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QUARTERLY RESEARCH REPORT TO THE NASA MANNED SPACECRAFT CENTER

# THE MEASUREMENT OF RADIATION EXPOSURE OF ASTRONAUTS BY RADIOCHEMICAL TECHNIQUES

April 3, 1972 Through July 2, 1972



by

R. L. Brodzinski

July 15, 1972

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## ABSTRACT

Cosmic radiation doses to the crews of the Apollo 14, 15 and 16 missions of 142 $\pm$ 80, 340 $\pm$ 80, and 210 $\pm$ 130 mR respectively are calculated from the specific activities of $^{22}$Na and $^{24}$Na in the postflight urine specimens of the astronauts. The specific activity of $^{59}$Fe is higher in the urine than in the feces of the Apollo 14 and 15 astronauts, and a possible explanation is given. The concentrations of $^{40}$K, $^{42}$K, $^{51}$Cr, $^{60}$Co, and $^{137}$Cs in the urine are also reported for these astronauts.

The radiation doses received by pilots and navigators flying high altitude missions during the solar flare of March 27-30, 1972 are calculated from the specific activity of $^{24}$Na in their urine. These values are compared with the expected radiation dose calculated from the known shape and intensity of the proton spectrum and demonstrate the magnitude of atmospheric shielding.

The concentrations of Na, K, Rb, Cs, Fe, Co, Ag, Zn, Hg, As, Sb, Se, and Br have been measured in the urine specimens from the Apollo 14 and 15 astronauts by neutron activation analysis. The mercury and arsenic levels are much higher than expected. No significant differences were observed between pre- and postflight samples.

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## TASK - DETERMINATION OF THE RADIONUCLIDE CONTENT OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

Astronauts engaged in space flight are subjected to cosmic radiation which induces radioactive isotopes in their bodies. The radiation dose received from cosmic particles can be determined from the quantities of these induced radionuclides.(1) The concentrations of the induced activities can be ascertained by direct whole-body counting of the astronauts or by indirect measurement such as counting that fraction of the radionuclides excreted in the feces and urine. This latter approach has been used on all manned Apollo missions. In addition to the induced activities, several fallout, injected, or naturally occurring radioisotopes have been measured, and variations in their concentrations may be indicative of changes in the biological life processes occasioned by the space environment or serve as identifying "fingerprints."

The concentrations of the radioisotopes listed in Tables I and II have been normalized by dividing each decay corrected disintegration rate by the weight of the respective stable element in the sample. Those listed in Table III have been normalized to the volume of urine. All samples were handled according to procedures described earlier.(1) Cosmic radiation doses of 142 ± 80, 340 ± 160 and 210 ± 130 mR are calculated for the crews of the Apollo 14, 15, and 16 missions respectively from a comparison of the specific activities of the radiosodium isotopes in their urine and in the urine of radiotherapy patients.(2) These doses for the Apollo 14 and 15 missions are lower than previously reported values(3-4) which were based on radiosodium activities normalized to the volume of urine rather than the more accurate normalization to the weight of stable sodium used here. The radiosodium data for the Apollo 16 mission will be normalized to stable sodium as soon as activation analysis of the specimens is completed, and the results will be given in a later report. The cosmogenic $^{24}Na$ activities observed in the Apollo 16 specimens are only upper limits due to the postflight injection of uncertain quantities of $^{24}Na$. Relatively large amounts of the reactor produced radioisotope $^{42}K$ are injected into the astronauts. Inevitably, small quantities of $^{24}Na$ are also present from activation of stable sodium impurities in the potassium compounds. If a sample of the injected spike can be analyzed, a correction for the amount of injected $^{24}Na$ can be easily made. Unfortunately, the spike used for the Apollo 16 mission was not obtained in time to measure the $^{24}Na$ activity. Reirradiation of the spike provided a lower limit of the $^{24}Na$ contamination. However, the exact correction factor could not be obtained since the ratio of the $^{24}Na$ to $^{42}K$ activities increases with time after irradiation due to differences in the half-life, and the elapsed time between the original irradiation and the injection is not known. For future missions it is recommended that samples of all injected radioisotopes be analyzed at the same time as any biological specimens.

The specific activities of $^{59}Fe$ in the urine of Apollo 14 and 15 astronauts given in Tables I and II are significantly higher than the corresponding specific activities in the feces.[5] The only plausible explanation for this is that the $^{59}Fe$ does not enter the astronauts' bodies by oral ingestion (unless it were in some preferentially assimilated chemical form which seems highly unlikely). Rather, the radioiron is probably injected into the astronauts as a tracer or as an impurity in a tracer. Since the preponderance of orally ingested iron passes directly through the gastrointestinal tract, the $^{59}Fe$ eliminated in the feces is substantially diluted relative to that eliminated in the urine which would account for the lower specific activities observed in the feces.

The $^{42}K$ concentrations reported in Tables II and III and the $^{51}Cr$ concentrations in Table III arise from injection of the respective radioisotopes. The $^{40}K$, $^{60}Co$, and $^{137}Cs$ concentrations are all quite normal and within the range of values observed for previous missions.

During the period March 27-30, 1972, a fairly large solar excursion took place. The proton flux incident on earth from this event was monitored by orbiting satellites in the two energy intervals 5-21 MeV and 21-70 MeV. The weighted average energies of these intervals are 8 and 31 MeV,respectively. During the peak intensity of the flare, two high altitude air sampling missions were flown by the United States Air Force, and the urine from the pilot and navigator of each of these missions was collected and analyzed for $^{24}Na$ content shortly after touchdown. Almost all of the solar protons were attenuated in the atmosphere above the aircraft. However, secondary neutrons generated in the air will deliver a radiation dose to these pilots similar to the radiation dose delivered to astronauts from the secondary neutrons generated in the hull of their spacecraft. The measured proton intensity above the atmosphere during these two flights sustained radiation doses of 1.197 and 2.102 gm RAD $cm^{-2}$.

The specific activities of $^{24}Na$ in the urine of the pilot and navigator for the first flight were $3.2 \pm 1.0$ and <0.73 d/m/g Na and for the second flight were $9.5 \pm 5.9$ and $5.4 \pm 3.4$ d/m/g Na. These activities correspond to radiation doses of $0.53 \pm 0.17$, <0.12, $1.57 \pm 0.98$, and $0.90 \pm 0.56$ mR when compared to the specific activities of $^{24}Na$ in the urine of neutron irradiated radiotherapy patients.(2)

Without the benefit of atmospheric and aircraft shielding, the personnel on these flights would have received doses of 52 and 92 mR from the primary proton spectrum assuming they were average size men.(6) The effective shielding thickness was greater than 100 g $cm^{-2}$ and afforded a dose reduction of about 100-fold. This would certainly be an upper limit for the dose reduction to astronauts in space since the effective shielding thickness of their spacecraft is significantly less than 100 g $cm^{-2}$.

## TASK - NEUTRON ACTIVATION ANALYSIS OF FECES AND URINE FROM ASTRONAUTS ENGAGED IN SPACE FLIGHT

This program was instituted in an attempt to foresee any possible metabolic changes in astronauts caused by conditions of weightlessness and prolonged physical inactivity which may have been manifested by an uptake or loss of an element or elements by their bodies. The primary concern had been the terrestrially observed phenomenon of osteoporosis (loss of skeletal calcium), although changes in the uptake and excretion rates of other essential microconstituents of the body, such as cobalt, iron, selenium, and the alkali metals, were also important. Lack of precisely known intake values have continually hampered the effectiveness of the program, although useful comparisons have been made to normal dietary intakes. Body losses of calcium, potassium, and iron were observed during early manned Apollo missions,[7] but these losses have since been checked.

The concentrations of Na, K, Rb, Cs, Fe, Co, Ag, Zn, Hg, As, Sb, Se and Br have been measured in pre-and post-flight urine specimens from the Apollo 14 and 15 astronauts by a previously described technique of instrumental neutron activation analysis.[1,8,9] These are reported in Tables IV through IX. Very little information is available regarding normal or anticipated levels of silver and antimony in urine. Thus, the significance of these Apollo 14 and 15 values is uncertain. The cobalt concentrations are similar to those previously reported,[9,10] but are still much lower than would normally be expected.[11] The mercury levels are higher than any previously observed[9,10] and a great deal higher than normally expected.[11] Also, the concentrations of arsenic measured in these specimens are significantly higher than anticipated.[11] All other elements are present at normally expected levels.

Although the concentrations of cobalt are unexplainably low while those of mercury and arsenic are high, there is no significant difference in the pre- and postflight levels of any of the reported elements. Thus, while people in general, including the astronauts, may have increased body burdens of mercury and arsenic from pollution, there is no evidence that space flight has any effect on the uptake or loss of these or any other elements.

## EXPENDITURES

The following table documents the expenditures according to task and total cost incurred from April 3, 1972 through July 2, 1972.

| TASK | EXPENDITURES |
|---|---|
| Determination of the Radionuclide Content of Feces and Urine from Astronauts Engaged in Space Flight | $ 4,043 |
| Neutron Activation Analysis of Feces and Urine from Astronauts Engaged in Space Flight | $ 2,022 |
| Search for Lunar Atmosphere | $ 1,005 |
| TOTAL COSTS | $ 7,070 |

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TABLE I

RADIOACTIVITY IN URINE FROM APOLLO 14 ASTRONAUTS

| Astronaut | Flight Period | dis/min $^{24}Na$ per g Na | dis/min $^{59}Fe$ per g Fe | dis/min $^{60}Co$ per g Co | dis/min $^{137}Cs$ per g Cs |
|---|---|---|---|---|---|
| LMP | F-27 | | $(1.45 \pm 0.23) \cdot 10^6$ | | |
| CDR | F-27 | | $(1.81 \pm 0.28) \cdot 10^6$ | | $(2.16 \pm 0.47) \cdot 10^7$ |
| CMP | F-27 | | $(2.04 \pm 0.46) \cdot 10^6$ | | $(1.29 \pm 0.72) \cdot 10^7$ |
| LMP | R+24→ R+48 | | $(1.10 \pm 0.17) \cdot 10^6$ | $(5.8 \pm 2.3) \cdot 10^6$ | $(6.3 \pm 1.1) \cdot 10^6$ |
| CDR | R+24 → R+48 | $0.60 \pm 0.34$ | $(1.69 \pm 0.23) \cdot 10^6$ | | $(1.29 \pm 0.20) \cdot 10^7$ |
| CMP | R+24→ R+48 | | $(9.6 \pm 1.3) \cdot 10^5$ | | $(1.24 \pm 0.21) \cdot 10^7$ |

## TABLE II

## RADIOACTIVITY IN URINE FROM APOLLO 15 ASTRONAUTS

| Astronaut | Flight Period | dis/min $^{22}Na$ per g Na | dis/min $^{24}Na$ per g Na | dis/min $^{42}K$ per g K | dis/min $^{59}Fe$ per g Fe | dis/min $^{137}Cs$ per g Cs |
|---|---|---|---|---|---|---|
| CDR | F-27 | $0.46\pm0.37$ | | | $(3.84\pm0.50)\cdot10^{5}$ | $(2.35\pm0.28)\cdot10^{7}$ |
| CMP | F-28 | | | | $(1.54\pm0.59)\cdot10^{5}$ | $(6.5\pm1.2)\cdot10^{6}$ |
| LMP | F-27 | $0.26\pm0.21$ | | | | $(1.34\pm0.17)\cdot10^{7}$ |
| CDR | R+0 | | $110\pm20$ | $(5.33\pm0.53)\cdot10^{5}$ | $(1.72\pm0.61)\cdot10^{6}$ | $(7.17\pm0.73)\cdot10^{7}$ |
| CMP | R+0 | $0.86\pm0.46$ | $373\pm50$ | $(6.47\pm0.65)\cdot10^{5}$ | | $(4.64\pm0.49)\cdot10^{7}$ |
| LMP | R+0 | $0.63\pm0.36$ | $301\pm41$ | $(7.85\pm0.79)\cdot10^{5}$ | $(2.14\pm0.22)\cdot10^{6}$ | $(1.09\pm0.11)\cdot10^{8}$ |
| CDR | R+1 | | $440\pm80$ | $(5.91\pm0.59)\cdot10^{5}$ | $(9.44\pm0.99)\cdot10^{5}$ | $(3.59\pm0.38)\cdot10^{7}$ |
| CMP | R+1 | | $430\pm70$ | $(5.36\pm0.54)\cdot10^{5}$ | $(1.24\pm0.18)\cdot10^{6}$ | $(3.16\pm0.34)\cdot10^{7}$ |
| LMP | R+1 | | $380\pm60$ | $(5.83\pm0.58)\cdot10^{5}$ | $>1.1\cdot10^{6}$ | $(2.18\pm0.26)\cdot10^{7}$ |

## TABLE III

## RADIOACTIVITY IN URINE FROM APOLLO 16 ASTRONAUTS

| Astronaut | Flight Period | dis/min/ml on 4/27/72 @ 1245 PDT | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $^{22}Na$ | $^{24}Na$ | $^{40}K$ | $^{42}K$ | $^{51}Cr$ | $^{59}Fe$ | $^{60}Co$ | $^{137}Cs$ |
| CDR | F-30 | | | 2.342±0.057 | | 0.527±0.060 | | | |
| CMP | F-30 | | | 7.725±0.080 | | | 0.043±0.012 | 0.002±0.001 | 0.0631±0.0061 |
| LMP | F-30 | | | 2.907±0.055 | | 12.15±0.08 | 0.0366±0.0083 | | 0.0331±0.0049 |
| CDR | F-15 | 0.0023±0.0013 | | 6.533±0.076 | | 0.401±0.066 | | | |
| CMP | F-15 | | | 6.760±0.098 | | | | | |
| LMP | F-15 | 0.0018±0.0015 | | 2.056±0.069 | | | | | |
| CDR | F-5 | 0.0043±0.0016 | | 2.887±0.070 | | 177.2±2.4 | | | |
| CMP | F-5 | | | 3.996±0.065 | | 293.3±2.9 | 0.0346±0.0097 | | 0.0380±0.0056 |
| LMP | F-5 | | | 1.349±0.052 | | 77.2±1.5 | 0.0541±0.0084 | | 0.0202±0.0050 |
| CDR | R+0 | 0.0025±0.0012 | | 3.738±0.062 | 8350±220 | 3762±9 | | | 0.1007±0.0058 |
| CMP | R+0 | 0.0028±0.0007 | ≤4.3 | 5.257±0.065 | 12,390±220 | 9154±14 | 0.2808±0.0098 | 0.0071±0.0012 | 0.5679±0.0085 |
| LMP | R+0 | | ≤4.4 | 3.130±0.062 | 6780±230 | 6115±12 | 0.1130±0.0094 | 0.13±0.002 | 0.2225±0.0061 |
| CDR | R+1 | 0.0027±0.0013 | | 2.896±0.062 | 2720±680 | 866±15 | | | |
| LMP | R+1 | 0.0020±0.0015 | | 2.459±0.066 | 8760±770 | 657±14 | 0.050±0.010 | 0.002±0.001 | 0.0349±0.0063 |

## TABLE IV

## Na, K, Rb AND Cs CONCENTRATIONS IN APOLLO 14 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | Na | | K | | Rb | | Cs | |
|---|---|---|---|---|---|---|---|---|---|
| | | μg/ml | g/Day* | μg/ml | g/Day* | μg/ml | mg/Day* | μg/ml | μg/Day* |
| LMP | F-27 | 2530 | 3.54 | 1400 | 2.0 | 0.634 | 0.888 | 0.00327 | 4.57 |
| CDR | F-27 | 1740 | 2.44 | 1960 | 2.74 | 0.865 | 1.21 | 0.00394 | 5.5 |
| CMP | F-27 | 2670 | 3.74 | 2330 | 3.26 | 0.852 | 1.19 | 0.00264 | 3.69 |
| LMP | R+24→ R+48 | 3150 | 4.41 | 3700 | 5.2 | 1.87 | 2.62 | 0.00806 | 11.3 |
| CDR | R+24→ R+48 | 1800 | 2.5 | 1990 | 2.79 | 1.05 | 1.48 | 0.00421 | 5.89 |
| CMP | R+24→ R+48 | 1240 | 1.74 | 1660 | 2.32 | 0.688 | 0.963 | 0.00295 | 4.13 |

* Assuming 1400 ml/Day.

## TABLE V

### Fe, Co, Ag, Zn AND Hg CONCENTRATIONS IN APOLLO 14 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | Fe | | Co | | Ag | | Zn | | Hg | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | µg/ml | µg/Day* | µg/ml | µg/Day* | µg/ml | µg/Day* | µg/ml | mg/Day* | µg/ml | µg/Day* |
| LMP | F-27 | 0.468 | 655 | 0.00120 | 1.68 | 0.000261 | 0.365 | 0.488 | 0.683 | 0.00113 | 1.58 |
| CDR | F-27 | 0.449 | 628 | 0.000941 | 1.32 | 0.000121 | 0.169 | 0.415 | 0.581 | 0.00287 | 4.02 |
| CMP | F-27 | 0.294 | 412 | 0.000395 | 0.553 | 0.000133 | 0.186 | 0.353 | 0.494 | 0.00302 | 4.23 |
| LMP | R+24→ R+48 | 0.285 | 398 | 0.000469 | 0.657 | 0.000137 | 0.192 | 0.764 | 1.07 | 0.00260 | 3.64 |
| CDR | R+24→ R+48 | 0.217 | 304 | 0.000388 | 0.543 | 0.0000381 | 0.0533 | 0.379 | 0.531 | 0.00214 | 3.00 |
| CMP | R+24→ R+48 | 0.291 | 407 | 0.000684 | 0.958 | 0.0000549 | 0.0769 | 0.495 | 0.693 | 0.00202 | 2.83 |

* Assuming 1400 ml/Day

TABLE VI

As, Sb, Se AND Br CONCENTRATIONS IN APOLLO 14 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | As | | Sb | | Se | | Br | |
|---|---|---|---|---|---|---|---|---|---|
| | | μg/ml | μg/Day* | μg/ml | μg/Day* | μg/ml | μg/Day* | μg/ml | mg/Day* |
| LMP | F-27 | 0.462 | 647 | 0.00523 | 7.32 | 0.0132 | 18.5 | 2.78 | 3.89 |
| CDR | F-27 | 0.254 | 356 | 0.00312 | 4.37 | 0.0276 | 38.6 | 2.17 | 3.04 |
| CMP | F-27 | 0.411 | 575 | 0.000575 | 0.805 | 0.0193 | 27.0 | 3.15 | 4.41 |
| LMP | R+24→ R+48 | 0.702 | 983 | 0.000769 | 1.08 | 0.0780 | 109 | 3.07 | 4.30 |
| CDR | R+24→ R+48 | <0.27 | <380 | 0.000780 | 1.09 | 0.0329 | 46.1 | 1.53 | 2.14 |
| CMP | R+24→ R+48 | <0.19 | <270 | 0.000979 | 1.37 | 0.0263 | 36.8 | 1.56 | 2.18 |

* Assuming 1400 ml/Day.

## TABLE VII

## Na, K, Rb AND Cs CONCENTRATIONS IN APOLLO 15 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | Na | | K | | Rb | | Cs | |
|---|---|---|---|---|---|---|---|---|---|
| | | μg/ml | g/Day | μg/ml | g/Day | μg/ml | mg/Day | μg/ml | μg/Day |
| CDR | F-27 | 1660 | 1.67 | 3470 | 3.49 | 1.60 | 1.60 | 0.00532 | 5.35 |
| CMP | F-28 | 3210 | 2.47 | 4320 | 3.33 | 1.86 | 1.43 | 0.00574 | 4.42 |
| LMP | F-27 | 3010 | 4.98 | 2850 | 4.72 | 2.49 | 4.12 | 0.00688 | 11.4 |
| CDR | R+0 | 1730 | 2.63 | 2590 | 3.94 | 0.989 | 1.50 | 0.00454 | 6.90 |
| CMP | R+0 | 2080 | 1.65 | 2110 | 1.68 | 1.63 | 1.30 | 0.00664 | 5.28 |
| LMP | R+0 | 2040 | 2.44 | 1680 | 2.01 | 0.762 | 0.910 | 0.00373 | 4.46 |
| CDR | R+1 | 1580 | 2.59 | 1360 | 2.23 | 0.766 | 1.26 | 0.00429 | 7.04 |
| CMP | R+1 | 1530 | 2.45 | 2390 | 3.82 | 1.25 | 2.00 | 0.00554 | 8.86 |
| LMP | R+1 | 1490 | 1.70 | 2280 | 2.60 | 1.03 | 1.18 | 0.00464 | 5.29 |

## TABLE VIII

### Fe, Co, Ag, Zn AND Hg CONCENTRATIONS IN APOLLO 15 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | Fe µg/ml | Fe µg/Day | Co µg/ml | Co µg/Day | Ag µg/ml | Ag µg/Day | Zn µg/ml | Zn mg/Day | Hg µg/ml | Hg µg/Day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CDR | F-27 | 0.276 | 277 | 0.000695 | 0.698 | 0.000101 | 0.102 | 0.912 | 0.917 | 0.00688 | 6.91 |
| CMP | F-28 | 0.255 | 196 | 0.000471 | 0.363 | 0.000118 | 0.0909 | 0.701 | 0.540 | 0.00716 | 5.51 |
| LMP | F-27 | | | 0.000933 | 1.54 | 0.000205 | 0.339 | 0.704 | 1.165 | 0.00708 | 11.7 |
| CDR | R+0 | 0.206 | 313 | 0.000446 | 0.678 | 0.0000460 | 0.0699 | 0.539 | 0.819 | 0.00522 | 7.93 |
| CMP | R+0 | | | 0.00121 | 0.962 | 0.0000828 | 0.0658 | 1.24 | 0.986 | | |
| LMP | R+0 | 0.240 | 287 | 0.000412 | 0.492 | 0.000640 | 0.765 | 0.389 | 0.465 | 0.00248 | 2.96 |
| CDR | R+1 | 0.292 | 479 | 0.000463 | 0.759 | | | 0.422 | 0.692 | 0.00148 | 2.43 |
| CMP | R+1 | 0.344 | 550 | 0.000511 | 0.818 | 0.000130 | 0.208 | 0.481 | 0.770 | 0.00454 | 7.26 |
| LMP | R+1 | <0.19 | <210 | 0.000434 | 0.495 | 0.0000710 | 0.0809 | 0.401 | 0.457 | 0.00572 | 6.52 |

## TABLE IX

## As, Sb, Se AND Br CONCENTRATIONS IN APOLLO 15 ASTRONAUT URINE SAMPLES

| Astronaut | Flight Period | As | | Sb | | Se | | Br | |
|---|---|---|---|---|---|---|---|---|---|
| | | µg/ml | mg/Day | µg/ml | µg/Day | µg/ml | µg/Day | µg/ml | mg/Day |
| CDR | F-27 | 0.472 | 0.474 | 0.00113 | 1.14 | 0.0693 | 69.6 | 2.73 | 2.74 |
| CMP | F-28 | 1.14 | 0.878 | 0.000933 | 0.718 | 0.0529 | 40.7 | 5.19 | 4.00 |
| LMP | F-27 | 1.21 | 2.00 | 0.000812 | 1.34 | 0.0785 | 130 | 5.04 | 8.34 |
| CDR | R+0 | 0.531 | 0.807 | 0.000869 | 1.32 | 0.0326 | 49.6 | 1.98 | 3.01 |
| CMP | R+0 | 0.614 | 0.488 | 0.00111 | 0.882 | 0.0795 | 63.2 | 1.58 | 1.26 |
| LMP | R+0 | 0.526 | 0.629 | 0.000867 | 1.04 | 0.0378 | 45.2 | 1.96 | 2.34 |
| CDR | R+1 | 0.435 | 0.713 | 0.00402 | 6.59 | 0.0269 | 44.1 | 2.03 | 3.33 |
| CMP | R+1 | <0.45 | <0.72 | 0.00119 | 1.90 | 0.0353 | 56.5 | 2.22 | 3.55 |
| LMP | R+1 | 0.510 | 0.581 | 0.000539 | 0.614 | 0.0396 | 45.1 | 2.10 | 2.39 |

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