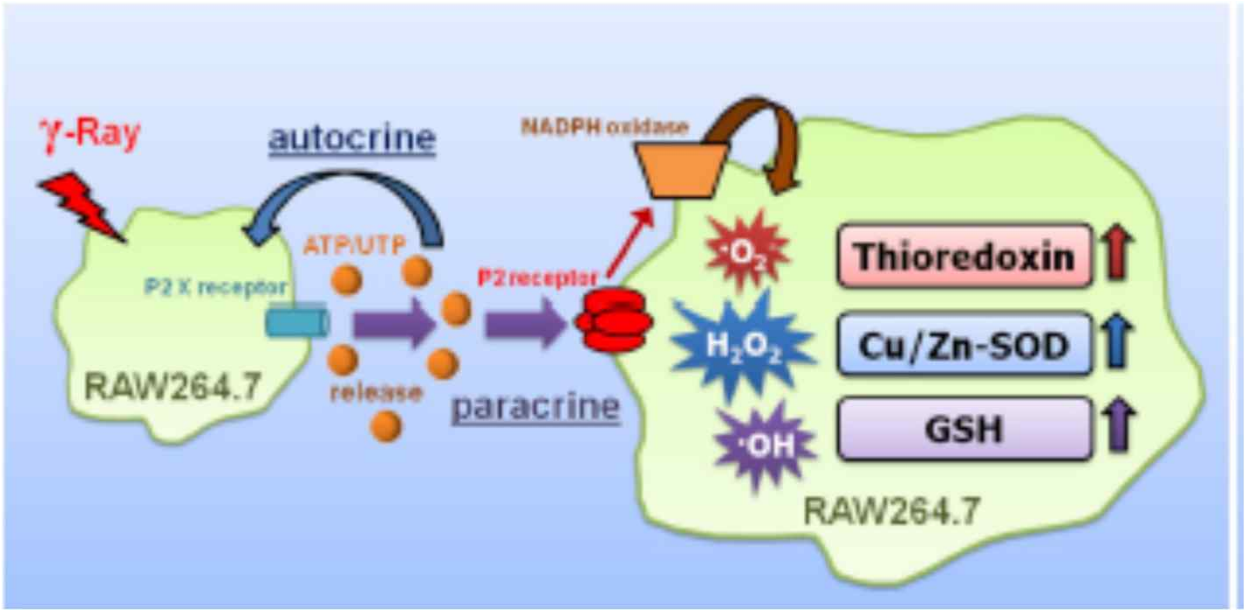


Fig. Model for radiation-induced reactive oxygen species (ROS) production in RAW264.7 cells

(Scott and Tharmalingam, 2019)

SCIENTIFIC REPORTS

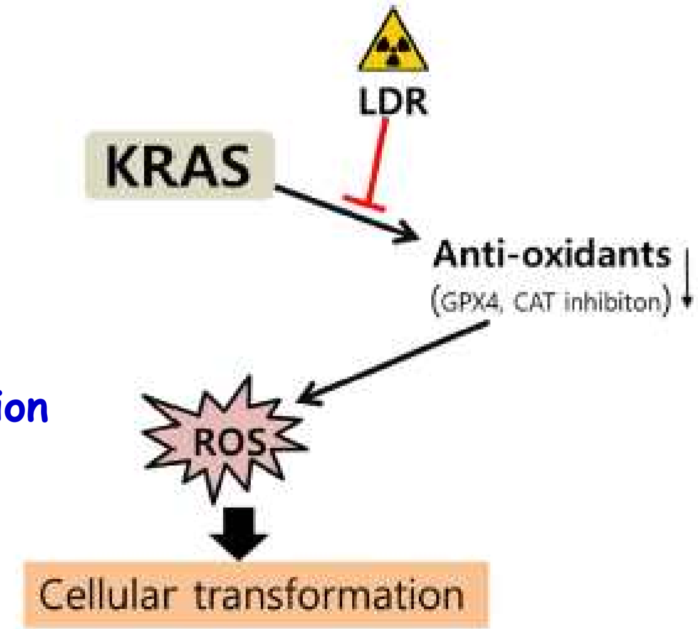
OPEN

Beneficial effects of low dose radiation in response to the oncogenic KRAS induced cellular transformation

Received: 30 May 2015
Accepted: 22 September 2015
Published: 30 October 2015

Rae-Kwon Kim[1,*], Min-Jung Kim[2,*], Ki Moon Seong[2,*], Neha Kaushik[1], Yongjoon Suh[1], Ki-Chun Yoo[1], Yan-Hong Cui[1], Young Woo Jin[2], Seon Young Nam[3] & Su-Jae Lee[1]

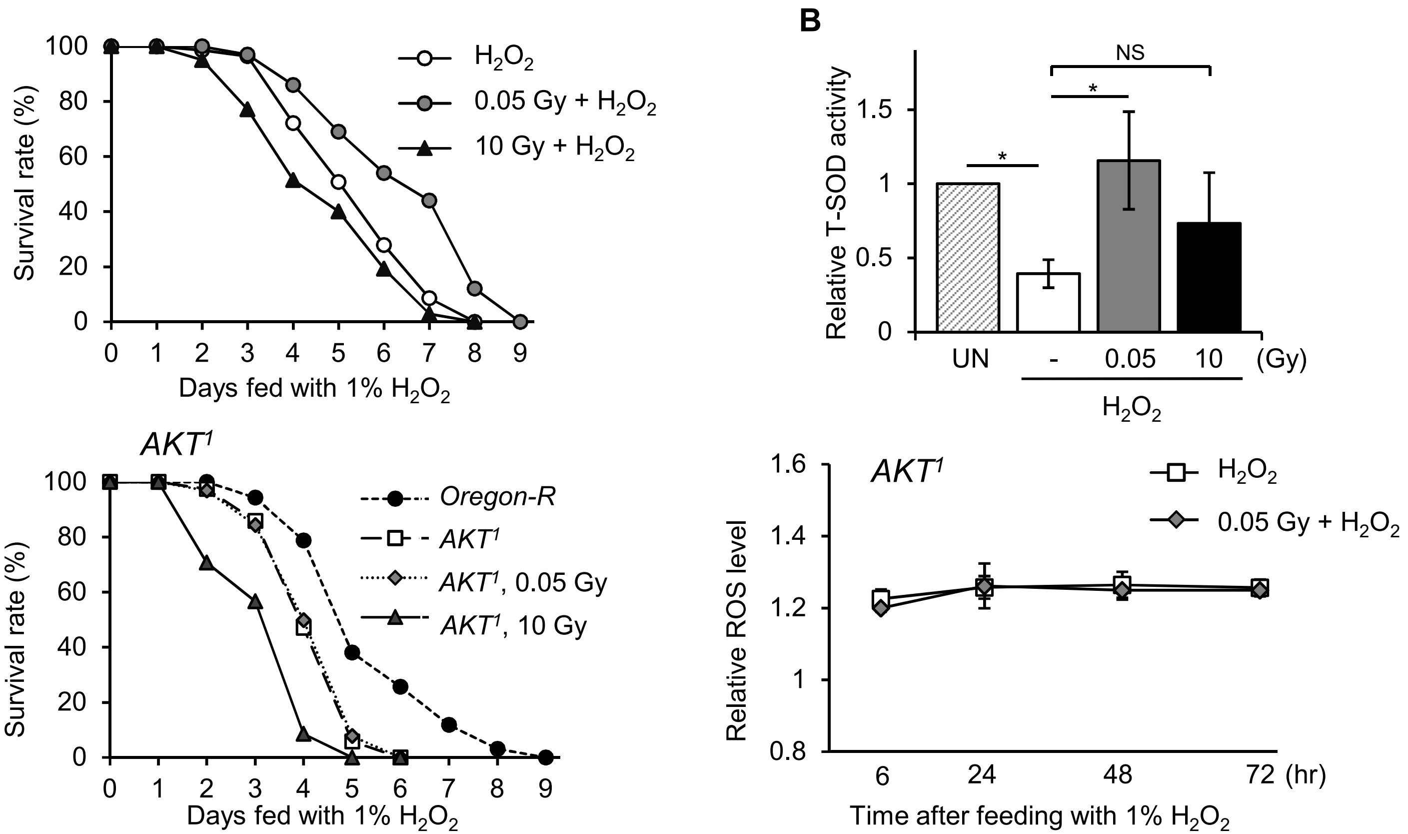
Recently low dose irradiation has gained attention in the field
understanding of the molecular consequences of low dose irra
concerning its risks on human beings. In this article, we report
of blocking the oncogenic *KRAS*-induced malignant transforma
we showed that low dose irradiation, at doses of 0.1 Gray (Gy);
response against oncogenic *KRAS* -induced malignant transfor
the induction of antioxidants without causing cell death and a
attenuation of reactive oxygen species (ROS). Importantly, we



LDR inhibits KRAS induced cellular transformation via anti-oxidants and ROS regulation

Low-dose radiation increases the lifespan of Drosophila under oxidative stress conditions

To be published in IJRB



▶ <u>**Low-dose ionizing radiation of 0.05 Gy extends the lifespan**</u> and survival rates under H_2O_2-induced oxidative stress conditions <u>**by controlling ROS levels via AKT activation**</u>**.**

Molecular and Cellular Phenotypes of LDR

Adaptive response : Cell survival

- **<u>Low-dose radiation</u>** stimulates selective **<u>apoptosis of neoplastic transformed cells</u>**. Thus, the dose-response relationship for neoplastic transformation has been found to be **<u>hormetic</u>** *(Bauer, 2011).*
- The reduction in transformation relative risk (RR) at low doses is related to the **<u>protective processes (ex, DNA damage repair and apoptosis of transformed cells)</u>** that operate at the molecular, cellular, and tissue levels *(Bauer, 2007).*
- The LNT model for cancer induction is not supported by radiobiological data *(Scott and Tharmalingam, 2019)*

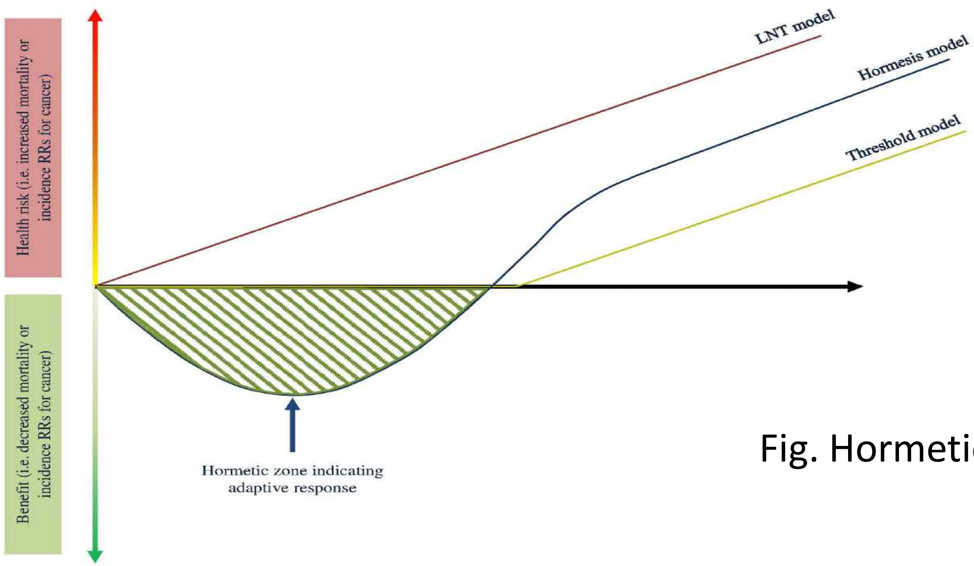


Fig. Hormetic model for radiation risk

(Iavicoli et al., 2023)

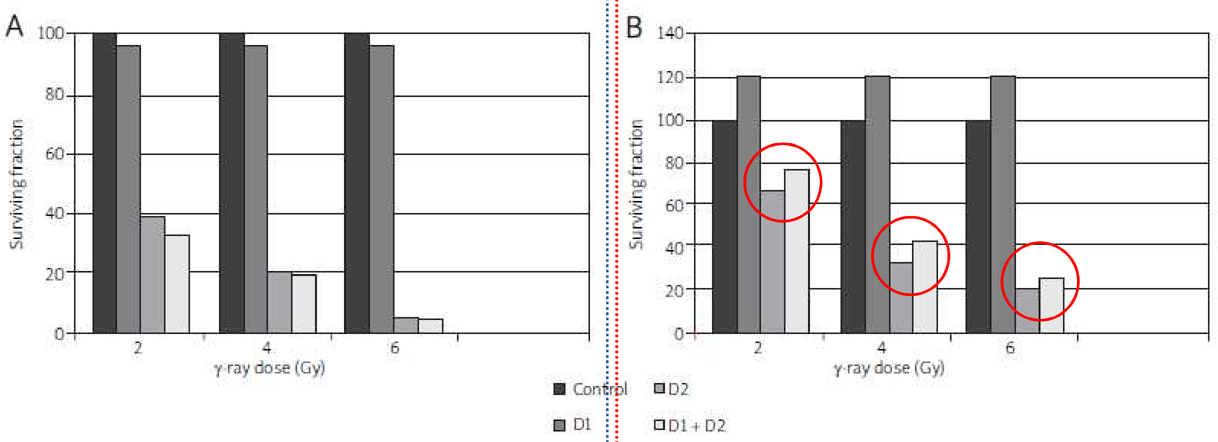
Different responses of tumor and normal cells to low-dose radiation

Yu et al., Contemp Oncol(Pozn), 2013

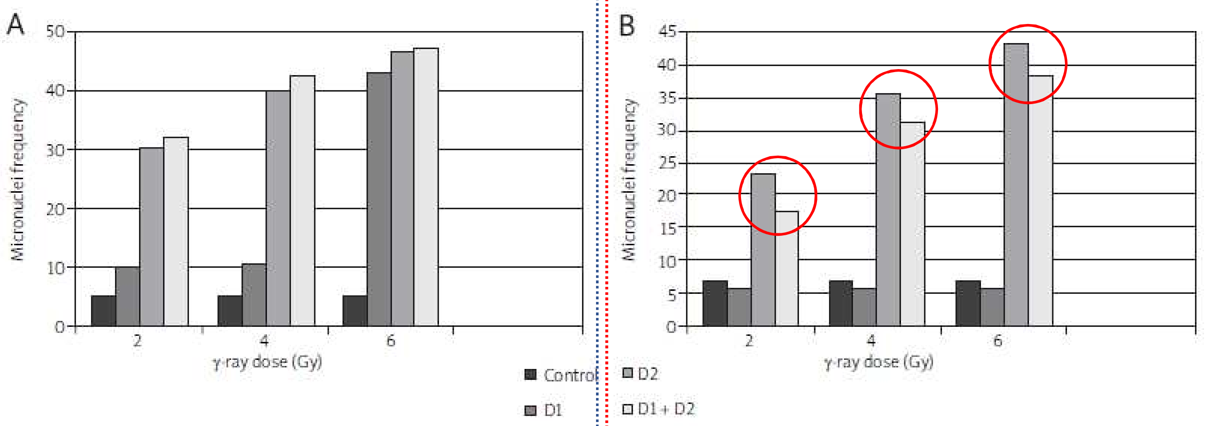
Cell survival

Cancer cells **Normal cells**

D1 – 75 mGy
D2 – 2, 4 and 6 Gy

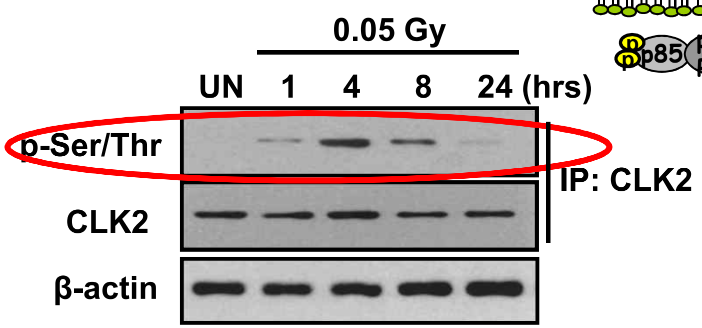


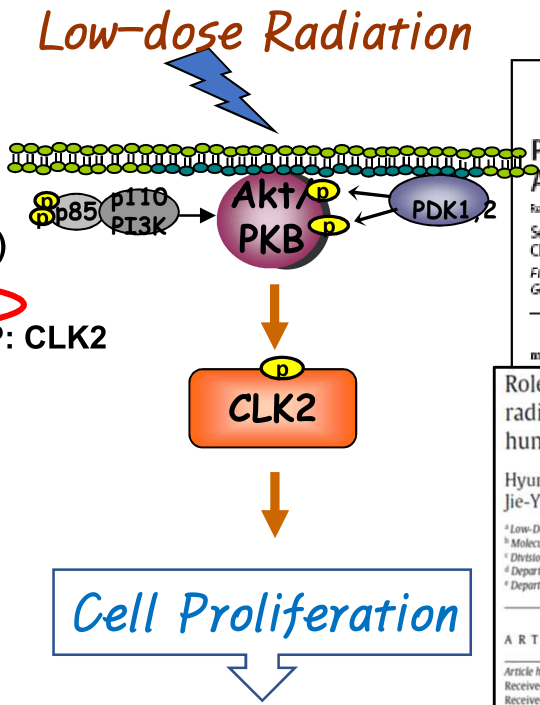
DNA damage

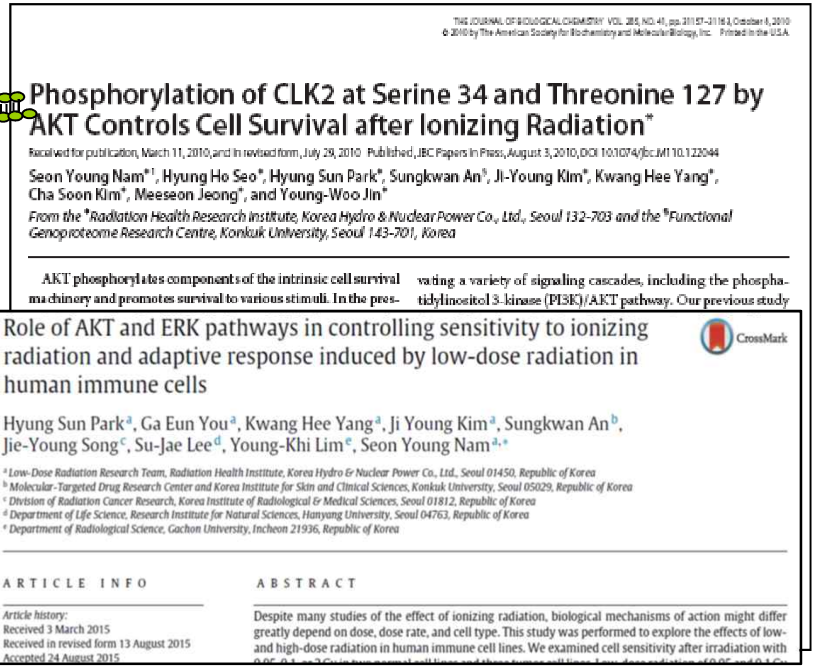


Normal cell specific adaptive response!

Low-dose radiation promotes cell proliferation







THE JOURNAL OF BIOLOGICAL CHEMISTRY VOL. 285, NO. 41, pp. 31157–31163, October 8, 2010

Phosphorylation of CLK2 at Serine 34 and Threonine 127 by AKT Controls Cell Survival after Ionizing Radiation*

Received for publication, March 11, 2010, and in revised form, July 29, 2010 Published, JBC Papers in Press, August 3, 2010, DOI 10.1074/jbc.M110.122044

Seon Young Nam*[1], Hyung Ho Seo*, Hyung Sun Park*, Sungkwan An[§], Ji-Young Kim*, Kwang Hee Yang*, Cha Soon Kim*, Meeseon Jeong*, and Young-Woo Jin*

From the *Radiation Health Research Institute, Korea Hydro & Nuclear Power Co., Ltd., Seoul 132-703 and the [§]Functional Genoproteome Research Centre, Konkuk University, Seoul 143-701, Korea

AKT phosphorylates components of the intrinsic cell survival machinery and promotes survival to various stimuli. In the pres- vating a variety of signaling cascades, including the phosphatidylinositol 3-kinase (PI3K)/AKT pathway. Our previous study

Role of AKT and ERK pathways in controlling sensitivity to ionizing radiation and adaptive response induced by low-dose radiation in human immune cells

CrossMark

Hyung Sun Park[a], Ga Eun You[a], Kwang Hee Yang[a], Ji Young Kim[a], Sungkwan An[b], Jie-Young Song[c], Su-Jae Lee[d], Young-Khi Lim[e], Seon Young Nam[a,*]

[a] Low-Dose Radiation Research Team, Radiation Health Institute, Korea Hydro & Nuclear Power Co., Ltd., Seoul 01450, Republic of Korea
[b] Molecular-Targeted Drug Research Center and Korea Institute for Skin and Clinical Sciences, Konkuk University, Seoul 05029, Republic of Korea
[c] Division of Radiation Cancer Research, Korea Institute of Radiological & Medical Sciences, Seoul 01812, Republic of Korea
[d] Department of Life Science, Research Institute for Natural Sciences, Hanyang University, Seoul 04763, Republic of Korea
[e] Department of Radiological Science, Gachon University, Incheon 21936, Republic of Korea

ARTICLE INFO

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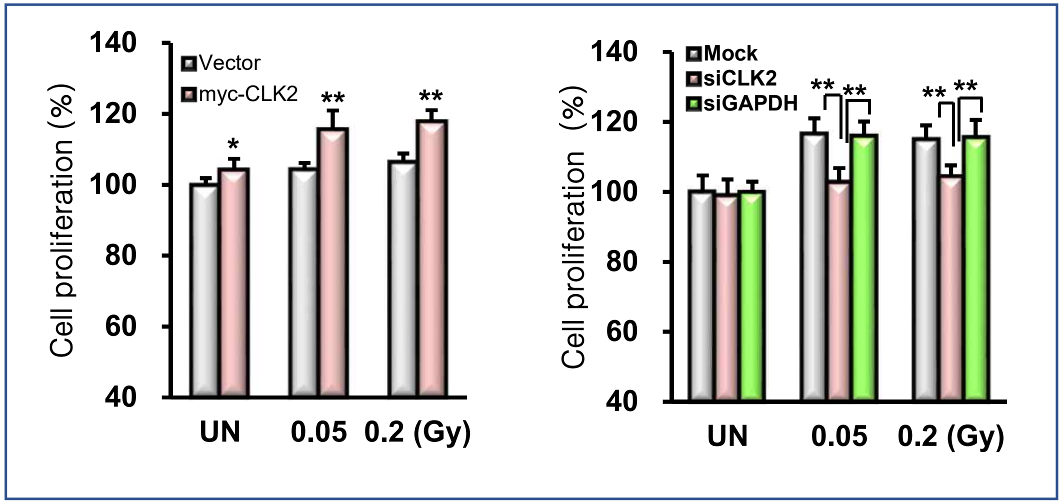
ABSTRACT

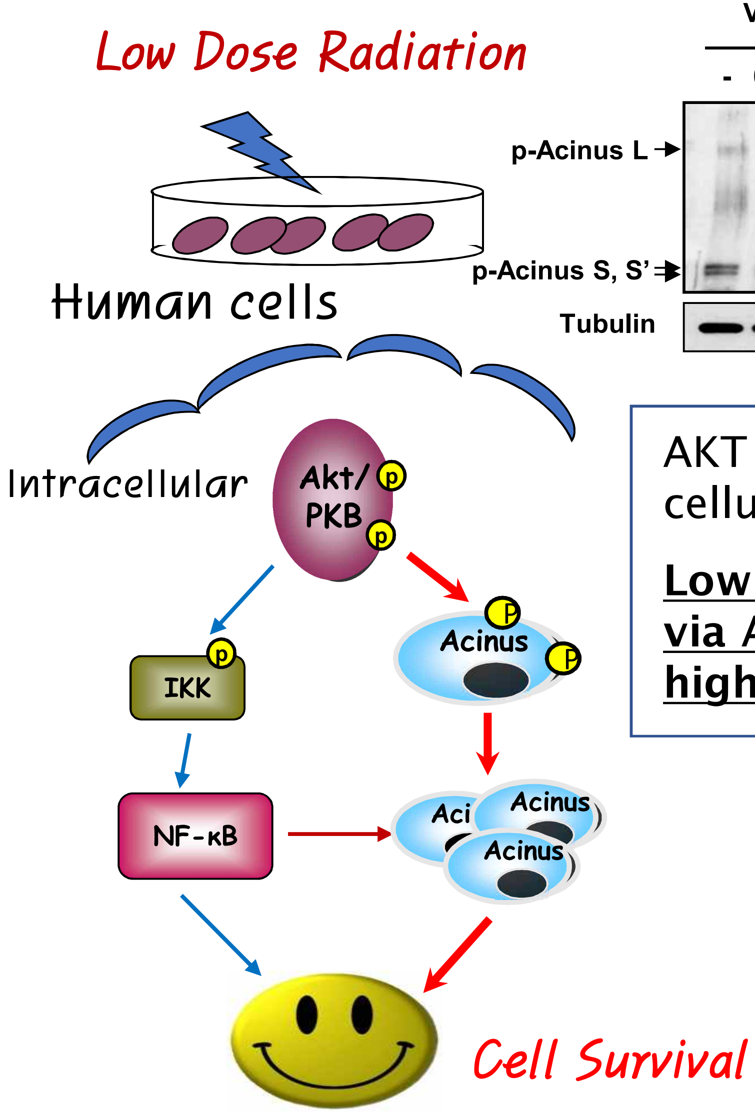
Despite many studies of the effect of ionizing radiation, biological mechanisms of action might differ greatly depend on dose, dose rate, and cell type. This study was performed to explore the effects of low- and high-dose radiation in human immune cell lines. We examined cell sensitivity after irradiation with

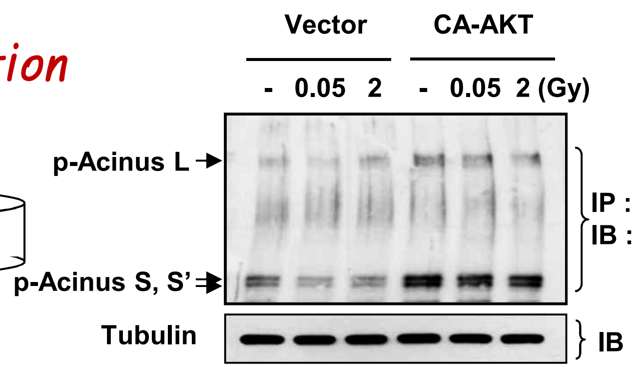


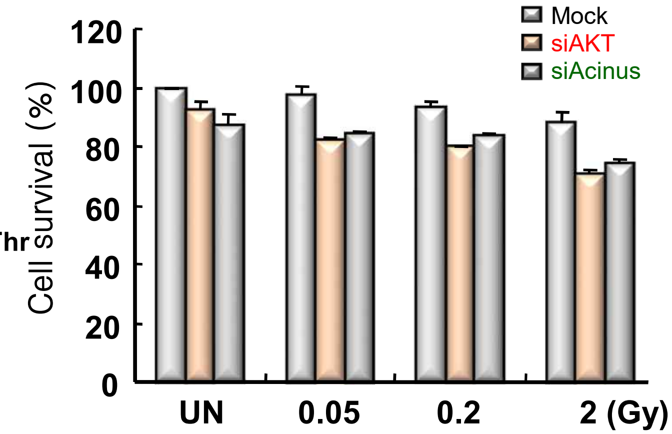
- Low-dose radiation induces **CLK2 phosphorylation via AKT activation** and promotes cell survival
- In normal cells lacking basal AKT activity, chronic low-dose radiation increases activation of the **ERK pathway**, which plays an important role in the **adaptive response** to radiation.

Nam et al., JBC, 2010; EJCB, 2015

Ionizing radiation activates cell protective molecules







AKT activation plays an important role in modulating cellular responses induced by ionizing radiation

Low dose radiation regulates **NF-kB/Acinus pathway via AKT activation** and then, **inhibits cell death during high dose radiation-induced apoptosis**.

Available online at www.sciencedirect.com
ScienceDirect
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European Journal of Cell Biology 88 (2009) 563–575
European Journal of Cell Biology
www.elsevier.de/ejcb

A critical role for AKT activation in protecting cells from ionizing radiation-induced apoptosis and the regulation of acinus gene expression

Hyung Sun Park[a], Yunha Yun[a], Cha Soon Kim[a], Kwang Hee Yang[a], Meeseon Jeong[a], Sung Kwan Ahn[b], Young-Woo Jin[a], Seon Young Nam[a,*]

[a]Radiation Health Research Institute, Korea Hydro & Nuclear Power Co. Ltd., Seoul 132-703, Republic of Korea
[b]Functional Genoproteome Research Centre, Konkuk University, Seoul 143-701, Republic of Korea

Received 5 December 2008; received in revised form 11 May 2009; accepted 11 May 2009

...d to cell survival, the roles of AKT in ...ells remain unclear. Here we show that (> 0.2 Gy) induced apoptosis through

Chronic low-dose radiation inhibits the cells death by cytotoxic high-dose radiation increasing the level of AKT and acinus proteins via NF-κB activation

Hyung Sun Park[1], Ki Moon Seong[1], Ji Young Kim[1], Cha Soon Kim[1], Kwang Hee Yang[1], Young-Woo Jin[1,2] & Seon Young Nam[1]

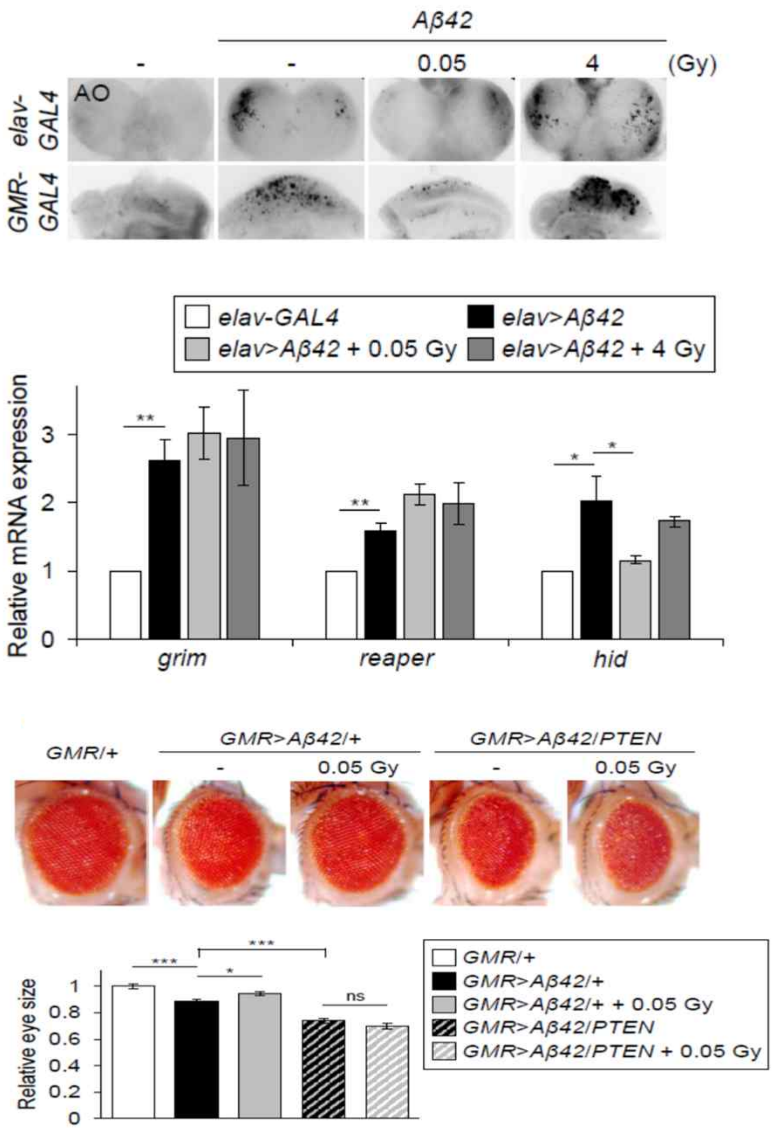
[1]Radiation Health Research Institute, Korea Hydro & Nuclear Power Co., Ltd, Seoul, Korea, and [2]Department of Planning & Research for Radiological Emergency, National Radiation Emergency Medical Center, Korea Institute of Radiological & Medical Sciences, Republic of Korea

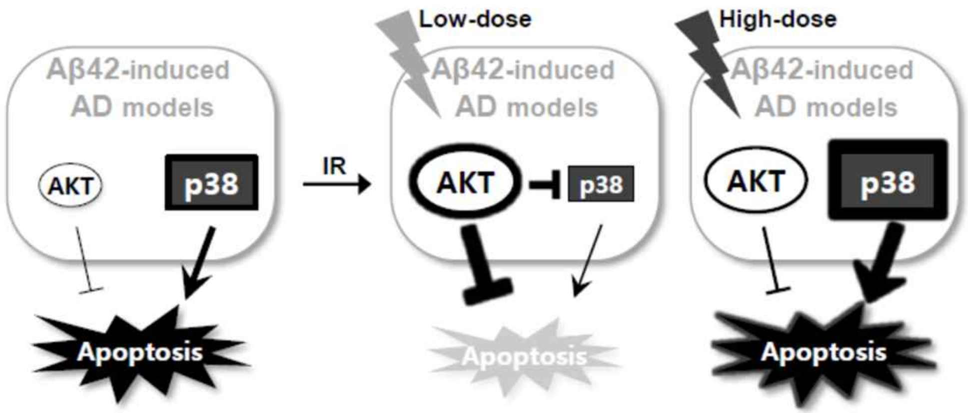
Abstract
Purpose: This study explored the effects of low-dose and low-dose-rate irradiation in human lung fibroblast CCD-18Lu cells

arrest, apoptosis, and carcinogenesis (Di Pietro et al. 1996, Krasilnikov et al. 1999, Cho et al. 2007, Portess et al. 2007, Wang et al. 2007). Low-dose ionizing radiation has been observed

Nam et al., EJCB, 2009; IJRB, 2013

The effects of low-dose radiation in *in vivo* models

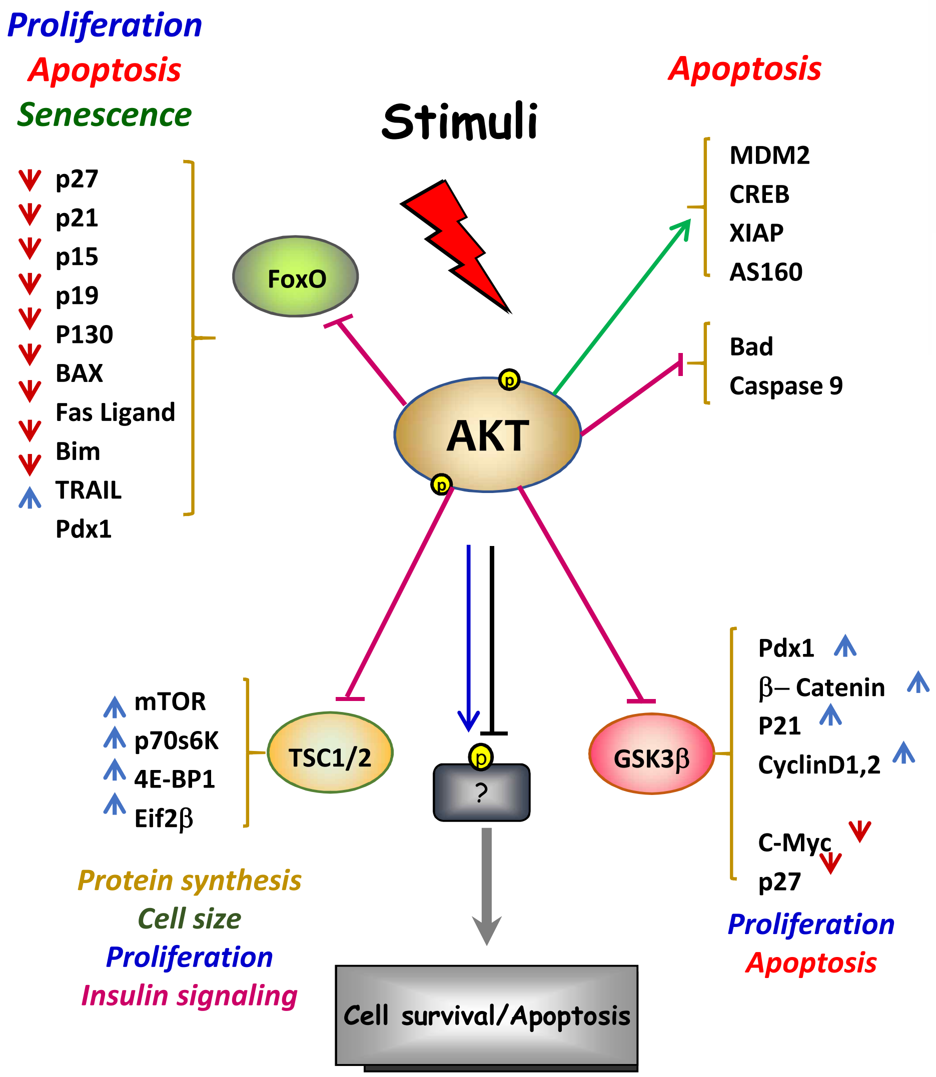




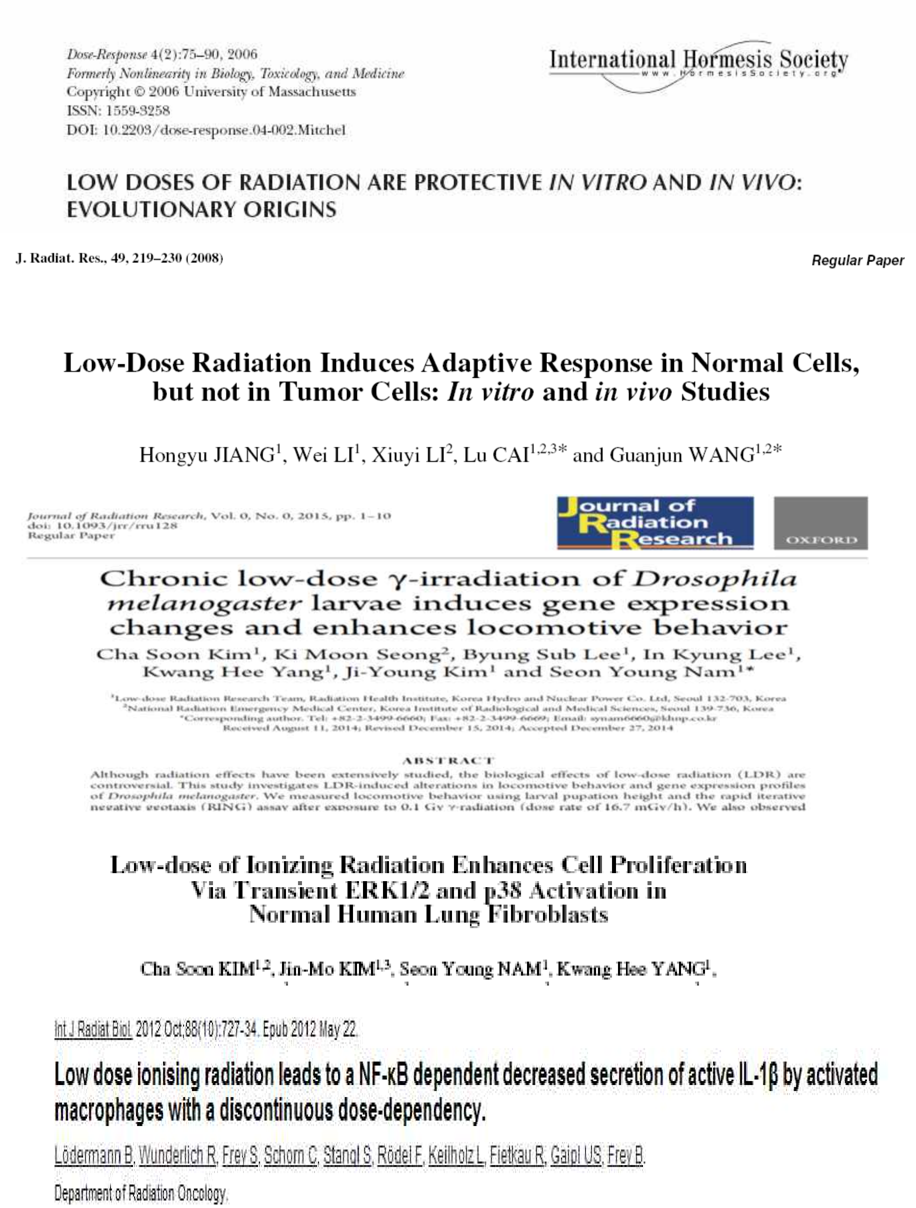
- Chronic low-dose γ-irradiation of Drosophila melanogaster larvae induces gene expression changes and enhances locomotive behavior
- **Low-dose radiation alleviates Aβ42-induced cell death via regulating AKT** and p38 pathways in Drosophila Alzheimer's disease models

Nam et al., JRR 2015; Bio. Open, 2019

Adaptive responses by LDR and related molecular changes



Nam et al., EJCB, 2009; JBC, 2010; JRR, 2015; IJRB, 2017



Dose-Response 4(2):75–90, 2006
Formerly Nonlinearity in Biology, Toxicology, and Medicine
Copyright © 2006 University of Massachusetts
ISSN: 1559-3258
DOI: 10.2203/dose-response.04-002.Mitchel

International Hormesis Society

LOW DOSES OF RADIATION ARE PROTECTIVE *IN VITRO* AND *IN VIVO*: EVOLUTIONARY ORIGINS

J. Radiat. Res., 49, 219–230 (2008)

Regular Paper

Low-Dose Radiation Induces Adaptive Response in Normal Cells, but not in Tumor Cells: *In vitro* and *in vivo* Studies

Hongyu JIANG[1], Wei LI[1], Xiuyi LI[2], Lu CAI[1,2,3*] and Guanjun WANG[1,2*]

Journal of Radiation Research, Vol. 0, No. 0, 2015, pp. 1–10
doi: 10.1093/jrr/rru128
Regular Paper

Journal of Radiation Research — OXFORD

Chronic low-dose γ-irradiation of *Drosophila melanogaster* larvae induces gene expression changes and enhances locomotive behavior

Cha Soon Kim[1], Ki Moon Seong[2], Byung Sub Lee[1], In Kyung Lee[1], Kwang Hee Yang[1], Ji-Young Kim[1] and Seon Young Nam[1*]

[1]Low-dose Radiation Research Team, Radiation Health Institute, Korea Hydro and Nuclear Power Co. Ltd, Seoul 132-703, Korea
[2]National Radiation Emergency Medical Center, Korea Institute of Radiological and Medical Sciences, Seoul 139-736, Korea
*Corresponding author. Tel: +82-2-3499-6660; Fax: +82-2-3499-6669; Email: synam6660@khnp.co.kr
Received August 11, 2014; Revised December 15, 2014; Accepted December 27, 2014

ABSTRACT

Although radiation effects have been extensively studied, the biological effects of low-dose radiation (LDR) are controversial. This study investigates LDR-induced alterations in locomotive behavior and gene expression profiles of *Drosophila melanogaster*. We measured locomotive behavior using larval pupation height and the rapid iterative negative geotaxis (RING) assay after exposure to 0.1 Gy γ-radiation (dose rate of 16.7 mGy/h). We also observed

Low-dose of Ionizing Radiation Enhances Cell Proliferation Via Transient ERK1/2 and p38 Activation in Normal Human Lung Fibroblasts

Cha Soon KIM[1,2], Jin-Mo KIM[1,3], Seon Young NAM[1], Kwang Hee YANG[1],

Int J Radiat Biol. 2012 Oct;88(10):727-34. Epub 2012 May 22.

Low dose ionising radiation leads to a NF-κB dependent decreased secretion of active IL-1β by activated macrophages with a discontinuous dose-dependency.

Lödermann B, Wunderlich R, Frey S, Schorn C, Stangl S, Rödel F, Keilholz L, Fietkau R, Gaipl US, Frey B.

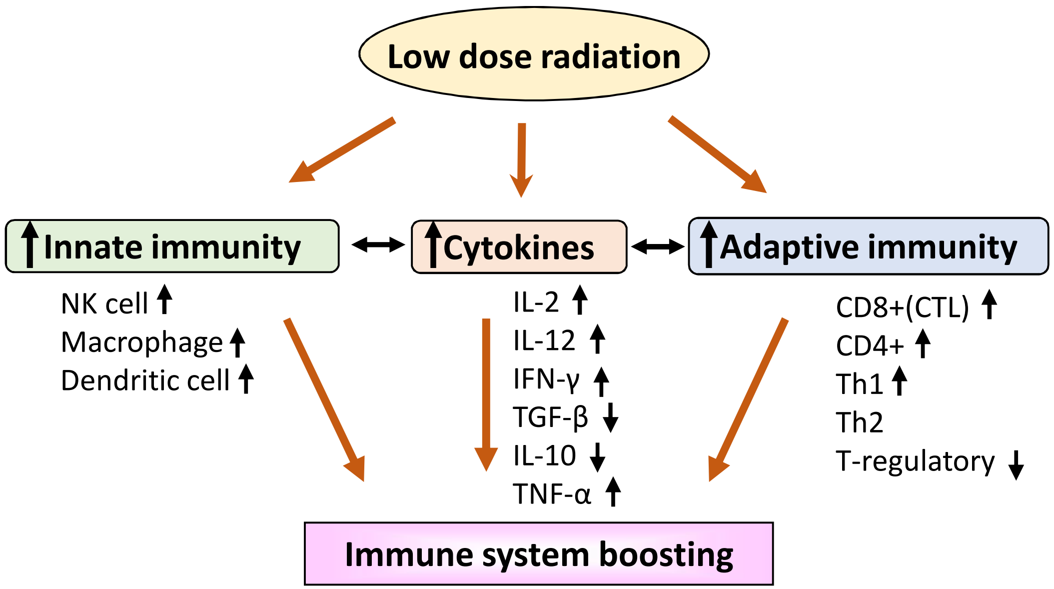
Department of Radiation Oncology.

Molecular and Cellular Phenotypes of LDR

Immunological activity

- **<u>Low radiation doses</u>** and dose rates can **<u>attenuate an ongoing inflammatory process</u>** and this strategy has been used in treating inflammatory and degenerative diseases *(Frey et al., 2015).*

- LDR leads **<u>to immune system boosting and local tumor control</u>** *(B. R. Scott and S. Tharmalingam, 2019).*



Immune system components modulation by LDR

- While high doses of radiation suppress the immune system, low doses and dose rates can **<u>stimulate anticancer immunity</u>** which can aid in cancer prevention *(Liu et al., 2007; Liu, 2003; Ren, et al., 2006; Janiak et al., 2017).*

Transcriptome analysis of low-dose ionizing radiation-impacted genes in CD4+ T-cells undergoing activation and regulation of their expression of select cytokines

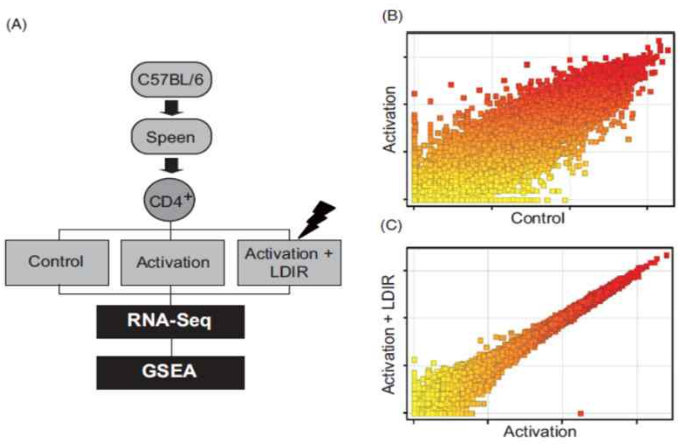


Fig. Overview of transcriptome analysis

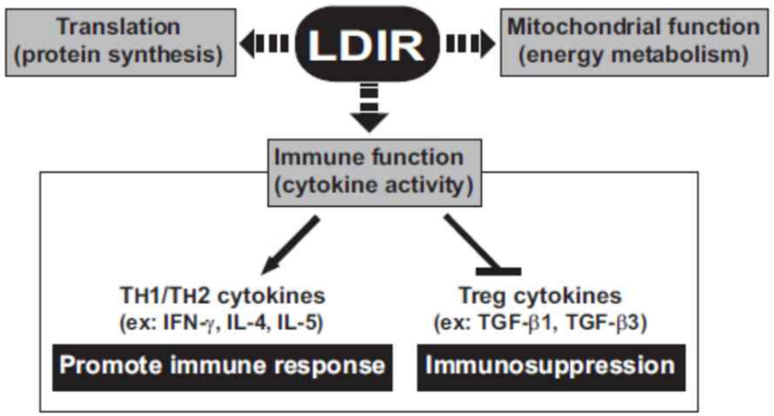


Fig. Model for LDIR-regulated cellular functions

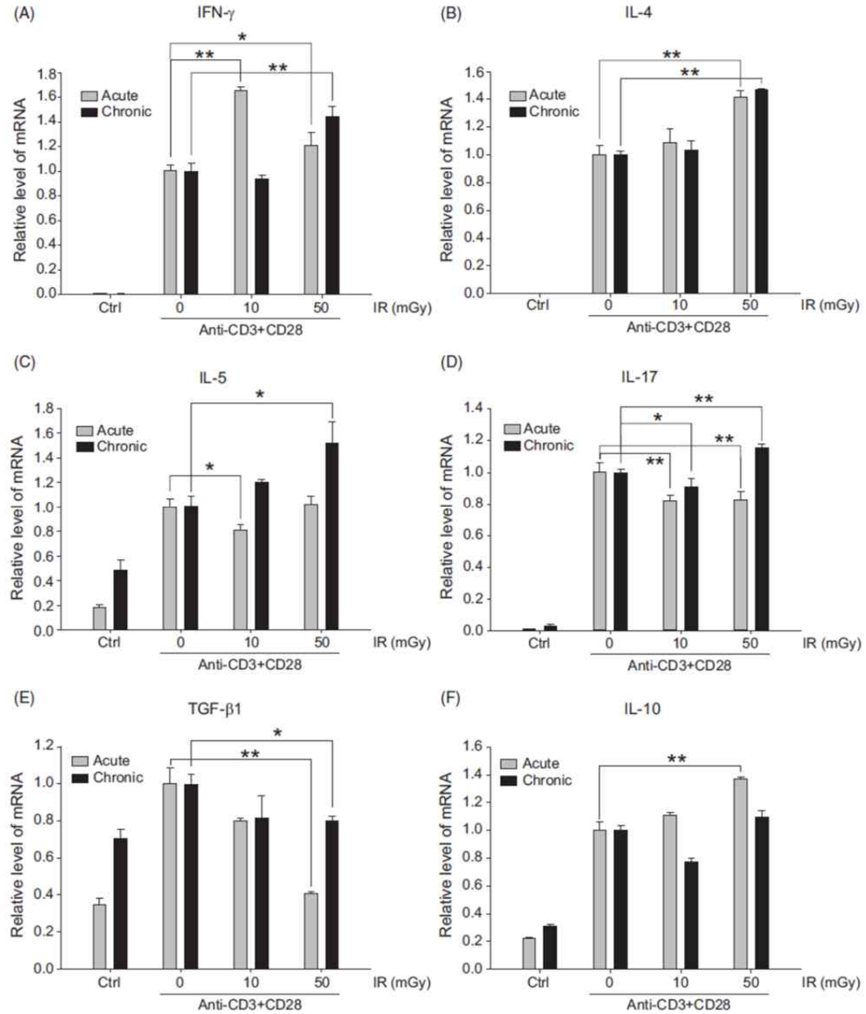
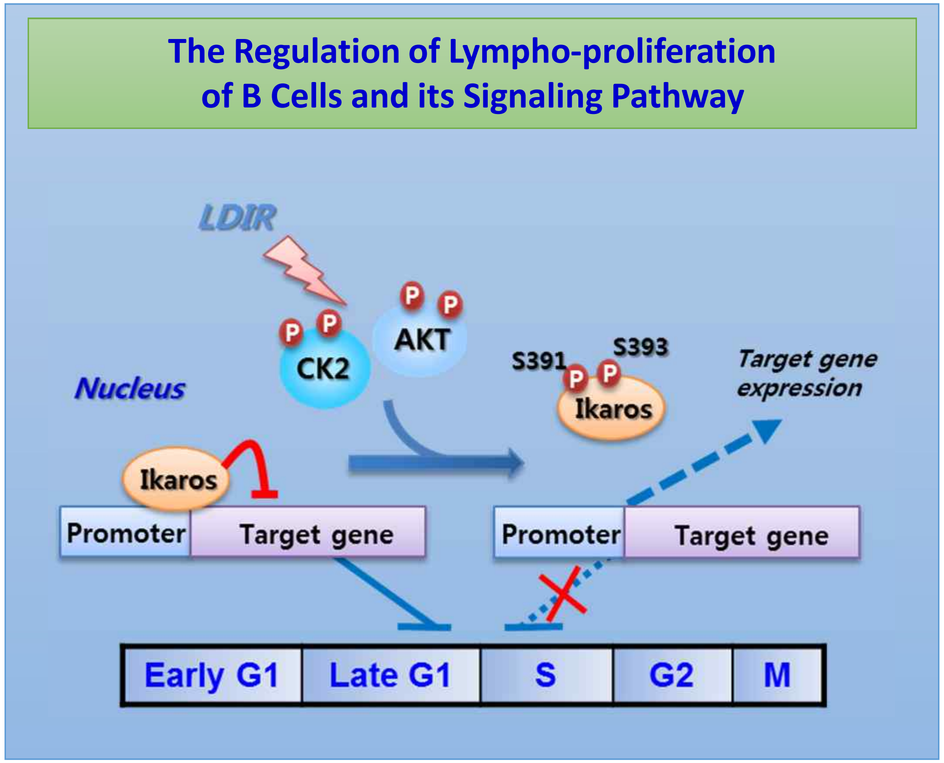


Fig. LDIR effects on cytokine gene expression in CD4+ T-cells undergoing activation.

Cho et al., JIT, 2019

The effects of low-dose radiation in immunological activity



International Journal of
Radiation Oncology
biology • physics
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Biology Contribution

Site-Specific Phosphorylation of Ikaros Induced by Low-Dose Ionizing Radiation Regulates Cell Cycle Progression of B Lymphoblast Through CK2 and AKT Activation

Seong-Jun Cho, PhD,* Hana Kang, MS,* Min Young Kim, MS,† Jung Eun Lee, PhD,* Sung Jin Kim, MS,* Seon Young Nam, PhD,* Ji Young Kim, PhD,* Hee Sun Kim, PhD,* Suhkneung Pyo, PhD,‡ and Kwang Hee Yang, PhD*

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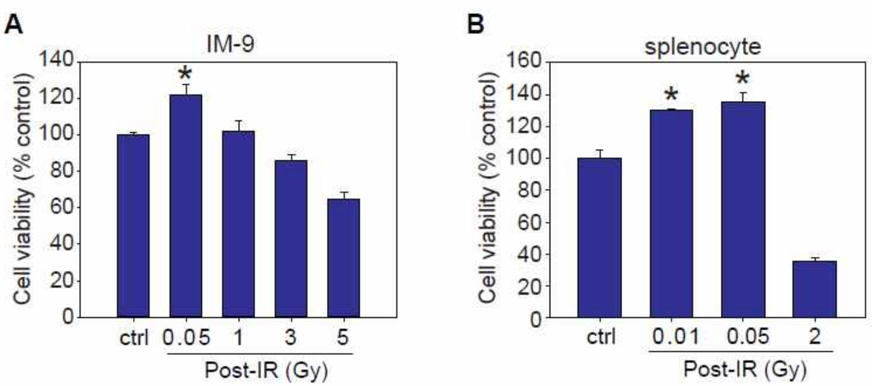
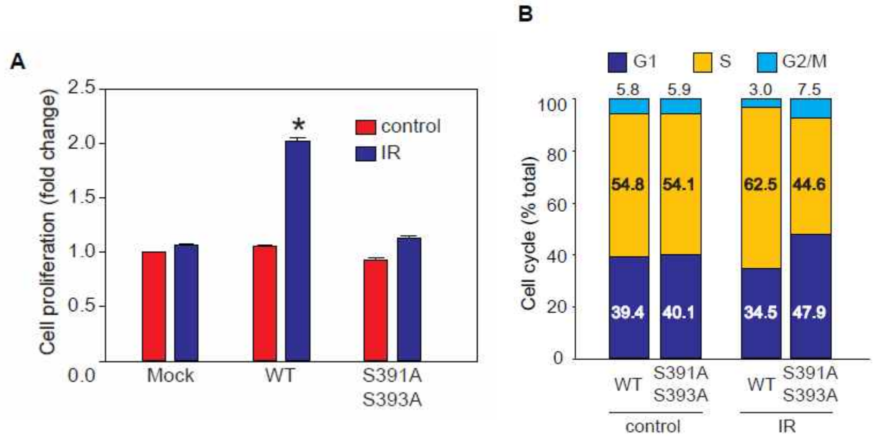
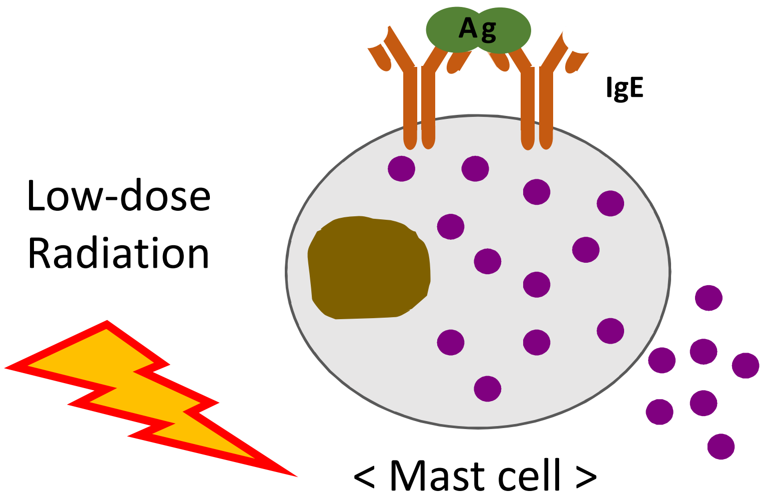




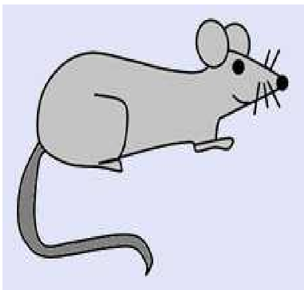
LDIR increases cell proliferation of B lymphoblast and splenocytes.

LDIR-specific phosphorylation regulates cell proliferation and cell cycle progression of B cells

Effects of low-dose radiation on the allergic response



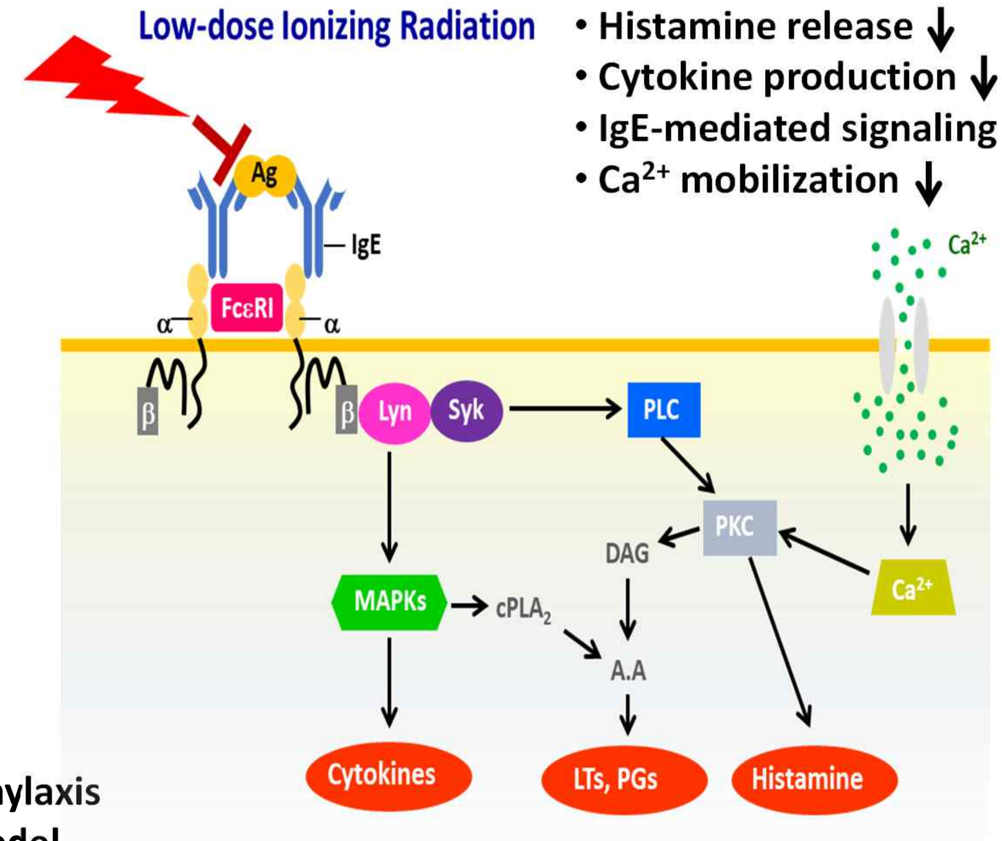
< Mast cell >



- IgE-mediated passive cutaneous anaphylaxis
- IgE-mediated late-phase cutaneous model

< Mouse model >

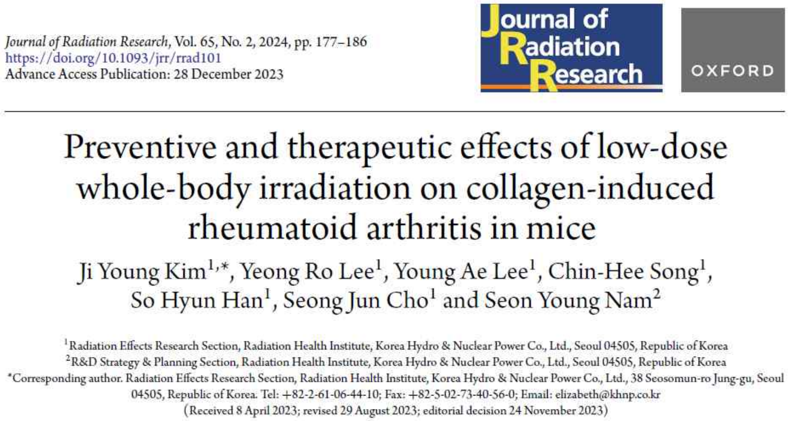
- Histamine release ↓
- Cytokine production ↓
- IgE-mediated signaling ↓
- Ca^{2+} mobilization ↓



Allergic Response Inhibition

Kim et al., JBC, 2012; Plos one, 2015; Sci. Rep. 2019

The effects of low-dose radiation on rheumatoid arthritis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Journal of Radiation Research

OXFORD

Preventive and therapeutic effects of low-dose whole-body irradiation on collagen-induced rheumatoid arthritis in mice

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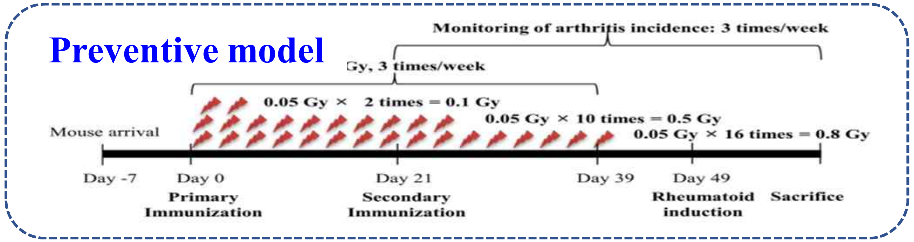
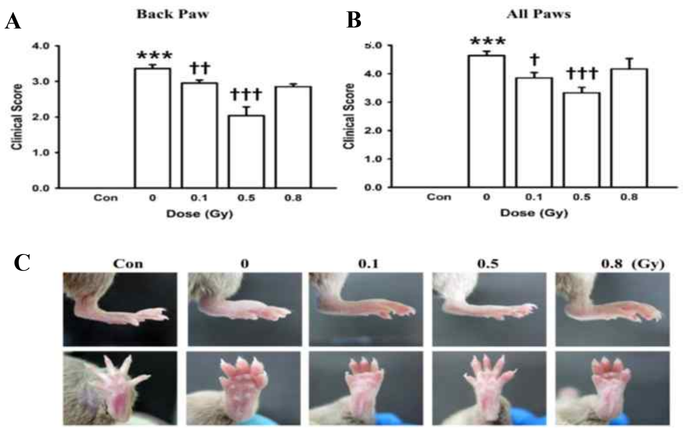
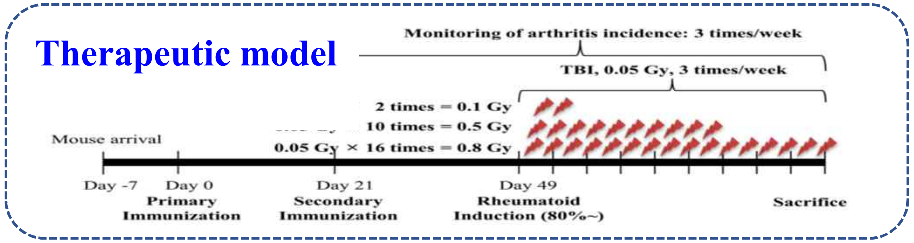
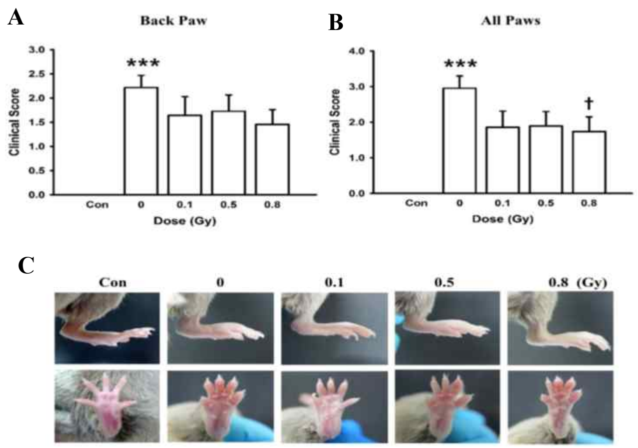
(Received 8 April 2023; revised 29 August 2023; editorial decision 24 November 2023)

- **Preventive effects : IgG↓,**
  inflammatory cytokines(IL-1ß, TNF-α,)↓
  Clinical score↓, Incidence↓
- **Therapeutic effects : IgG↓,**
  inflammatory cytokines(IL-1ß, IL-6)↓
  Clinical score↓



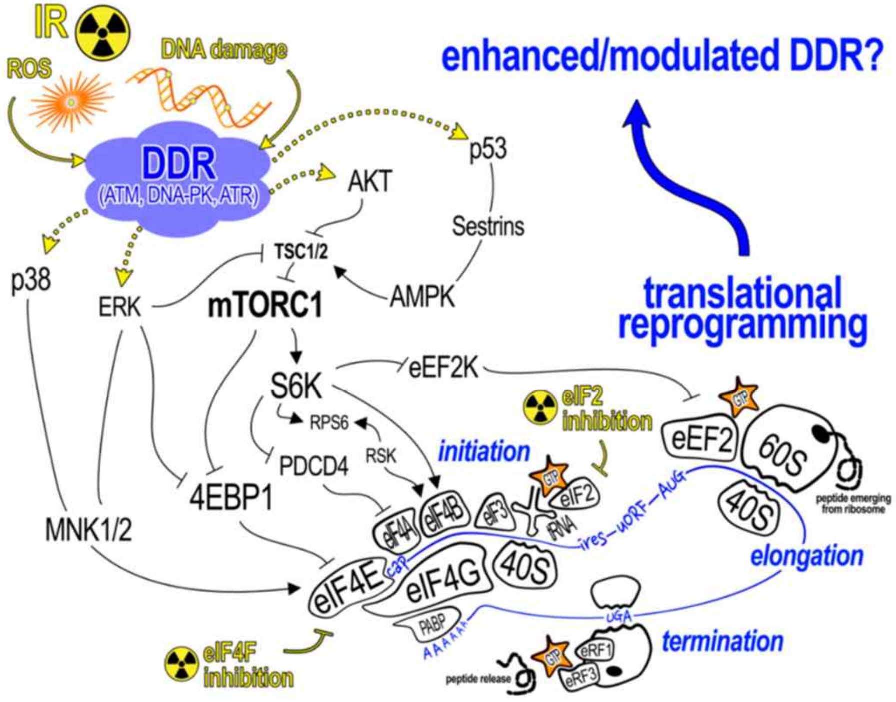






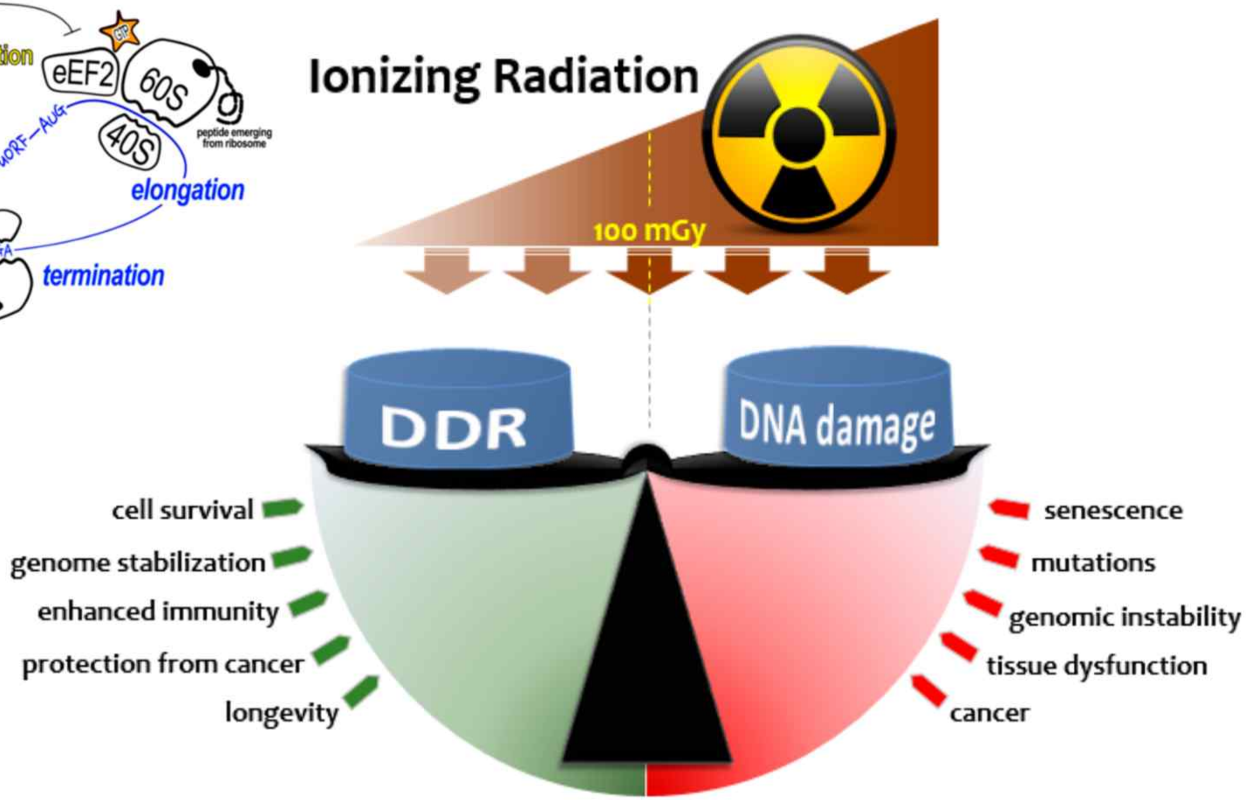
Low Dose Radiation : A Link to Radiation Hormesis?

Kabilan et al., Int. J. Mol. Sci., 2020



Low Dose Radiation:

- *de novo* protein synthesis
- translational reprogramming
- DNA damage signaling control
- Radiation hormesis phenotype



Clinical Trials : Therapeutic potential of LDR against cancer, dementia, and diabetes

Journal of Alzheimer's Disease 80 (2021) 1119–1128
DOI 10.3233/JAD-200620
IOS Press

Low Doses of Ionizing Radiation as a Treatment for Alzheimer's Disease: A Pilot Study

Jerry M. Cuttler[a], Eslam Abdellah[b], Yael Goldberg[b], Sarmad Al-Shamaa[b], Sean P. Symo
Sandra E. Black[e,f,g] and Morris Freedman[b,g,h,i,*]
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Alzheimer 's Disease: Possible Mechanisms Behind Neurohormesis Induced by Exposure to Low Doses of Ionizing Radiation

Bevelacqua J. J.[1], Mortazavi S. M. J.[2,3*]

ABSTRACT
In 2016, scientists reported that human exposure to low doses of ionizing radia
(CT scans of the brain) might relieve symptoms of both Alzheimer's disease (AD)
Parkinson disease (PD). The findings were unbelievable for those who were not fa

Therapeutic potential of low dose ionizing radiation against cancer, dementia, and diabetes: evidences from epidemiological, clinical, and preclinical studies

Jagdish Gopal Paithankar[1] · Subash Chandra Gupta[2,3] · Anurag Sharma[1]

Received: 22 June 2022 / Accepted: 14 December 2022 / Published online: 3 January 2023

Abstract
The growing use of ionizing radiation (IR)-based diagnostic and treatment methods has been linked to increasing chronic diseases among patients and healthcare professionals. However, multiple factors such as IR dose, dose-rate, and duration of exposure influence the IR-induced chronic effects. The predicted links between low-dose ionizing radiation (LDIR) and health risks are controversial due to the non-availability of direct human studies. The studies pertaining to LDIR effects have importance in public health as exposure to background LDIR is routine. It has been anticipated that data from epidemiological and clinical reports and results of preclinical studies can resolve this controversy and help to clarify the notion of

Update on a Patient With Alzheimer Disease Treated With CT Scans

Dose-Response:
An International Journal
January-March 2017:1-2
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sagepub.com/journalsPermissions.nav
DOI: 10.1177/1559325817693167
journals.sagepub.com/home/dos
SAGE

Jerry M. Cuttler[1], Eugene R. Moore[2], Victor D. Hosfeld[3], and David L. Nadolski[4]

This letter updates the April 2016 case report[1] about an 81-year-old patient who was in the final stages of advanced Alzheimer disease (AD) in hospice care. A neuropsychologist examined her on May 21, 2015, and concluded that she was "completely nonresponsive." Following treatment by 4 computed tomography (CT) scans of the brain from July to August 2015, the patient made a remarkable recovery. A fifth scan on October 1 caused a setback, from which she gradually recovered. On November 20, she was judged to be no longer eligible for hospice care because her condition was sufficiently improved. Since then, she has participated in a stimulating, dementia day care program. Photos on December 4, 2015, Figures 1 and 2, demonstrate restoration of appetite and responsiveness.

Recognizing that the efficacy of the CT scan treatments would likely be transitory, the patient's spouse requested ongoing booster scans every 4 to 5 months. These started on February 24, 2016, about 21 weeks after the October 1 treatment.

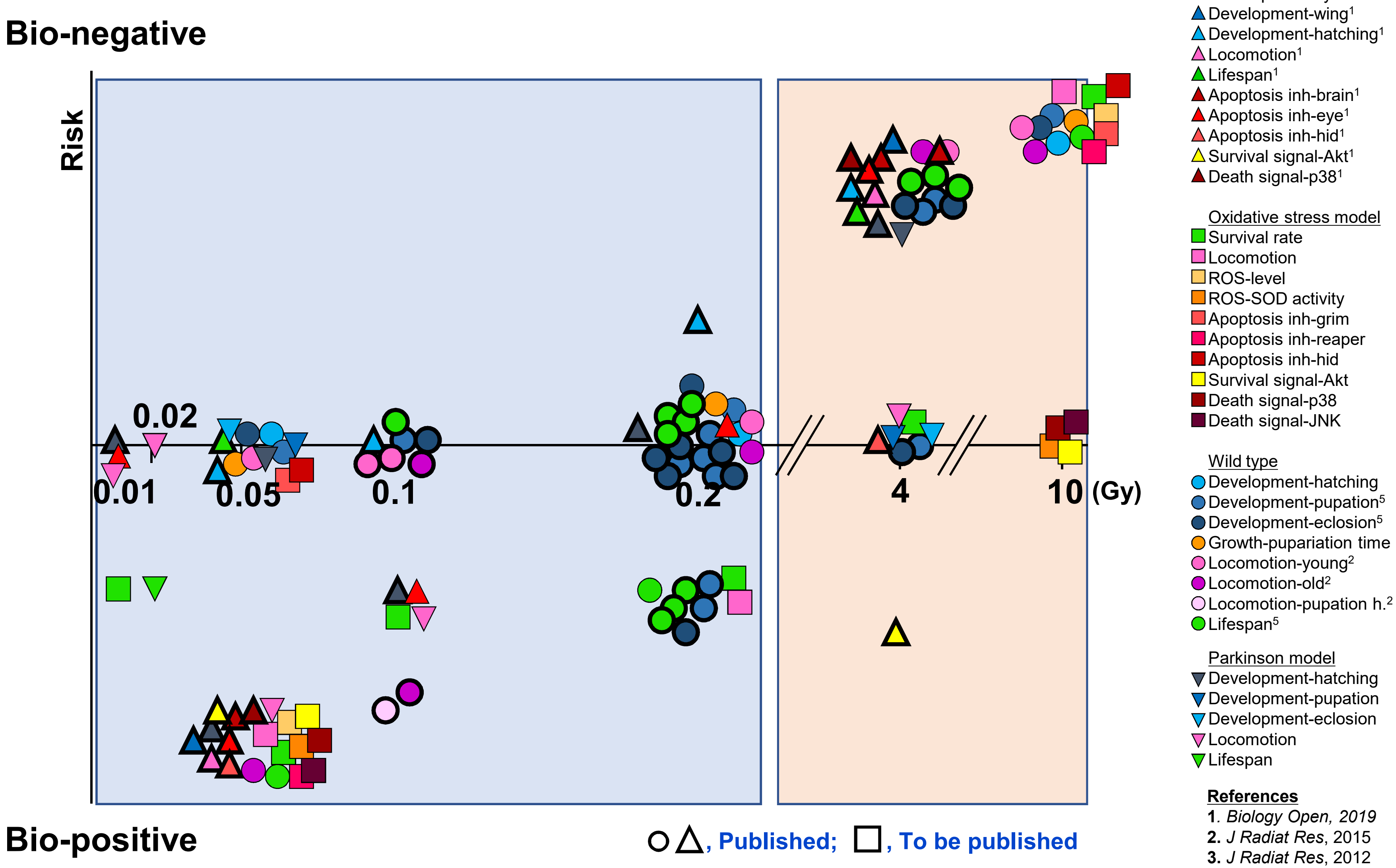
Dr William D. MacInnes (note 1) reexamined the patient on April 15, 2016. His progress note states:

> Unlike our last visit, Mrs XXX was able to give simple verbal responses to direct, simple questions. Not all of her responses were related to the direct questions, but she seemed to be reacting appropriately to the prosody and nonverbal cues of those

Fig. Restoration of appetite of patient with Alzheimer disease(AD)

Summary : Biological response of radiation dose

Drosophila *in vivo* models



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1. *Biology Open, 2019*
2. *J Radiat Res*, 2015
3. *J Radiat Res*, 2012
4. *Biogerontology*, 2011
5. *대한산업의학회지*, 2008
6. *Int J Radiat Biol*, To be published

Summary : Biological Effects of Low-dose Radiation

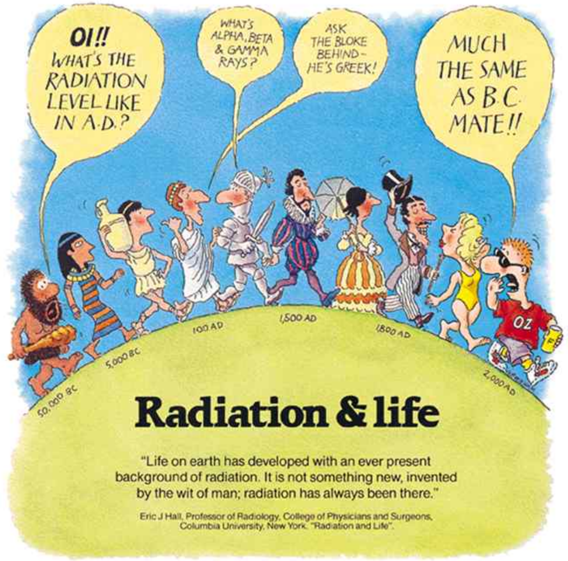
▷ Natural defenses mechanism after exposure to low-dose radiation

- **Adaptive or defense responses (such as DNA damage repair, antioxidative function, and immune activation)**
- Depends on the type of radiation, doses and dose rates, cell- or tissue-type etc.
- **These protective systems play an important role in the final biological phenotype** after LDR exposures.

▷ Dose-response model based on radiobiological evidence reviewed

- **The LNT model dose not fully account for biological effects** of low dose (and low dose rate) radiation.
- **The possibility of existence of other dose-response models** such as **threshold or hormetic** model cannot be ruled out.
- More research is needed to appropriately determine the dose-response relationship of low dose radiation.

Our life & Radiation……



"All things are poison,
and nothing is without poison;
the dosages alone makes it
so a thing is not a poison."

– Paracelsus (1493–1541) –

Thank you for your attention~