PRODUCTION OF RADIOISOTOPES IN PAKISTAN RESEARCH REACTOR: PAST, PRESENT AND FUTURE

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1. INTRODUCTION

Radioisotope production to service different sectors of economic significance constitutes an important ongoing activity of many national nuclear programs. Radioisotopes, formed by nuclear reactions on targets in a reactor or cyclotron, require further processing in almost all cases to obtain them in a form suitable for use. The availability of short-lived radionuclides from radionuclide generators provides an inexpensive and convenient alternative to in-house radioisotope production facilities such as cyclotrons and reactors. The reactor offers large volume for irradiation, simultaneous irradiation of several samples, economy of production and possibility to produce a wide variety of radioisotopes. The accelerator-produced isotopes relatively constitute a smaller percentage of total use. The accelerators are generally used to produce those isotopes which can not be produced by reactor or which have unique properties.

The isotope production program involves several interrelated activities such as target fabrication, irradiation in reactor or accelerator, transportation of irradiated target to radioactive laboratory, radiochemical processing or encapsulation in sealed source, quality control and transportation to end users. During these steps radiation doses are monitored for safety of personnel as well as for environment. Various supporting and regulatory bodies work together for a successful program of isotope production and their use. Pakistan Nuclear Regulatory Authority (PNRA) an independent organization look after the regulatory issue regarding the safe production and use of radiation at country level, whereas Nuclear Safety Committee PINSTECH (NSCP) and Health Physics Division are responsible at institute level. Pakistan Atomic Energy Commission (PAEC) has also Directorate of Safety (DOS) and Safeguards and Disarmament Cell.

For many years Isotope Production Laboratories are meeting all the demands of Sodium Iodide (^{131}I), Sodium phosphate (^{32}P), PAKGEN ^{99m}Tc generators and cold kits for ^{99m}Tc radiopharmaceuticals for PAEC nuclear medical centers. Now a day PINSTECH is also providing its products to various private and government hospitals, treating patient with nuclear medicine. Radioisotopes find applications in various fields such as nuclear medicine, diagnosis and cure of disease, hydrology, sedimentology, agriculture and industry. Large amounts of ^{24}Na, ^{82}Br, ^{51}Cr, ^{99}Mo, ^{134}Cs, ^{140}La etc., were prepared for such applications.

2. RADIOISOTOPE PRODUCTION FACILITIES IN PAKISTAN

Two research reactors are available for production of radioisotopes at PINSTECH, Islamabad. One cyclotron facility is operational at Shaukhat Khanum Memorial Hospital, Lahore, while another at INMOL, Lahore is under installation stage. Two Tandem accelerators, one in Islamabad and second in Lahore are used for research purposes and no attempt has been made for isotope production research.

2.1. Pakistan Research Reactors 1 and 2

Production of radioisotopes started since Pakistan Research Reactor-1 (PARR-1) went critical in December 1965. Pakistan Institute of Nuclear Science and Technology (PINSTECH) Islamabad is operating two research reactors (PARR-1 and 2) to provide services to the users for the production of radioisotopes and for neutron irradiation. Salient features of both reactors are presented in Table I. Since initial criticality, PARR-1 has rendered invaluable service in the training of manpower, production of radioisotopes and as a source of neutrons for basic and applied research. To reduce nuclear proliferation concerns it became essential that its core be converted for operation with low enriched uranium (< 20% ^{235}U) fuel. The PARR-1 is a swimming pool type research reactor originally designed for a thermal power of 5 MW. Its core has been redesigned to operate with LEU fuel at a power level of 9 MW in 1992 and 10 MW in 1998.

Pakistan Research Reactor-2 (PARR-2) is a 30 kW tank-in-pool type research facility. It uses Highly Enriched Uranium (HEU) as its fuel, light water as moderator and metallic beryllium as reflector. Fission heat generated in the core is removed through natural convection. The reactor core is enclosed in an aluminum vessel suspended in an underground pool. Long-term reactivity compensation is achieved by increasing the thickness of top beryllium reflector. Reactor has ten irradiation sites, five of which are located inside the beryllium reflector while the rest surround the reflector. The thermal neutron fluxes in these sites are 10^{12} and 5 x 10^{11} $cm^{-2}s^{-1}$, respectively. These irradiation sites are accessed through pneumatic sample transfer tubes.

Large scale production of radioisotopes has been carried using PARR-1, while short lived radioisotopes produced in PARR-2 are used for R&D work.

2.1.1. Experimental facilities

Pakistan Research Reactor-1 (PARR-1) is equipped with a number of experimental facilities**.**

— Six radial beam tubes and one tangential through tube;
— Core side irradiation facility;
— Thermal column;
— Three pneumatic rabbit stations;
— Dry gamma irradiation cell;
— Hot cell; and
— Bulk irradiation area.

TABLE I: MAIN FEATURES OF PARR-1 AND PARR-2

Technical Data	PARR-1	PARR-2
Reactor type	Pool	Tank-in-pool
Thermal power, steady, kW	10 000.000	30.000
Max flux SS, thermal, $cm^{-2}s^{-1}$	1.5×10^{14}	1.0×10^{12}
Max flux SS, fast, $cm^{-2}s^{-1}$	6.0×10^{13}	3.2×10^{11}
Moderator and coolant	Light water	Light water
Reflector	Graphite, water	Beryllium, water
Control rod material	Ag, In, Cd	Cd
Criticality with LEU	Oct 1991	-
Power increase	9 MW in May 1992	-
Power increase	10 MW in Feb 1998	-
Experimental Data		
Channels	Horizontal: 7	Vertical: 10
Max flux, $cm^{-2}s^{-1}$	Horizontal: 4.7×10^{13}	Vertical: 1×10^{12}
Horizontal use	Basic research	Small irradiation sites: 8×7 cm^3
Vertical use	Neutron activation analysis	Large irradiation sites: 2×25 cm^3
Core irradiation facilities	2	-
Core max neutron flux, $cm^{-2}s^{-1}$	1.5×10^{14}	
Reflector irradiation facilities	3	10

2.1.2. Core irradiation facilities

Flux traps have been provided for incore irradiation of samples. In the first high power core the unperturbed neutron flux in the flux traps varies from 3.5×10^{13} to about 2×10^{14} with an average of about 1.3×10^{14}. In the equilibrium core, average thermal neutron flux of the order of 6×10^{13} and 1.6×10^{14} $cm^{-2}s^{-1}$ is expected at locations C-4 and C-7, respectively. In addition, the area outside the graphite reflector can be utilized for core side irradiation.

2.1.3. Pneumatic rabbit system

Three independent pneumatic tubes, 57 mm ϕ are provided to deliver sample capsules called “rabbits” into the high neutron flux areas around the core. A constant exhaust system, vented to the stack, allows the rabbits to be inserted or removed while the reactor is in operation. The irradiation time is controlled manually or by an automatic timer. Two pneumatic tubes terminate in the Chemical and Isotope Laboratory at the beam port floor while the third terminates in the hot cell.

The rabbit travel speed to and from the reactor is 10 to 13 m/s depending up on the weight of the rabbit. The maximum weight of the sample including the “rabbit” is limited to 400 g. The thermal neutron flux varies with core configuration and control rod position. In the first high power core it is of the order of 4.5 x 10^{13} for RS-1 and RS-3 and 2.4 x 10^{13} for RS-2.

2.2. Laboratory facilities for radioisotope production

During irradiation of target a number of radionuclides of different half-lives and energies can be produced along with the radioisotope of interest. The irradiated target will often require chemical processing to separate the radioisotope of interest. The radioisotope may also often have to be further processed and purified to obtain a product which could be used effectively and safely for the intended purpose. The extent of the facilities to be included and areas to be allocated will depend on the volume of activities.

2.2.1. Radioisotope processing facilities

Various facilities available for radioisotope processing are as follows:

— ^{131}I Production cell (Wet distillation technique). Maximum capacity per batch 10 Ci;
— ^{131}I Production cell (Dry distillation technique). Maximum capacity per batch 10 Ci;
— ^{32}P Production cell (Dry distillation technique). Maximum capacity per batch 10 Ci;
— ^{35}S Production glove box;
— ^{99}Mo Loading Facility for preparation of ^{99m}Tc generators (100Ci/batch);
— ^{99}Mo Production facility (under commissioning phase);
— Hot cell with master slave manipulators;
— Fume hoods and glove boxes (For small scale production of different radionuclides and R&D work);
— Workshop for target preparation and sealed source fabrication; and
— Laboratories for determination of radionuclidic, radiochemical and biological purity.

2.2.2 Production of ^{131}I

Wet and dry distillation cells are available. In wet distillation, the neutron irradiated tellurium is dissolved in an oxidizing medium (chromic and sulphuric acid) converting tellurium to telluric acid wherein the elemental iodine is released and converted to iodic acid (HIO_3). This is reduced with oxalic acid releasing elemental iodine vapor, (distilled at 140^{o}C) which is collected in alkaline scrubbers as sodium iodide in sodium sulphate/sodium bisulphate/ NaOH solution. In dry distillation, the irradiated tellurium dioxide is heated at a temperature ~700^{o}C under vacuum. The ^{131}I released from the matrix of the target as vapor is then trapped in carbonate/bicarbonate buffer.

Weekly demand of Iodine-131 in Pakistan is 4–5 Ci. Iodine-131 labeled MIBG (20–30 mCi) by isotope exchange method is also prepared for diagnostic applications.

2.2.3. Production of ^{32}P

Neutron irradiated Sulfur is distilled at 450^{o}C in a quartz furnace. Residual ^{32}P is dissolved in dilute HCl and H_2O_2 and finally purified by passing through cation exchange column. The product obtained is H_3PO_4. Yearly demand of ^{32}P is <0.5 Ci.

2.2.4. ^{99}Mo loading facility

Under IAEA Technical Co-operation Project PAK/4/40, Institute of Isotopes Co. Ltd, Budapest Hungary, provided the ^{99}Mo Loading Facility for the manufacturing of fission ^{99}Mo based alumina column chromatography ^{99m}Tc generators in a clean room environment. The laboratory is divided into dress change rooms, preparatory room, generator loading room, test elution room and packaging room. The generator loading room is provided with two hot cells, air locks and two laminar air flow. The door of each change area are interlocked to maintain air pressure differential. Because of the importance of ^{99m}Tc generator in nuclear medicine, clean system is provided during active operation to get the product free from bacteria and pyrogens. This is achieved by installing HVAC system, which provides clean airs to the various premises of facility through HEPA filters.

Hot cells are installed in clean room facility of class 10 000 to meet GMP regulation during ^{99m}Tc generator production. In order to contain radioactive particles in the cells, negative air

pressure is provided which is connected to the main negative pressure line installed in the building. At the moment 16 Curies (at reference date, 6-days Ci) of ^{99}Mo (for conversion to ^{99m}Tc generators) is being imported weekly from South Africa in Pakistan.

2.2.5. ^{99}Mo production facility

To overcome the problems associated with the import of ^{99m}Tc generators/^{99}Mo, such as availability of hard currency, increase in the price of ^{99}Mo, import policies, delay and changes in supply schedule, etc. the indigenous production of ^{99}Mo in the country was approved by Ministry of Science and Technology of Pakistan. Hot Cell facilities with master slave manipulators have been installed for separation of fission ^{99}Mo from neutron irradiated Al/U alloy target plates in PARR-1. The plant is under commissioning phase and will produce ^{99}Mo for country needs and export in near future. The approval was granted by International Atomic Energy Commission (IAEA) on irradiation of HEU target plates for the generation of ^{99}Mo in PARR-I. Protocol of Safeguard to Al/HEU Target Plates for ^{99}Mo production has been agreed between Pakistan and IAEA. The spent HEU will be stored in spent fuel bay of PARR-1 and after accumulation of 1000 g spent HEU, it will be sealed in a container by IAEA and safeguard will apply.

3. QUALITY CONTROL

To satisfy the requirements for Good Manufacturing Practice in Nuclear Medicine, all radiopharmaceuticals employed for diagnostic and therapeutic applications must be subjected to a quality control (QC) step to determine radiochemical, radionuclidic, chemical, and biological purity etc. Gamma spectrometry and instant thin layer/paper chromatography are employed for the determination of radionuclidic and radiochemical purity, respectively. Sterility and pyrogen tests are performed for biological quality control of the final products. Ionization chambers are used for assay of radioactivity. Chemical purity is generally determined after the decay of radioactivity by means of spot tests, UV/VIS spectrophotometry and optical emission spectrometry.

Radionuclidic quality control laboratory is equipped with, NaI and Ge detector coupled with Canberra 85, multichannel analyzer, Alpha and Beta counters, dose calibrators and gross gamma counters. Radiochemical quality control laboratory is equipped with, 2π scanner, HPLC, electrophoresis, gamma counter, spectrophotometer, pH meter, radiochromatographic apparatus. Biological quality control laboratory has laminar flow, incubators, oven, biodistribution, sterility, pyrogenicity testing facility.

4. RADIOISOTOPE PRODUCTION ACTIVITIES IN PARR-1

Production of radioisotopes started since Pakistan Research Reactor-1 (PARR-I) went critical in December 1965, however large scale production could not be started until the Isotope Production Laboratories were established in 1972. Many unprocessed radioisotope were produced and applied mainly in hydrology and radiochemistry. Past activities of radioisotope production belongs up to 1999, present activities from 2000 to 2010, while future may comprise up to 2025.

Table 2 presents the list of isotopes produced by using PARR-1. Many radioisotope used in diagnostic medicine has been replaced by ^{99m}Tc labeled compounds. Table 3 lists the freeze dried kits prepared and supplied to various medical centers in Pakistan.

TABLE 2. RADIOISOTOPES PRODUCED IN PARR-1

No	Radio-nuclide	Chemical form	Maximum activity/Batch	Year	Application
1	^{24}Na	Sodium carbonate	50 mCi	1966	(R & D)
2	^{32}P	Sodium phosphate	50 mCi >1Ci	1978 1986	Therapy, Agriculture
3	^{35}S	Sodium sulphate	10 mCi	1995	β^- source (R&D)
4	^{46}Sc	Scandium glass	50 Ci	1967	Hydrology
5	^{47}Sc	Scandium chloride	mCi	2005	R&D
6	^{51}Cr	Sodium chromate EDTA Complex	100 mCi 100 mCi	1972	Diagnosis, hydrology diagnosis
7	^{59}Fe	Ferric chloride	5 mCi	1994	R & D
8	^{60}Co	Metal	10 mCi	1980	γ source (Educational)
9	^{64}Cu	Copper chloride	50 mCi	1988	R&D
10	^{65}Zn	Zinc chloride	mCi	1989	R&D
11	^{75}Se	L-Selenomethionine	10 mCi	1982	Diagnosis
12	^{77}As	Arsenic chloride	mCi	2007	R&D
13	^{82}Br	Potassium bromide Ammonium bromide Dibromobenzene	~1Ci ~1Ci ~1Ci	1972	Industry, hydrology Industry, hydrology Industry, hydrology
14	^{99}Mo	^{99m}Tc-Generator (n,γ)	150 mCi	1973	Diagnosis
15	^{99}Mo	^{99m}Tc-Generator (PAKGEN) local	~1Ci 500 mCi	2002 (2010)	Diagnosis
16	^{111}Ag	Silver chloride	5 mCi	1995	R & D
17	^{113}Sn	Tin chloride	mCi	1996	R & D
18	^{115}Cd	Cadmium chloride	mCi	1996	R & D
19	^{125}Sb	Antimony chloride	1 mCi	1994	sealed source
20.	^{131}I	Sodium Iodide, oral solution Sodium ortho-idohippurate MIBG	~7Ci 20 mCi 30 mCi	1979 1980 2000	Diagnosis/Therapy Diagnosis Diagnosis
21	^{133}Ba	Barium chloride	μCi	1996	sealed source
22	^{134}Cs	Cesium chloride	100 mCi	1993	R&D
23	^{140}La	Lanthanum chloride	~ 1Ci	2003	Hydrology
24	^{153}Sm	^{153}Sm-EDTMP	~ 1Ci	1999	Therapy
25	^{152,154}Eu	Metal	~10 mCi	1995	Calibration source
26	^{166m}Ho	Holmium oxide	μCi	1995	Calibration source
27	^{166}Ho	Particles	>100 mCi	1995	Therapy
28	^{177}Lu	^{177}Lu-EDTMP	500 mCi	2008	Therapy
29	^{186,188}Re	^{186,188}Re-EHDP	>100 mCi	1995	Therapy
30	^{188}W	Generator of ^{188}Re (^{188}W- ^{188}Re)	5 mCi	1988	R&D
31	^{198}Au	Colloidal, gold chloride, Potassium auro cyanide	~ 1 Ci	1974	Therapy, tracer

32	^{199}Au	Gold chloride	~ 10mCi	1994	R&D
33	^{197}Hg	Neohydrin	100 mCi	1977	Diagnosis
34	^{203}Hg	Neohydrin	10 mCi	1977	Diagnosis
35	^{210}Po	Metal	Ci	1982	R&D

TABLE 3. IN-VIVO KITS FOR ^{99M}TC-RADIOPHARMACEUTICALS

No	Freeze-dried kits	Supply from PINSTECH	Uses
1	PINSCAN DTPA	1987	Kidney imaging
2	PINSCAN EHIDA	1987	Hepatobiliany studies
3	PINSCAN Tin colloid	1990	Liver imaging
4	PINSCAN Ca Hepta Gluconate	1990	Kidney scanning
5	PINSCAN DMSA III	1990	Renal studies
6	PINSCAN DISIDA	1990	Hepatobiliary studies
7	PINSCAN PIPIDA	1990	Hepatobiliany studies
8	PINSCAN BRIDA	1990	Hepatobiliary studies
9	PINSCAN Sucralfate / Ulsanic	1991	Stomach scanning
10	PINSCAN MDP	1992	Bone imaging
11	PINSCAN Pyrophosphate	1994	RBC/MUGA studies
12	PINSCAN MIBI	1995	Heart imaging
13	PINSCAN Phytate	1996	Liver/spleen imaging
14	PINSCAN MAG-3	1996	Kidney scanning
15	PINSCAN DMSA V	2000	Head/neck carcinoma
16	PINSCAN EHDP	2000	Bone, transchelating agent
17	PINSCAN HMPAO	2001	Brain studies
18	PINSCAN Dextran	2002	Lymphoscintigraphy
19	PINSCAN Ciprofloxacin	2003	Infection imaging
20	PINSCAN Ubiquicidin	2003	Infection imaging
21	PINSCAN Tetrophosmin	2008	Heart imaging

5. RESEARCH AND DEVELOPMENT ACTIVITIES

IAEA has been providing guidance in research and development activities related to creation of new facilities in radioisotope production and use. Table 4 gives the list of Technical Cooperation and Coordinated Research Program activities at PINSTECH, Islamabad.

5.1 Radiotherapeutics

Radiotherapeutics are radiolabeled molecules designed to deliver therapeutic doses of ionizing radiation to specific disease sites with high specificity in the body. Unsealed source radiolabeled agents have been used for treatment of cancers for over six decades. Therapies such as ^{131}I-sodium iodide for treatment of thyroid cancer and ^{89}Sr-strontium chloride and ^{32}P-sodium phosphate for the relief of bone pain associated with skeletal metastasis are well established. For the last three decades PINSTECH has been regularly supplying ^{131}I and ^{32}P to

nuclear medical centers in Pakistan. In past ^{198}Au colloid produced at PINSTECH was also supplied for patient studies. Currently ^{177}Lu is being supplied for labeling of EDTMP used for bone pain palliation at four medical centers.

5.1.1 Beta particle emitting radionuclides

Radionuclides that decay by β^- particle emission are used most extensively for radiotherapeutic applications in current clinical practices. Utilization of β^- particle emitters provides a mechanism to produce a highly homogenous radiation dose even though their deposition is heterogeneously distributed in tumors. Radiochemical separation methods have been developed for obtaining no-carrier-added isotopes from neutron irradiated target matrix activity. Table 5 gives the details of target material, technique and the radionuclide produced in no-carrier-added or carrier added form.

TABLE 4. IAEA TC AND CRP PROJECTS

No	Research Contract No	Title	Work performed
1	PAK/6/012 1989-1992	Preparation and quality control of radiopharmaceuticals with special emphasis on the "Bulk production of ^{99m}Tc radiopharmaceuticals kits.	Clean room facility. 15 cold kits are regularly produced
2	PAK/4/040 1998-2000	Establishment of loading facility for the production of ^{99m}Tc generators for Nuclear Medicine.	Generator production laboratory. More than 30 generators are weekly produced.
3	PAK/8668 1994-1998	Preparation and evaluation of radioisotopes for therapeutic applications.	^{186}Re-HEDP, ^{153}Sm-EDTMP and ^{153}Sm -MDP complexes
4	PAK/8970 1995-1999	^{99m}Tc labeled peptides for imaging of peripheral receptors.	^{125}I-RC-160 ^{99m}Tc-RC-160
5	PAK/10107 1998-2002	Labeled Biomolecules with ^{153}Sm, ^{188}Re and ^{90}Y for Targeted Radiotherapy.	^{188}Re-Lanreotide ^{99m}Tc-Lanreotide ^{131}I-Lanreotide
6	PK/11263 2000 -2003	Development of kits for ^{99m}Tc radiopharmaceutical for infection imaging.	^{99m}Tc-UBI ^{99m}Tc-HYNIC-UBI
7	PK/12130 2002-2005	Laboratory evaluation of beta emitting radionuclides (^{131}I, ^{177}Lu, ^{166}Ho) and radiopharmaceuticals for radiotherapy.	^{131}I-DOTATATE, ^{177}Lu-DOTATATE, ^{166}Ho-DOTATATE and ^{153}Sm-DOTATATE
8	PK/13929 2006-2010	Optimization of the preparation and quality control of ^{177}Lu based therapeutic radiopharmaceuticals.	^{177}Lu-EDTMP ^{177}Lu-HA
9	PK/13362 2005-continue	Establish techniques for small scale indigenous ^{99}Mo production using LEU fission or neutron activation.	Safety analysis; neutronic and thermal hydraulic analysis, radioactive waste management, Annular target preparation
10	PK/14854 2008-continue	The development of therapeutic radiopharmaceuticals based on ^{188}Re and ^{90}Y for radionuclide therapy.	Separation of ^{90}Y via colloid formation

5.1.2 Radionuclide generators for ^{99m}Tc and ^{188}Re

The availability of short-lived radionuclides from radionuclide generators provides an inexpensive and convenient alternative to in-house radioisotope production facilities such as

cyclotrons and reactors. Few generator systems developed at PINSTECH are described in Table 6.

The radioactive concentration of $^{99m}Tc/^{188}Re$ from their generators is dependent upon the specific activity of $^{99}Mo/^{188}W$, which dictates the bed size of the alumina/gel column and the volume of physiological saline needed as eluent. Because of the high content of inactive molybdenum/tungsten in neutron irradiated MoO_3/WO_3, large columns containing alumina/gel are needed to produce chromatographic $^{99}Mo \rightarrow ^{99m}Tc/^{188}W \rightarrow ^{188}Re$ generators. This results in large elution volumes containing relatively high $^{99}Mo/^{188}W$ contents and low concentrations of $^{99m}Tc/^{188}Re$. The decrease in radioactive concentration, or specific volume, places a limitation on some of the clinical procedures.

Different concentration techniques using ion exchange and solvent extraction techniques have been developed at our institute (Table 7).

TABLE V: BETA PARTICLE EMITTING RADIONUCLIDES PRODUCED AT PINSTECH

No	Radionuclide	Half-life	Target	Separation Technique	Ref
1	^{32}P	14.2 d	S	Dry distillation	1
2	^{47}Sc	3.41 d	Ti	Silica gel column	2
3	^{64}Cu / ^{67}Cu	12.7 h / 61.9 h	Zn	Ion exchange	3, 4
4	^{77}As	1.6 d	Ge	HZO column	5
5	^{90}Y	64.1 h	^{90}Sr	precipitation	6
6	^{90}Y*	64.1 h	Y	Carrier added	7
7	^{111}Ag	7.45 d	Pd	Ion exchange/adsorption	8, 9
8	^{115m}In	4.49 h	^{115}Cd	Ion exchange	10, 11
9	^{113m}In	99.48 min	^{113}Sn	Ion exchange	11
10	^{131}I	8.02 d	TeO_2	Dry distillation	12
11	^{153}Sm*	46.75 h	Sm	Carrier added	13
12	^{166}Ho*	26.8 h	Ho	Carrier added	13
13	^{186}Re*	90.64 h	Re	Carrier added	13
14	^{188}Re	16.98 h	^{188}W	Precipitation	14
15	^{177}Lu*	6.71 d	Lu	Carrier added	15
16	^{199}Au	3.139 d	Pt	Adsorption	16

*Carrier added

TABLE VI: RADIONUCLIDE GENERATORS

No	Generator	Adsorbent	Eluant	Yield	Ref
1	$^{99}Mo/^{99m}Tc$	Hydrated titanium dioxide	0.9% saline	85%	17
2	^{99}Mo-^{99m}Tc	Alumina	0.9%saline	85%	18
3	$^{115}Cd/^{115m}In$	AG 50W-X8	DTPA/EDTA	95%	19
4	$^{113}Sn/^{113m}In$ $^{115}Cd/^{115m}In$	Hydrated antimony pentaoxide	0.5 M HCl	66% 87%	20
5	^{109}Pd /^{109m}Ag	AG 50W-X8	0.9% saline	45%	21
6	^{109}Cd / ^{109m}Ag	AG 50W-X8	0.1 M NaCl	40-70%	22

TABLE VII: CONCENTRATOR SYSTEMS FOR ^{99M}TC, ^{188}RE AND ^{68}GA

No	Radionuclide	Eluant	Concentrator adsorbent	Concentration Fold	Ref
1	^{99m}Tc generator ^{188}Re generator	Acetone	Alumina	10	23
2	^{99m}Tc generator ^{188}Re generator	0.7 M acetic acid + 0.0225 M NaCl	QMA Sep-Pak	4.5 4	24
3	^{99m}Tc generator ^{188}Re generator	Saline	Ag and Alumina	50	25
4	$^{188}ReO4^-$	MEK	-	High	26
5	$^{99m}TcO4^-$	0.15 M HCl	Lead (Pb)	50	27
6	$^{99m}TcO4^-$	0.02 M Na_2SO_4	Alumina	2	28
7	$^{99m}TcO4^-$	0.02 M Na_2SO_4	Lead cation and alumina	38	29
8	^{68}Ga	MEK	-	High	30

6. CONCLUSIONS

Pakistan Research Reactor-1 has been used for the production of radioisotopes for more than 4 decades. Commonly used isotopes of ^{131}I and ^{32}P in radiotherapy have been produced in sufficient quantities to meet the country demand. Fission molybdenum-99, the most important radionuclide will be produced in large quantities for local and export purposes in near future. Facilities for manufacturing of sealed radioactive sources of ^{60}Co, ^{125}I and ^{192}Ir etc are being created for economical use of PARR-1.

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