Cancer Association of South Africa (CANSA)

Fact Sheet on Effective Radiation Received from Routine Mammography

Introduction

Ionizing radiation is any form of radiation with enough energy to break off electrons from atoms (that is, to ionize the atoms). This radiation can break the chemical bonds in molecules, including DNA molecules, thereby disturbing their normal functioning. X-rays and gamma rays are the only common forms of radiation with sufficient energy to penetrate and damage body tissue below the surface of the skin.

[Picture Credit: Ionizing Radiation]

Among the many sources of ionizing radiation are traditional X-rays, computed tomography (CT) scans, fluoroscopy, and other medical radiological procedures. A newer source of X-rays is the use of backscatter scanners (low-level X-rays used to create a two-sided image by reflecting the waves in the direction in which they originated) in airport security (Brenner, 2011). Sources of gamma rays include emissions from nuclear power plants, scientific research involving radionucleotides, military weapons testing, and nuclear medicine procedures such as bone, thyroid and lung scans (EPA, 2005). (Breast Cancer Fund).

[Picture Credit: Backscatter Scanner]

Key Facts on Ionizing Radiation

According to the World Health Organization (WHO) key facts about ionizing radiation include:

- Ionizing radiation is a type of energy released by atoms in the form of electromagnetic waves or particles

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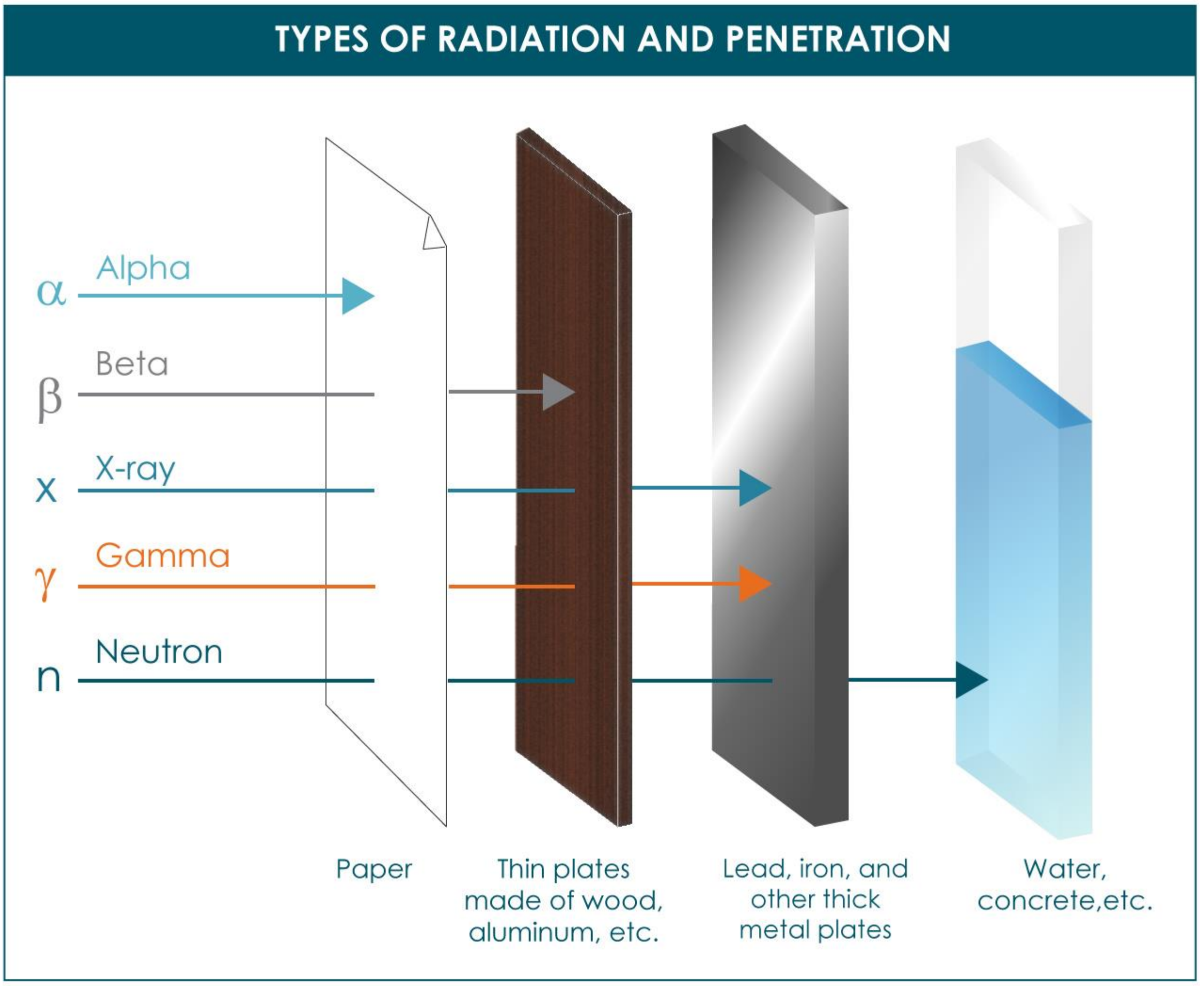
- People are exposed to natural sources of ionizing radiation, such as in soil, water, and vegetation, as well as in human-made sources, such as x-rays and medical devices
- Ionizing radiation has many beneficial applications, including uses in medicine, industry, agriculture and research
- As the use of ionizing radiation increases, so does the potential for health hazards if not properly used or contained
- Acute health effects such as skin burns or acute radiation syndrome can occur when doses of radiation exceed certain levels
- Low doses of ionizing radiation can increase the risk of longer term effects such as cancer

(World Health Organization).

Different Types of Ionizing Radiation

Ionizing radiation takes a few forms: Alpha, beta, and neutron particles, and gamma and X-rays. All types are caused by unstable atoms, which have either an excess of energy or mass (or both). In order to reach a stable state, they must release that extra energy or mass in the form of radiation.



Alpha Radiation - alpha radiation occurs when an atom undergoes radioactive decay, giving off a particle (called an alpha particle) consisting of two protons and two neutrons (essentially the nucleus of a helium-4 atom), changing the originating atom to one of an element with an atomic number 2 less and atomic weight 4 less than it started with. Due to their charge and mass, alpha particles interact strongly with matter, and only travel a few centimetres in air. Alpha particles are unable to penetrate the outer layer of dead skin cells, but are capable, if an alpha emitting substance is ingested in food or air, of causing serious cell damage. Alexander Litvinenko is a famous example. He was poisoned by polonium-210, an alpha emitter, in his tea.

Beta Radiation - beta radiation takes the form of either an electron or a positron (a particle with the size and mass of an electron, but with a positive charge) being emitted from an atom. Due to the smaller mass, it is able to travel further in air, up to a few meters, and can be stopped by a thick piece of plastic, or even a stack of paper. It can penetrate skin a few centimetres, posing somewhat of an external health risk. However, the main threat is still primarily from internal emission from ingested material.

Gamma Radiation - gamma radiation, unlike alpha or beta, does not consist of any particles, instead consisting of a photon of energy being emitted from an unstable nucleus. Having no mass or charge, gamma radiation can travel much farther through air than alpha or beta, losing (on average) half its energy for every 500 feet. Gamma waves can be stopped by a thick or dense enough layer material, with high atomic number materials such as lead or depleted uranium being the most effective form of shielding.

X-Rays -X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released. X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well.

Neutron Radiation - neutron radiation consists of a free neutron, usually emitted as a result of spontaneous or induced nuclear fission. Able to travel hundreds or even thousands of meters in air, they are however able to be effectively stopped if blocked by a hydrogen-rich material, such as concrete or water. Not typically able to ionize an atom directly due to their lack of a charge, neutrons most commonly are indirectly ionizing, in that they are absorbed into a stable atom, thereby making it unstable and more likely to emit off ionizing radiation of another type. Neutrons are, in fact, the only type of radiation that is able to turn other materials radioactive.
(Mirion Technologies).

Measuring Radiation Dosage

The scientific unit of measurement for radiation dose, commonly referred to as effective dose, is the milliseivert (mSv). Other radiation dose measurement units include rad, rem, roentgen, sievert, and gray.

Because different tissues and organs have varying sensitivity to radiation exposure, the actual radiation risk to different parts of the body from an x-ray procedure varies. The term effective dose is used when referring to the radiation risk averaged over the entire body.

The effective dose accounts for the relative sensitivities of the different tissues exposed. More importantly, it allows for quantification of risk and comparison to more familiar sources of exposure that range from natural background radiation to radiographic medical procedures.
(Radiologyinfo).

Health Effects of Ionizing Radiation
Radiation damage to tissue and/or organs depends on the dose of radiation received, or the absorbed dose which is expressed in a unit called the gray (Gy). The potential damage from an absorbed dose depends on the type of radiation and the sensitivity of different tissues and organs.

The *effective dose* is used to measure ionizing radiation in terms of the potential for causing harm. The sievert (Sv) is the unit of effective dose that takes into account the type of radiation and sensitivity of tissues and organs. It is a way to measure ionizing radiation in terms of the potential for causing harm. The Sv takes into account the type of radiation and sensitivity of tissues and organs.

The Sv is a very large unit so it is more practical to use smaller units such as millisieverts (mSv) or microsieverts (μSv). There are one thousand μSv in one mSv, and one thousand mSv in one Sv. In addition to the amount of radiation (dose), it is often useful to express the rate at which this dose is delivered (dose rate), such as microsieverts per hour (μSv/hour) or millisievert per year (mSv/year).

Beyond certain thresholds, radiation can impair the functioning of tissues and/or organs and can produce acute effects such as skin redness, hair loss, radiation burns, or acute radiation syndrome. These effects are more severe at higher doses and higher dose rates. For instance, the dose threshold for acute radiation syndrome is about 1 Sv (1000 mSv).

If the radiation dose is low and/or it is delivered over a long period of time (low dose rate), the risk is substantially lower because there is a greater likelihood of repairing the damage. There is still a risk of long-term effects such as cancer, however, that may appear years or even decades later. Effects of this type will not always occur, but their likelihood is proportional to the radiation dose. This risk is higher for children and adolescents, as they are significantly more sensitive to radiation exposure than adults.

Epidemiological studies on populations exposed to radiation, such as atomic bomb survivors or radiotherapy patients, showed a significant increase of cancer risk at doses above 100 mSv. More recently, some epidemiological studies in individuals exposed to medical exposures during childhood (paediatric CT) suggested that cancer risk may increase even at lower doses (between 50-100 mSv).

Prenatal exposure to ionizing radiation may induce brain damage in foetuses following an acute dose exceeding 100 mSv between weeks 8-15 of pregnancy and 200 mSv between weeks 16-25 of pregnancy. Before week 8 or after week 25 of pregnancy human studies have not shown radiation risk to foetal brain development. Epidemiological studies indicate

that the cancer risk after foetal exposure to radiation is similar to the risk after exposure in early childhood.
(World Health Organization).

Risks and Benefits of Medical Radiation
Risks and benefits of medical radiation include:

Computed Tomography (CT) scans - there is considerable evidence that medical X-rays, which include mammography, fluoroscopy and computed tomography (CT) scans are an important and controllable cause of breast cancer (Gofman, 1999; Ma, 2008). Although there has been a substantial decrease in exposures to ionizing radiation from individual X-rays over the past several decades, there has been a sixfold increase in exposure to medical sources of radiation from the mid-1980s through 2007, with an annual increase of 16 percent, primarily arising from the increased use of CT scans and nuclear medicine (Larson, 2011).

When a CT scan is directed to the chest, the individual receives the equivalent radiation of 30 to 442 chest X-rays (Redberg, 2009). Recent modelling of the long-term effects of cardiac CT angiography, a source of comparably high radiation to the chest, demonstrates a statistically significant increase in risk for breast cancer, especially in pre-menopausal women (Huda, 2011).

Mammography - many experts believe that the low-dose exposures to radiation received as a result of mammography procedures are not sufficient to increase risk for breast cancer. However, damage from lower-energy sources of X-rays, including those used in mammography, cannot be predicted by estimating risk from models based on higher doses (Heyes, 2009). Recent evidence indicates that the lower-energy X-rays provided by mammography result in substantially greater damage to DNA than would be predicted by these models. Evidence also suggests that risk of breast cancer caused by exposure to mammography radiation may be greatly underestimated (Heyes, 2009).

As with other risk factors for breast cancer, evidence indicates that both age at exposure and the individual's genetic profile influence the degree of increased risk for disease in women exposed to multiple mammograms. For example, women who had multiple mammograms more than five years prior to diagnosis had an increased risk for breast cancer, but the effect was only statistically significant for women whose first mammograms occurred before the age of 35 (Ma, 2008).

This age effect is of particular concern, since it is often recommended that high-risk women, including those with either of the BRCA mutations, begin annual mammography screening at ages 25 to 30. Further complicating this age-related finding are the data now demonstrating that young women with the very mutations that lead them to begin mammography screenings at earlier ages are actually more vulnerable to the cancer-inducing effects of early and repeated exposures to mammograms. This increased vulnerability has been found in women with BRCA mutations (Berrington de Gonzales, 2009) as well as in women with other relatively uncommon variations in genes known to be involved in the process of DNA repair (Millikan, 2005).

The detrimental risks from mammography might also be heightened in older women, whose breast epithelial cells have gone through several decades of cell division. Cells derived from older women's breast tissue were more sensitive to the DNA-damaging effects of low-energy radiation, increasing the likelihood of later conversion to cancerous cells (Soler, 2009).

As women are now facing the need to make their own decisions about whether to undergo routine screening mammography, it is critical that both physicians and women are better educated about mammography's potential harms, along with its potential benefits (Gotzsche, 2009; Jansen-van der Weide, 2010).

Radiation Therapy - some studies suggest that doctors and patients should carefully evaluate the risks and benefits of radiation therapy for survivors of early-stage breast cancer, particularly older women. Women older than 55 derive less benefit from radiation therapy in terms of reduced rate of local recurrence and may face increased risks of radiation-induced cardiovascular complications (EBGTCG, 2000), as well as secondary cancers such as leukaemias and cancers of the lung, oesophagus, stomach and breast (Mellemkjaer, 2006; Roychoudhuri, 2004).

More recent data indicate that women younger than 45 who received the higher radiation exposure associated with post-lumpectomy radiotherapy (as compared to post-mastectomy radiation) had a 1.5-fold to 2.5-fold increase in later contralateral breast cancer diagnoses.

This effect was especially prominent in younger women with a substantial family history of breast cancer (Hooning, 2007; Ng, 2009; Stovall, 2008).

Effective Radiation Dose in Adults

Following are comparisons of effective radiation dose in adults with background radiation exposure for several radiological procedures.

For this procedure:	*** An adult's approximate effective radiation dose is:**
ABDOMINAL REGION	
Computed Tomography (CT) - Abdomen and Pelvis	10 mSv
Computed Tomography (CT) - Abdomen and Pelvis, repeated with and without contrast material	20 mSv
Computed Tomography (CT) - Colonography	6 mSv
Intravenous Pyelogram (IVP)	3 mSv
Radiography (X-ray) - Lower GI Tract	8 mSv
Radiography (X-ray) - Upper GI Tract	6 mSv

BONE	
Radiography (X-ray) - Spine	1.5 mSv
Radiography (X-ray) - Extremity	0.001 mSv
CENTRAL NERVOUS SYSTEM	
Computed Tomography (CT) - Head	2 mSv
Computed Tomography (CT) - Head, repeated with and without contrast material	4 mSv
Computed Tomography (CT) - Spine	6 mSv
CHEST	
Computed Tomography (CT) - Chest	7 mSv
Computed Tomography (CT) - Lung Cancer Screening	1.5 mSv
Radiography - Chest	0.1 mSv
DENTAL	
Intraoral X-ray	0.005 mSv
HEART	
Coronary Computed Tomography Angiography (CTA)	12 mSv
Cardiac CT for Calcium Scoring	3 mSv
MEN'S IMAGING	
Bone Densitometry (DEXA)	0.001 mSv
NUCLEAR MEDICINE	
Positron Emission Tomography – Computed Tomography (PET/CT)	25 mSv
WOMEN'S IMAGING	
Bone Densitometry (DEXA)	0.001 mSv
Mammography	0.4 mSv

Please note that the above chart attempts to simplify a highly complex topic for patients' informational use. Patients with radiation dose questions should consult with their radiation physicists and/or radiologists as part of a larger discussion on the benefits and risks of radiologic care.

The International Commission on Radiological Protection (ICRP) Report 103 states: "The use of effective dose for assessing the exposure of patients has severe limitations that must be considered when quantifying medical exposure", and "The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case especially with x-ray diagnostics."
(Radiologyinfo).

American Cancer Society Guidelines on Mammograms
Regular mammograms can often help find breast cancer at an early stage, when treatment is most likely to be successful. A mammogram can find breast changes that could be cancer years before physical symptoms develop. Results from many decades of research clearly show that women who have regular mammograms are more likely to have breast cancer found early, less likely to need aggressive treatment (like surgery to remove the entire breast [mastectomy] and chemotherapy), and more likely to be cured.

Mammograms are not perfect. They miss some cancers. And sometimes more tests will be needed to find out if something found on a mammogram is or is not cancer. There is also a small possibility of being diagnosed with a cancer that never would have caused any problems had it not been found during screening. It is important that women getting mammograms know what to expect and understand the benefits and limitations of screening.

The goal of screening tests for breast cancer is to find it before it causes symptoms (like a lump that can be felt). *Screening* refers to tests and exams used to find a disease in people who don't have any symptoms. *Early detection* means finding and diagnosing a disease earlier than might have happened if you'd waited for symptoms to start.

Breast cancers found during screening exams are more likely to be smaller and still confined to the breast. The size of a breast cancer and how far it has spread are some of the most important factors in predicting the *prognosis* (outlook) of a woman with this disease.

The American Cancer Society Guidelines for Women at Average Risk for Breast Cancer.
Women with a personal history of breast cancer, a family history of breast cancer, a genetic mutation known to increase risk of breast cancer (such as BRCA), and women who had radiation therapy to the chest before the age of 30 are at higher risk for breast cancer, not average-risk.

Women ages 40 to 44 should have the choice to start annual breast cancer screening with mammograms if they wish to do so. The risks of screening as well as the potential benefits should be considered.

Women age 45 to 54 should get mammograms every year.

Women age 55 and older should switch to mammograms every 2 years, or have the choice to continue yearly screening.

Screening should continue as long as a woman is in good health and is expected to live 10 more years or longer.

All women should be familiar with the known benefits, limitations, and potential harms associated with breast cancer screening. They should also be familiar with how their breasts normally look and feel and report any changes to a health care provider right away.

The American Cancer Society Guidelines for Women Who are at High Risk for Breast Cancer

These guidelines are based on certain risk factors. Women who fall in this group should get an MRI and a mammogram every year. This includes women who:

- Have a lifetime risk of breast cancer of about 20% to 25% or greater, according to risk assessment tools that are based mainly on family history (such as the Claus model – see below)
- Have a known *BRCA1* or *BRCA2* gene mutation
- Have a first-degree relative (parent, brother, sister, or child) with a *BRCA1* or *BRCA2* gene mutation, and have not had genetic testing themselves
- Had radiation therapy to the chest when they were between the ages of 10 and 30 years
- Have Li-Fraumeni syndrome, Cowden syndrome, or Bannayan-Riley-Ruvalcaba syndrome, or have first-degree relatives with one of these syndromes

(American Cancer Society).

Mayo Clinic Guidelines on Mammograms

At Mayo Clinic, doctors offer mammograms to women beginning at age 40 and continuing annually. When to begin mammogram screening and how often to repeat it is a personal decision based on your preferences.

Not all organisations agree on breast cancer screening guidelines, but most emphasise working with one's doctor to determine what is right for one's particular situation.

Mayo Clinic supports screening beginning at age 40 because screening mammograms can detect breast abnormalities early in women in their 40s. Findings from randomised trials of women in their 40s and 50s have demonstrated that screening mammograms decrease breast cancer deaths by 15 to 29 percent.

Mammogram screening is not perfect. A study concluded that despite more women being diagnosed with early breast cancer due to mammogram screening, the number of women diagnosed with advanced breast cancer has not decreased. The study suggested that some women with early breast cancer were diagnosed with cancer that may never have affected their health.

Unfortunately doctors cannot distinguish dangerous breast cancers from those that are non-life-threatening, so annual mammograms remain the best option for detecting cancer early and reducing the risk of death from breast cancer.

The main concern about mammograms for breast cancer screening is the chance of a false positive result. This means that an abnormality is detected but, after additional testing, it turns out to not be cancer. This is especially a concern in younger women in their 40s and 50s, who may be more likely to have a false positive result.

If an abnormality is detected on a mammogram, a woman may be asked to have additional mammogram images taken and, possibly, additional imaging tests, such as ultrasound.

These tests may determine the abnormality shown on the original mammogram is not cancer.

In some cases, it may be necessary for a woman to undergo a biopsy procedure to remove a sample of breast tissue for testing. For many women, having a biopsy that confirms there is no cancer present is reassuring and does not increase anxiety.

Mayo Clinic advises that if someone is concerned about when to start breast cancer screening and how often to repeat it, to work with her doctor to make an informed decision. Together they can decide what is best for each individual based on personal preferences, medical history and individual breast cancer risk.

Talk with a doctor about:

- One's personal risk of breast cancer
- The benefits, risks and limitations of screening mammograms
- The role of breast self-examinations for breast awareness in helping one become more familiar with one's breasts, which may help one identify abnormalities or changes

(Mayo Clinic).

The Cancer Association of South Africa (CANSA) Guidelines and Position on Mammograms

The Cancer Association of South Africa (CANSA) is aware that the starting age for regular breast screening by means of a mammogram has been raised to 45 years. This applies to First World countries where access to health care is freely available to everyone.

The South African situation is, however, totally different:

- The majority of South African women do not enjoy access to health care
- During 2011 a total of 1 370+ women between the ages 20 and 44 were diagnosed with breast cancer

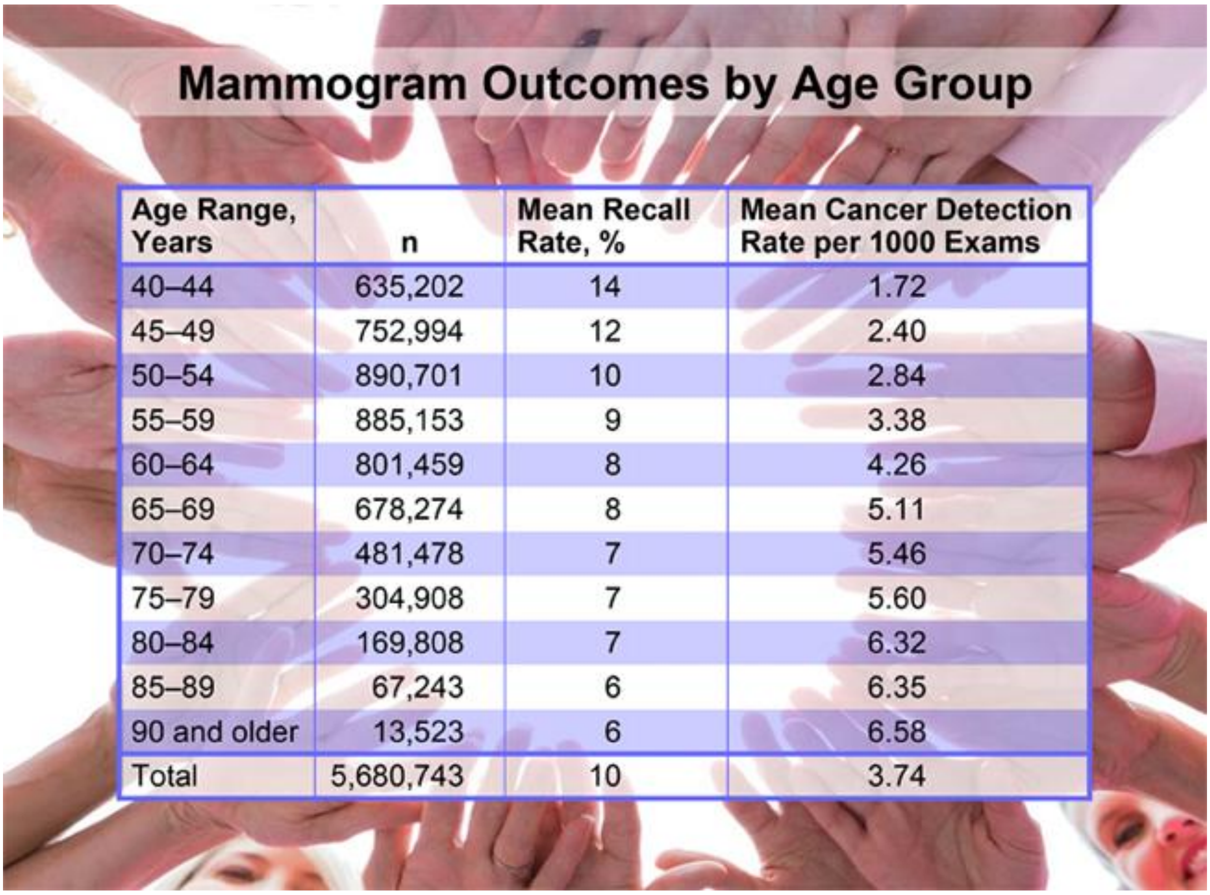
CANSA, therefore, advocates a mammogram every year for all women from age 40 for purposes of non-symptomatic breast screening.

CANSA further advocates that:

- Women who are at risk and those that have had breast health problems in the past should consult their respective health professional to determine a schedule applicable to them
- Women aged 40 to 54 should have an annual mammogram
- Women 55 years and older should change to having a mammogram every 2 years – or have the choice to continue with an annual mammogram
- Screening should continue as long as a woman is in good health and is expected to live 10 years or longer
- Every woman should be informed of the known benefits, limitations, and potential harms linked to breast cancer screening by means of a mammogram

Mammograms In Women Older than 74
As women get older, the precision of breast cancer screening with mammography increases because the rate of false-positive results decreases and the detection of cancer increases significantly, according to new research presented at the Radiological Society of North America 2016 Annual Meeting.

This calls into question the recommendation of the US Preventive Services Task Force (USPSTF) that women undergo screening every 2 years only until age 74. Age 75 seems to be an arbitrary cut-off. The decision to stop mammography screening should be made on the basis of individual patient values, comorbidities, and health status — not some random cut-off age.


Mammogram Outcomes by Age Group

Age Range, Years	n	Mean Recall Rate, %	Mean Cancer Detection Rate per 1000 Exams
40–44	635,202	14	1.72
45–49	752,994	12	2.40
50–54	890,701	10	2.84
55–59	885,153	9	3.38
60–64	801,459	8	4.26
65–69	678,274	8	5.11
70–74	481,478	7	5.46
75–79	304,908	7	5.60
80–84	169,808	7	6.32
85–89	67,243	6	6.35
90 and older	13,523	6	6.58
Total	5,680,743	10	3.74

(Medscape).

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Sources and References

American Cancer Society
http://www.cancer.org/cancer/breastcancer/moreinformation/breastcancerearlydetection/breast-cancer-early-detection-acs-recs
http://www.cancer.org/cancer/news/news/american-cancer-society-releases-new-breast-cancer-guidelines

Backscatter Scanner
https://za.pinterest.com/pin/555631672753838929/

Berrington-de-Gonzalez, A., Berg, C., Visvanathan, K., & Robson, M. 2009. Estimated risk of radiation-induced breast cancer from mammographic screening for young BRCA mutation carriers. *J Natl Cancer Inst*, 101, 205–209.

Berrington-de-Gonzalez, A., Mahesh, M., & Kim, K.-P. 2009. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med*, 169, 2071–2077.

Breast Cancer Fund
http://www.breastcancerfund.org/clear-science/radiation-chemicals-and-breast-cancer/ionizing-radiation.html?referrer=https://www.google.co.za/

Brenner, D. J. 2011. Are x-ray backscatter scanners safe for airport passenger screening? For most individuals, probably yes, but a billion scans per year raises long-term public health concerns. *Radiology*, 259(1), 6–10.

Gofman, J. 1999. Radiation from Medical Procedures in the Pathogenesis of Cancer and Ischemic Heart Disease: Dose-response Studies with Physicians per 100,000 Population. San Francisco: CNR Book Division, Committee for Nuclear Responsibility.

Gotzsche, P., Hartling, O., Nielsen, M., Brodersen, J., & Jorgensen, K. 2009. Breast screening: the facts or maybe not. *Br Med J,* 338, 86.

EBCTCG, E. B. C. T. C. G. (n.d.). Favorable and unfavorable effects on long-term survival of radiotherapy for early breast cancer: An overview of the randomized trials. *Lancet*, 355, 1757–1770.

Heyes, G., Mill, A., & Charles, M. 2009. Mammography: oncogenecity at low doses. *J Radiol Protect*, 29, 123–132.

Hooning, M., Aleman, B., Hauptmann, M., Baaijens, M., Klijn, J., Noyon, R., Van Leeuwen, F. 2007. Roles of radiotherapy and chemotherapy in the development of contralateral breast cancer. *J Clin Oncol*, 34, 5561–5568.

Huda, W., Schoepf, U. J., Abro, J. A., Mah, E., & Costello, P. 2011. Radiation-related cancer risks in a clinical patient population undergoing cardiac CT. *Am J Roentgenol*, 196(2), W159–165.

Ionizing Radiation
https://za.pinterest.com/aboutkemila/radiation-awareness/

Jansen-Van Der Weide M 2009. Mammography screening and radiation-induced breast cancer among women with a familial or genetic predisposition: a meta-analysis. Published abstract of presentation at the 95th annual meeting of the Radiological Society of North America, Chicago.

Larson, P.S., Ungarelli, R.A., de las Morenas, A. (*et al*). 2006. In utero exposure to diethylstilbestrol (DES) does not increase genomic instability in normal or neoplastic breast epithelium. *Cancer*, 107:2122-2126.

Ma, H., Hill, C., Bernstein, L., & Ursin, G. 2008. Low-dose medical radiation exposure and breast cancer risk in women under age 50 years overall and by estrogen and progesterone receptor status: Results from a case-control and a case-case comparison. *Breast Cancer Res Treat*, 109, 77–90.

Mayo Clinic
http://www.mayoclinic.org/tests-procedures/mammogram/expert-answers/mammogram-guidelines/faq-20057759

Medscape
http://www.medscape.com/viewarticle/872502?nlid=110981_2823&src=WNL_mdplsnews_161202_mscpedit_nurs&uac=163396FT&spon=24&impID=1245977&faf=1

Mellemkjaer, L., Friis, S., Olsen, J., Scelo, G., Hemminki, K., Tracey, E., Brennan, P. 2006. Risk of second cancer among women with breast cancer. *Int J Cancer*, 118, 2285–2292.

Millikan, R.C.., Player, J., Decotret, A., Tse, C., & Keku, T. 2005. Polymorphisms in DNA repair genes, medical exposure to ionizing radiation, and breast cancer risk. *Cancer Epidemiol Biomarkers Prev*, 14, 2326–2334.

Mirion Technologies
https://www.mirion.com/introduction-to-radiation-safety/types-of-ionizing-radiation/

Ng, A. K., & Travis, L. B. 2009. Radiation therapy and breast cancer risk. *J Nat Comp Cancer Network*, 7(10), 1121–1128.

Radiologyinfo
http://www.radiologyinfo.org/en/info.cfm?pg=safety-xray

Redberg, R. 2009. Cancer risks and radiation exposure from computed tomographic scans. How can we be sure that the benefits outweigh the risks. *Arch Intern Med*, 169, 2049–2050.

Roychoudhuri, R., Evans, H., Robinson, D., & Moller, H. 2004. Radiation-induced malignancies following radiotherapy for breast cancer. *Br J Cancer*, 91, 868–872.

Soler, D., Pampalona, J., Tusell, L., & Genesca, A. 2009. Radiation sensitivity increases with proliferation-associated telomere dysfunction in nontransformed human epithelial cells. *Aging Cell,* 8, 414–425.

Stovall, M., Smith, S. A., Langholz, B. M., Boice, J. D., Jr, Shore, R. E., Andersson, M., Bernstein, J. L. 2008. Dose to the contralateral breast from radiotherapy and risk of second primary breast cancer in the WECARE study. *Int J Rad Oncol*, 72(4), 1021–1030.

World Health Organization
http://www.who.int/mediacentre/factsheets/fs371/en/